2ND ANNUAL MINI-RETREAT

Institute for Sustainable Energy
AGENDA

4:00 pm Introductions
4:20 Update on federal funding outlook for energy-related research, Emily Burlij
4:30 Update on ISE activities
4:40 Five-minute, one-slide presentations
   Robert Kaufmann          Cutler Cleveland, Chris Meier, Michael Walsh
   Patrick Kinney           Justin Ren and David Jermain
   Richard Stuebi           Robert Metcalf
5:10 Eric Toone – Guest Presentation, plus Q and A
5:40 Discussion: new ideas for research/collaboration, advice to the ISE
6:00 Meeting adjourns; refreshments
Department of Energy Update
Department of Energy (DOE)

- Department of Energy (DOE) has three core missions:
  - Science and Energy (basic and applied research)
  - Nuclear Security (maintaining a credible nuclear deterrent)
  - Environmental Management (cleanup of Cold War legacy sites)
- Since he assumed leadership of DOE, Secretary Perry has been consistent with his 3 major priorities: maintaining the nuclear weapons stockpile, cybersecurity of energy assets, and high performance computing
- Focus of the R&D portfolio is on early stage research and high risk projects where there is no industry investment
- Research priorities include subsurface science, advanced reactor technologies, CO2 utilization technologies, technologies for oil and gas recovery, lightweight materials, materials in extreme environments, quantum materials, sensors, and computing
DOE Leadership

• In addition to Secretary Perry, DOE now has five other Senate confirmed officials in place (six out of 55)
  – Deputy Secretary of Energy Dan Brouillette, most recently Senior Vice President and Head of public policy at USAA
  – Under Secretary for Science Paul Dabbar, most recently Head of Energy Markets and Acquisitions at J.P. Morgan
  – Under Secretary for Energy Mark Menezes, most recently Vice President of Federal Relations for Berkshire Hathaway Energy
  – Assistant Secretary of Energy for Fossil Energy Steve Winberg, most recently Senior Program Manager at Battelle Memorial Institute
  – Assistant Secretary of Energy for Electricity Delivery and Energy Reliability Bruce Walker, most recently the Deputy County Executive for Putnam County, New York
• Pending nomination for David Jonas as General Counsel
FY 2017 Appropriations

• Full FY 2017 appropriations were finally enacted on May 5, 2017
• Office of Science at $5.39 billion (+0.8%); all program offices (with the exception of FES) received increases over FY 2016
• BES funded at $1.87 billion (+1.2%)
  – No specific allocation for EFRCs, but all 36 are fully funded
  – $24 million and $15 million for JCESR and JCAP, respectively
• BER funded at $612 million (+0.5%)
  – $75 million for three BRCs, $14 million short of FY 2017 request
• HEP (+3.8%), ASCR (+4.2%) and NP (+0.8%) all benefited; 13.2% cut to FES was result of dwindling support for ITER
• ARPA-E funded at $306 million (+5.1%)
• All applied programs, including EERE, received increases
FY 2018 DOE Budget Request

• FY 2018 budget proposal includes major increases to defense spending at the expense of non-defense discretionary programs, including R&D
• Proposed cuts are predicated on the supposed need to reduce size of federal workforce and refocus investments on fundamental research not tied to specific applications
• Office of Science would be cut by $920 million (-17%); all program offices except ASCR would see decreases
  – BES would be funded at $1.55 billion (-16.9%); EFRCs would be cut by $11 million, resulting in five fewer centers after FY 2018 competition
  – BER would be funded at $349 million (-42.9%); BRCs would receive $40 million, $35 million below FY 2017 and $49 million below proposed level for five centers
• All applied programs would see major cuts, ARPA-E would be eliminated entirely
• In keeping with Administration priorities, NNSA would see a 7.6% increase
FY 2018 Energy-Water Appropriations

