Technology and Future Energy Systems: Lessons from ARPA-E

Emerging Technologies Summit
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Learning Curves and Incumbent Technologies

- Transformational potential
- Existing learning curve
- New learning curve – disruptive technology

Steam-powered Cugnot (1769)
Benz Motorwagen (1885)
Ford Model T (1914)
Transitions Toward Market Adoption

- R&D
- Prototype
- Demonstration
- Commercialization

Valley of Death #1: Research Prototype
Valley of Death #2: Scale-up and Manufacture
Valley of Death #3: Full scale production
Lessons from ARPA-E:

**Goal-oriented R&D Management**

Expert, Empowered Program Directors

Limited-term funding under Cooperative Research Agreements

Project management for both technical and commercial goals

Projects cancelled if progress can’t be demonstrated

Mentoring in finding post-ARPA-E development funds
Since 2009 ARPA-E has invested approximately $1.5 billion across more than 580 projects, of which 262 have completed their ARPA-E support as of Feb 2017. 74 ARPA-E projects have cumulatively attracted more than $1.8 billion in private-sector follow-on funding (as of Feb 2017).
End use efficiency

Buildings use 72% of U.S. electricity and 55% of its natural gas

By 2030, Business as usual:
16% growth in electricity demand and additional 200 GW of electricity ($25-50 Billion/yr)

Source: LBNL Environmental Energy Technologies Division, 2009
BEETIT - 2010
Building Energy Efficiency Through Innovative Thermodevices
Lower energy approaches to heating, ventilation and air conditioning (HVAC).

DELTA - 2014
Delivering Efficient Local Thermal Amenities
Local thermal management for individual comfort, goal to reduce overall AC costs by allowing less stringent building-wide AC.

Shield - 2016
Single-Pane Highly Insulating Efficient Lucid Designs
Insulating, anti-condensation window materials with excellent optical quality, for cost-effective retrofits or replacements.

SENSOR – 2017 foa
Saving Energy in Structures with Occupancy Recognition
Reducing HVAC energy demand by accurately sensing building occupancy, allowing demand-based heating, cooling, ventilation.
BEETIT
Building Energy Efficiency Through Innovative Thermodevices

Goals
- Improve energy efficiency of HVAC systems by 50%
- Cost-competitive with conventional systems

Challenge

Portfolio
- 15 Project teams
- Opportunity areas:
  - Gas Cycles
  - Solid State Cooling
  - Absorption/Adsorption Cooling

Pathway to Impact
- Collaboration with Navy for expeditionary needs
- Commercial first markets
Project Example: Infinia Technology Corporation

- Heat pump that uses a Stirling cycle
- Heats and cools more efficiently than conventional vapor compression systems
- Cost-effective thermosiphon to enable the Stirling cycle at air conditioning temperatures

Products in development for both Military & Commercial Applications
   Direct replacement for existing units, using at least 33% less energy
Dehumidification using zeolite coated membranes that selectively allow water vapor to pass, but not air.

Potential Products:
- Humidity removal add-on, reducing fuel use by 10%
- Evaporative coolers that work in all climates, reducing fuel use by 33% (tropical) to 90% (arid)

Future Plans
- Scale-up underway: joint funding by ARPA-E / Pentagon / Military Sealift Command
- Performance tests planned for both commercial and military applications
DELTA
Delivering Efficient Local Thermal Amenities

Goals
- Local temperature for occupants that enables reductions of Heating Ventilation and Air Conditioning (HVAC) energy consumption by at least 15%
- Enable radical and sustainable architecture in next generation energy-efficient building design

Concept:

Portfolio
- 11 Project teams
- Four categories
  - Extended range, Close proximity, Thermal physiology, System combinations

Portfolio:
- High-efficiency heat pump
- Direct heating and cooling
- Comfort driven office equipment
- Radiative
- Conductive
- Convective
- Active heat removal
Personal heating and cooling

Ventilation comes to you

Comfort control through clothing
**SHIELD**
Single-Pane Highly Insulating Efficient Lucid Designs

**Goals**
- Halve the heat lost through single-pane windows
- Produce secondary benefits, such as improved soundproofing, reduced cold weather condensation, that will make retrofits more desirable

**Context**

<table>
<thead>
<tr>
<th></th>
<th>US total</th>
<th>Buildings HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>quads/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window losses</td>
<td>4.7</td>
<td>2.0</td>
</tr>
<tr>
<td>single pane</td>
<td>1.8</td>
<td>0.9</td>
</tr>
<tr>
<td>double pane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>net solar</td>
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</table>