• Congress has largely rejected proposed cuts in FY 2018 budget proposal as both the House and Senate would maintain or grow funding for Office of Science
  – House: $5.39 billion (flat relative to FY 2017)
  – Senate: $5.55 billion (+2.9%)
• While both bills would preserve funding for basic research, they divert substantially on applied programs
  – House would eliminate ARPA-E while Senate would increase by 7.8%
  – House would cut EERE by 47.2% while Senate would cut by 7.3%
  – Both bills would cut Nuclear, Fossil, and Electricity Delivery and Reliability
• NNSA would receive increases in both bills, though they would be smaller than those proposed by the Administration
## FY 2018 Office of Science Appropriations
(dollars in thousands)

<table>
<thead>
<tr>
<th>Science</th>
<th>FY 2016 Enacted Approp.</th>
<th>FY 2017 Enacted Approp.</th>
<th>FY 2018 President's Request</th>
<th>FY 2018 House Mark</th>
<th>FY 2018 Senate Mark</th>
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</thead>
<tbody>
<tr>
<td>Advanced Scientific Computing Research</td>
<td>621,000</td>
<td>647,000</td>
<td>722,010</td>
<td>694,200</td>
<td>763,000</td>
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<tr>
<td>Basic Energy Sciences</td>
<td>1,849,000</td>
<td>1,871,500</td>
<td>1,554,500</td>
<td>1,871,500</td>
<td>1,980,300</td>
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<tr>
<td>Biological and Environmental Research</td>
<td>609,000</td>
<td>612,000</td>
<td>348,950</td>
<td>582,000</td>
<td>633,000</td>
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<tr>
<td>Fusion Energy Sciences</td>
<td>438,000</td>
<td>380,000</td>
<td>309,940</td>
<td>395,000</td>
<td>232,000</td>
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<tr>
<td>High Energy Physics</td>
<td>795,000</td>
<td>825,000</td>
<td>672,700</td>
<td>825,000</td>
<td>860,000</td>
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<tr>
<td>Nuclear Physics</td>
<td>617,100</td>
<td>622,000</td>
<td>502,700</td>
<td>619,200</td>
<td>639,200</td>
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<td>Workforce Development for Teachers and Scientists</td>
<td>19,500</td>
<td>19,500</td>
<td>14,000</td>
<td>19,500</td>
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<tr>
<td>Science Laboratories Infrastructure</td>
<td>113,600</td>
<td>130,000</td>
<td>76,200</td>
<td>105,600</td>
<td>143,000</td>
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<td>Safeguards and Security</td>
<td>103,000</td>
<td>103,000</td>
<td>103,000</td>
<td>103,000</td>
<td>103,000</td>
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<tr>
<td>Program Direction</td>
<td>185,000</td>
<td>182,000</td>
<td>168,516</td>
<td>177,000</td>
<td>177,000</td>
</tr>
<tr>
<td><strong>Subtotal, Office of Science</strong></td>
<td><strong>5,350,200</strong></td>
<td><strong>5,392,000</strong></td>
<td><strong>4,472,516</strong></td>
<td><strong>5,392,000</strong></td>
<td><strong>5,550,000</strong></td>
</tr>
<tr>
<td>Recission of prior year balances</td>
<td>-3,200</td>
<td>-1,028</td>
<td>......</td>
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<tr>
<td><strong>Total, Office of Science</strong></td>
<td><strong>5,347,000</strong></td>
<td><strong>5,390,972</strong></td>
<td><strong>4,472,516</strong></td>
<td><strong>5,392,000</strong></td>
<td><strong>5,550,000</strong></td>
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Current Funding

• Since October 1, government has operated under a Continuing Resolution (CR) that keeps funding flat relative to FY 2017
• CR passed to give Congress time to negotiate a budget agreement to lift spending caps and work on omnibus bill for remainder of FY 2018
• Negotiations have started but progress is slow due to:
  – Disaster relief for hurricane and wildfire recovery
  – Budget resolution for tax reform
• Budget resolution has passed, but tax reform has a long way to go
• If broader budget agreement isn’t reached by December 8 (when current CR expires), Congress will likely pass another short-term CR to allow for continued negotiations
• Lack of funding certainty has prompted DOE to delay release of major solicitations, including EFRCs, Clean Water Technology Centers, SBIR/STTR, and Early Career Faculty awards
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# Faculty Advisory Board