**Challenge**

![silica aerogel](commons.wikimedia.org)

**Portfolio**
- 14 projects
- Opportunity Areas
  - Controlled nanostructures
  - Phononic engineering
  - Composite materials
**Project Spotlight: University of Colorado Boulder**

**Goal:** A flexible, transparent window film for application onto single-pane windows.

**Approach:** Liquid crystalline phases of nano-cellulose aerogel that has low-emissivity properties.

**Cost factor:** Fabrication from low-cost cellulose nano-rods from food industry waste.
Project Spotlight: IR Dynamics, LLC

**Location:** Santa Fe, NM

**Goal:** flexible window films that improve thermal insulation.

**Approach:** Composite of polymer-films with two embedded nanophase materials: transparent clay materials that act as a thermal barrier and IR thermochromic vanadium dioxide-based nanomaterials.
High Growth Applications Need Converters

- **Motor Drives**
  - Motors: 50% of all U.S. electrical energy usage.
  - Hybrid Electric Vehicles: Power Electronics are 20% of material cost.

- **Electronic Ballasts/LED**
  - Lighting consumes 12% of U.S. electricity.
  - Dimmable controls: Power electronics 30-50% of cost

- **Information Technology**
  - Computing technology: 5-10% of U.S. electricity.
  - Datacenters alone: ~2-3%.

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ADEPT - 2010
Agile delivery of electric power technology

Power Conversion Efficiency: Wide band-gap semiconductors for high-power, high-current applications

SWITCHES - 2013
Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems

Lowering the cost of wide band-gap devices to improve Energy Efficiency for electric motors

ENLITENED – 2016 foa
Energy-Efficient Light-Wave Integrated Technology Enabling Networks that Enhance Datacenters

Integrated photonic interconnects and switching networks to reduce data center demand for electricity

CIRCUITS – 2017 foa
Creating Innovative and Reliable Circuits using Inventive Topologies and Semiconductors

Novel circuit topologies, advanced control and drive electronics tailored to reduce power consumption across all sectors
Impacts from Innovation require technical discipline

### CIRCUITS

**Technical Requirements**

<table>
<thead>
<tr>
<th>Category</th>
<th>Target</th>
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</thead>
<tbody>
<tr>
<td>Power and Voltage</td>
<td>$\geq 10\ kW$ and $\geq 600\text{V}$</td>
</tr>
<tr>
<td>Efficiency ($Q = \frac{P_{\text{out}}}{P_{\text{class}}}$)</td>
<td>$\geq 97.5%$ ($Q \geq 39$) @ peak load</td>
</tr>
<tr>
<td></td>
<td>$\geq 95%$ ($Q \geq 19$) @ 5% peak load</td>
</tr>
<tr>
<td>Power Density</td>
<td>$\geq 150\ W/\text{in}^3$ ($\geq 9.15\ kW/\text{L}$)</td>
</tr>
<tr>
<td>Specific Power</td>
<td>$\geq 5\ kW/\text{kg}$</td>
</tr>
<tr>
<td>Operation</td>
<td>168-hour continuous basic operation</td>
</tr>
<tr>
<td>Relative Cost</td>
<td>$\leq 0.05\ $/$W$</td>
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### ENLITENED

**US Data Center Power Demand**

- Electrical chip I/O limit reached
- Network power becomes significant
- Chip I/O <1µJ/b
- Low-latency switch fabrics
- Growth Rate with ITRS Scaling CAGR = 7%
- “Ideal” Growth Rate: CAGR = 0%

2017 ARPA-E: **DE-FOA-0001727**  
2016 ARPA-E: **DE-FOA-0001566**
The social compact for technical R&D

▸ Optimism: Investments in science and engineering R&D over the last ½ century have created opportunities for dramatically improved technical capabilities, including applications in incumbent markets such as Energy. Developing such advanced technologies is essential for US competitiveness.

▸ Realism: The opportunities created by basic or curiosity driven research are too early stage and too high risk for commercial investment, but with focused development the best can be identified and prepared for commercial pathways.

▸ Engagement: We cannot afford to naively accept the tenet that basic science should be boxed off from follow-on activities, and that such follow-on activities are not appropriate for government support.

▸ The Future: How will we support the transitions of early-stage innovative technical ideas to readiness for commercial engagement?
Background slides
ARPA-E Impacts

https://arpa-e.energy.gov/impact
https://arpa-e.energy.gov/?q=engage/articles-publications