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<tbody>
<tr>
<td>Anthony Janetos</td>
<td>Professor and Director, Earth &amp; Environment</td>
</tr>
<tr>
<td>Michael Caramanis</td>
<td>CEESI Co-Director and Professor, College of Engineering</td>
</tr>
<tr>
<td>Nalin Kulatiyaka</td>
<td>Wing Tat Lee Family Professor in Management, Questrom School of Business</td>
</tr>
<tr>
<td>Cutler Cleveland</td>
<td>Professor, Earth &amp; Environment</td>
</tr>
<tr>
<td>Pamela Templer</td>
<td>Associate Professor of Biology</td>
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<tr>
<td>Madhu Dutta-Koehler</td>
<td>Associate Professor of the Practice and Program Coordinator, City Planning and Urban Affairs</td>
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<td>Vice President and Associate Provost for Research</td>
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**Executive Committee A/K/A Cognate Deans**

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<tr>
<td>Dennis Carlberg</td>
<td>Sustainability Director</td>
</tr>
<tr>
<td>Katharine Lusk</td>
<td>Executive Director, Initiative on Cities</td>
</tr>
</tbody>
</table>
HIGHLIGHTS OF YEAR 1

- $1 MM in project commitments
- 9 staff and 11 Senior Fellows
- Debut of Seminar Series
- 12 events
- New space at 650 Beacon Street
- 1st Annual Briefing
1ST ANNUAL BRIEFING

**Attendees**
- AES Solar Energy
- Commonwealth Edison
- Current powered by GE
- The Energy Biss
- Enviance
- Federal Energy Regulatory Commission
- Global Energy Interconnection Development and Cooperation Organization (GEIDCO)
- Goldman Sachs
- Invenergy LLC
- Moody’s Investor Services
- Morgan Stanley
- National Grid
- New York Power Authority
- Noble Americas
- Schlumberger-Doll Research
- SourceOne
- Timberland
- US General Services Administration
- US Navy
- Veolia North America

**Presenters**
- Jacqueline Ashmore
- Stephen Byrd
- Michael Caramanis
- Cutler Cleveland
- Peter Fox-Penner
- Michael Gevelber
- Jennifer Hatch
- John Helveston
- Malika Jeffries-EL
- Patrick Kinney
- Nalin Kulatilaka
- Cheryl LaFleur
- Michael Lapides
- Tom Little
- Rob Metcalfe
- Uday Pal
- Nathan Philips
- Jonathan Schrag
- Sheldon Simon
- Richard Stuebi
- Pam Templer

FERC Commissioner Cheryl LaFluer presents at the ISE 1st Annual Briefing
YEAR 2 PRIORITIES

- Move and get settled
- Execute on our projects!
- NSF and DOE funding
- Continue supporting our affiliated faculty
- Advisory committee and alumni outreach
- Evolve management structure
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Why is this important?

- **Policy Analysis** Reducing emissions generates local changes in temperature
- **Climate Impact** Systematic differences between developed and developing nations
- **Attribution** First direct evidence between human activity and climate

Pretis, F., R.K Kaufmann*, and S. Gopal, Local emissions affect local climate: attribution, impacts, and policy
Compute pollution emission reductions for complete conversion of light duty and/or heavy duty fleets to electricity

- Focus on region inside Rt 95?

Convert emission reductions to particulate matter and ozone air pollution levels at ground level using GEOS-Chem and statistical downscaling

- Both within and outside emission reduction region

Overlay pollution levels with populations, and compute changes in health status (e.g., mortality, hospital admissions, asthma exacerbations, school absences)

Extend to other cities
### Richard Stuebi: Portfolio of ISE Activities

<table>
<thead>
<tr>
<th>Area of Activity</th>
<th>ISE Collaborators</th>
<th>Status</th>
</tr>
</thead>
</table>
| Haiti            | • Jennie Hatch  
                  • Jacquie Ashmore | • Phase One literature review half-complete  
                  • Phase Two (2018) deep-dive on implications of electric cooking on microgrid economics |
| Energy Finance   | • Nalin Kulutilaka  
                  • Paulina Swartz | • Funded project under discussion with Hannon Armstrong to investigate correlation between stock performance and carbon emissions  
                  • Project under development regarding consequences of bundling solar loans through installers  
                  • Opportunity being explored for ExecEd on finance to solar project installers |
| Northeast US Energy Research | • Kira Fabrizio  
                             • Jacquie Ashmore | • Partnership discussions underway with NECEC to form regional economic/policy/strategy research capability  
                             • One funding sponsor already identified, others TBD |
| Greentown Labs   | • Jacquie Ashmore  
                  • Tess Kohanski  
                  • Paul McManus | • Early-stage of partnership discussions (a la Greentown-Tufts) |
BU/Columbia-Bloomberg-GEIDCO Project

(1) BU/Columbia: An overview of potential energy transition roadmaps of China and US (2030, 2040, 2050), primarily including energy structure, technical economy, carbon emission situation and key policies.

(2) GEIDCO: Electrification in Africa and Latin America

(3) BU/Columbia: A comparative study of electric vehicle and charging infrastructure network development in China and US

BU Team

- Principal investigator: Dr. Peter Fox-Penner
- Co-Leader: Dr. Justin Ren
- Senior Fellow ISE: David Jermain

Columbia University as partner is the effort

GEIDCO Vision

- Ultra high voltage transmission
- Globally interconnected renewable resources
- Universal access to affordable sustainable energy platforms

“Z” Energy Source Zone =

- wind power in the Arctic +
- 45° energy source belt +
- solar energy on the equator
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The Origin of Breakthrough Energy
One year later, BEC members committed more than $1 billion to Breakthrough Energy Ventures (BEV).

BEV evaluates potential investments based on four primary criteria:

- **Climate Impact**: We will invest in technologies that have the potential to reduce greenhouse gas emissions by at least half a gigaton.
- **Other Investments**: We will invest in companies with real potential to attract capital from sources outside of BEV and the broader Breakthrough Energy Coalition.
- **Scientific Possibility**: We will invest in technologies with an existing scientific proof of concept that can be meaningfully advanced.
- **Filling the Gaps**: We will invest in companies that need the unique attributes of BEV capital, including patience, judgment by scientific milestones, flexible investment capabilities, and a significant global network.
Breakthrough Landscape of Innovation

**ELECTRICITY**
- that have the potential for breakthrough technologies which can significantly reduce greenhouse gas emissions.

**TRANSPORTATION**
- Public Investment: Governments around the world commit budget to scientific research into new energy solutions.
- Scientific Innovations: Leading research institutions, primarily funded by governments, working in collaboration will deliver new and exciting discoveries, with a variety of potential applications.
- Companies & Products: New companies are formed around these innovations seeking capital from investors.
- Private Investors: Breakthrough Energy Coalition, SEO and other flexible capital is committed to investing in companies that will bring innovations from start-up to scale-up.

**AGRICULTURE**
- World Governments Invest in Basic Research

**MANUFACTURING**
- Low-GHG Liquid Fuels Production—Refineries
- Transportation System Efficiency Solutions
- Technology Solutions that Eliminate the Need for Travel
- Technology-Enabled Urban Planning and Design
- Low-GHG Air Transport
- Low-GHG Water-Borne Goods Transportation

**BUILDINGS**
- Energy Star
- Low-GHG Power Plants
- Solar, Distributed Power
- Smart, Energy-efficient Buildings
- emerging Energy

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November 15, 2017 Confidential
Megatrend 1: Enormous Quantities of Low Price Renewable Electricity
Deep Penetration of Intermittent Renewables:

- Use an optimal mix of wind and solar resources.
- Use transmission to connect regional grids.
- Adjust industrial use patterns.
- Develop long-term storage technologies.
- Develop flexible, dispatchable zero-carbon power sources.

Projected Growth in Intermittent Renewables

<table>
<thead>
<tr>
<th>Country</th>
<th>2015 Installed</th>
<th>2014 Curtailment Rate</th>
<th>2015 Curtailment Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>129.34 GW</td>
<td>8%</td>
<td>15%</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>24.25 GW</td>
<td>9%</td>
<td>18%</td>
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<tr>
<td>Ningxia</td>
<td>8.22 GW</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>Gansu</td>
<td>12.52 GW</td>
<td>11%</td>
<td>39%</td>
</tr>
<tr>
<td>Jilin</td>
<td>4.44 GW</td>
<td>15%</td>
<td>32%</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>5.03 GW</td>
<td>12%</td>
<td>21%</td>
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<tr>
<td>Xinjiang</td>
<td>16.14 GW</td>
<td>15%</td>
<td>32%</td>
</tr>
</tbody>
</table>
How Much Can That Storage Cost?

\[
LCOS = \frac{\sum (Capital_t + O&M_t + fuel_t) \times (1 + r)^{-t}}{\sum MWh_t \times (1 + r)^{-t}}
\]

Li et al., Joule 2017, 1, 306.
Where Are We Now?

2 - 4 Hour blocks; >$200/kWh

6 - 12 Hour blocks; <$100/kWh

Multi-day blocks; <$10/kWh
Storage Using Heat Pump and Engine

Store Energy as Heat

The thermal storage media is ~ $10/kWh, and lasts > 30 years.

Laughlin, R. *Journal of Renewable and Sustainable Energy* 9, 044103 (2017);
Ultra-Cheap, Earth Abundant Electrolytes


Geothermal: A Zero-Carbon Alternative?

Geothermal is an important, but small, resource. Traditional geothermal requires highly specialized geology.
EGS: A 100 GW Opportunity

Enhanced (or Engineered) Geothermal induces flow through the use of fluid and/or induced porosity.

Advances from shale extraction coupled with fundamental research in porosity and flow enable a massive opportunity.
Megatrend 2: A Burgeoning Middle Class

Total growth 2.38 billion

51%

India: 394,282,000
Nigeria: 216,306,000
Pakistan: 120,715,000
Democratic Republic of the Congo: 118,010,000
Ethiopia: 89,064,000
Tanzania: 83,665,000
United States: 67,091,000
Indonesia: 64,674,000
Uganda: 62,841,000

Growth of the global middle class

 Millions of persons in the global middle class, defined as living on $10-$100 per day

Sub-Saharan Africa
Middle East & North Africa
Central & South America
North America
Europe
Asia Pacific

Source: The Brookings Institution
Implication 1: Access to Energy

Sub-Saharan Africa electrification rates*
2011, % connected

- < 20
- 20-34
- 35-49
- 50+

*Same electrification rate assigned to Sudan and South Sudan
Source: McKinsey & Company

Electrifying India
Percentage of village households with electricity, by state

Jharkhand has the lowest household electrification level of just 39%
Source: Ganugovin
Implication 2: What Will We Eat?

\[ y = 4.06x^{0.76}, \quad r^2 = 0.76 \]
Implication 3: How Will We Move?

“In the developing world, buying a car is virtually synonymous with entry into the middle class... We propose the number of passenger cars in circulation serves as a reliable gauge of the size of a country's middle class.”

Shimelse Ali, Uri Dadush, 2012
Megatrend 3: Urbanization

2030 population
- 40M
- 25M
- 10M

Change in population from 2014 to 2030
- Pop. decline + 0-15%
- 16-30%
- 31-45%
- 46% or more

Bolded cities: projected to surpass 10 million people between 2014 and 2030

Luanda, Angola
Its population is expected to grow to 10.4 million in 2030, from 5.3 million in 2014, the fastest growth rate among the 2030 megacities. Lagos and Kinshasa are close behind.

Tokyo and Osaka
Both are expected to lose population due to low birth rates and declining immigration.

Source: United Nations World Urbanization Prospects
Tall Wood: A Practical Reality
“Far better it is to dare mighty things, to win glorious triumphs, even though checkered by failure, than to rank with those poor spirits who neither enjoy nor suffer much, because they live in the gray twilight that knows not victory nor defeat.”

Theodore Roosevelt, April 1899
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