Lessons from ARPA-E

AIP Assembly of Society Officers
American Center for Physics
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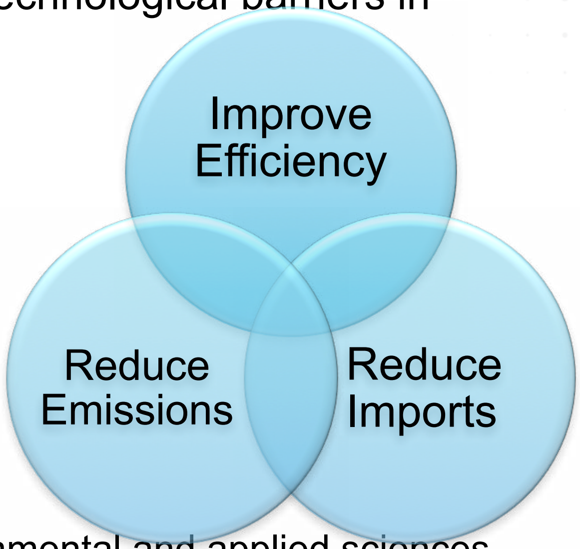
Distinguished University Professor

ARPA-E Authorizing Legislation

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies



Goals: **Ensure America's**

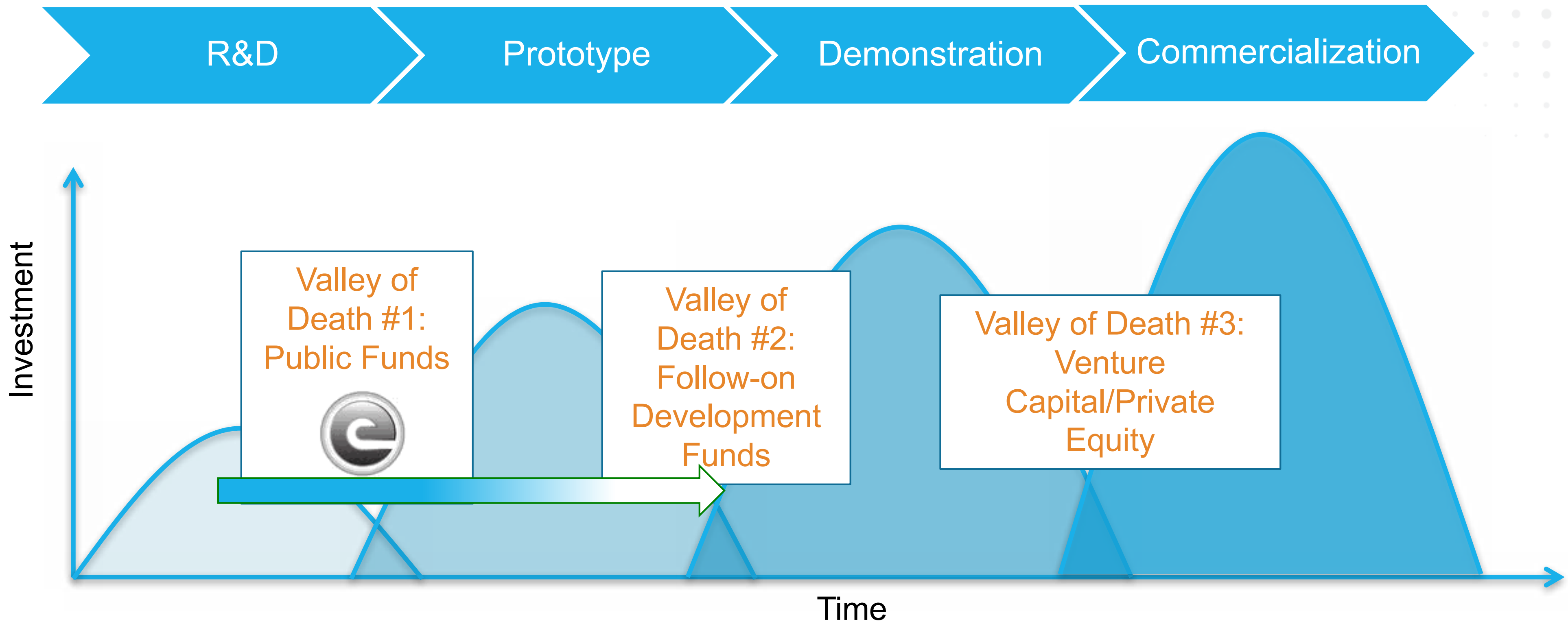
- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies

Means:

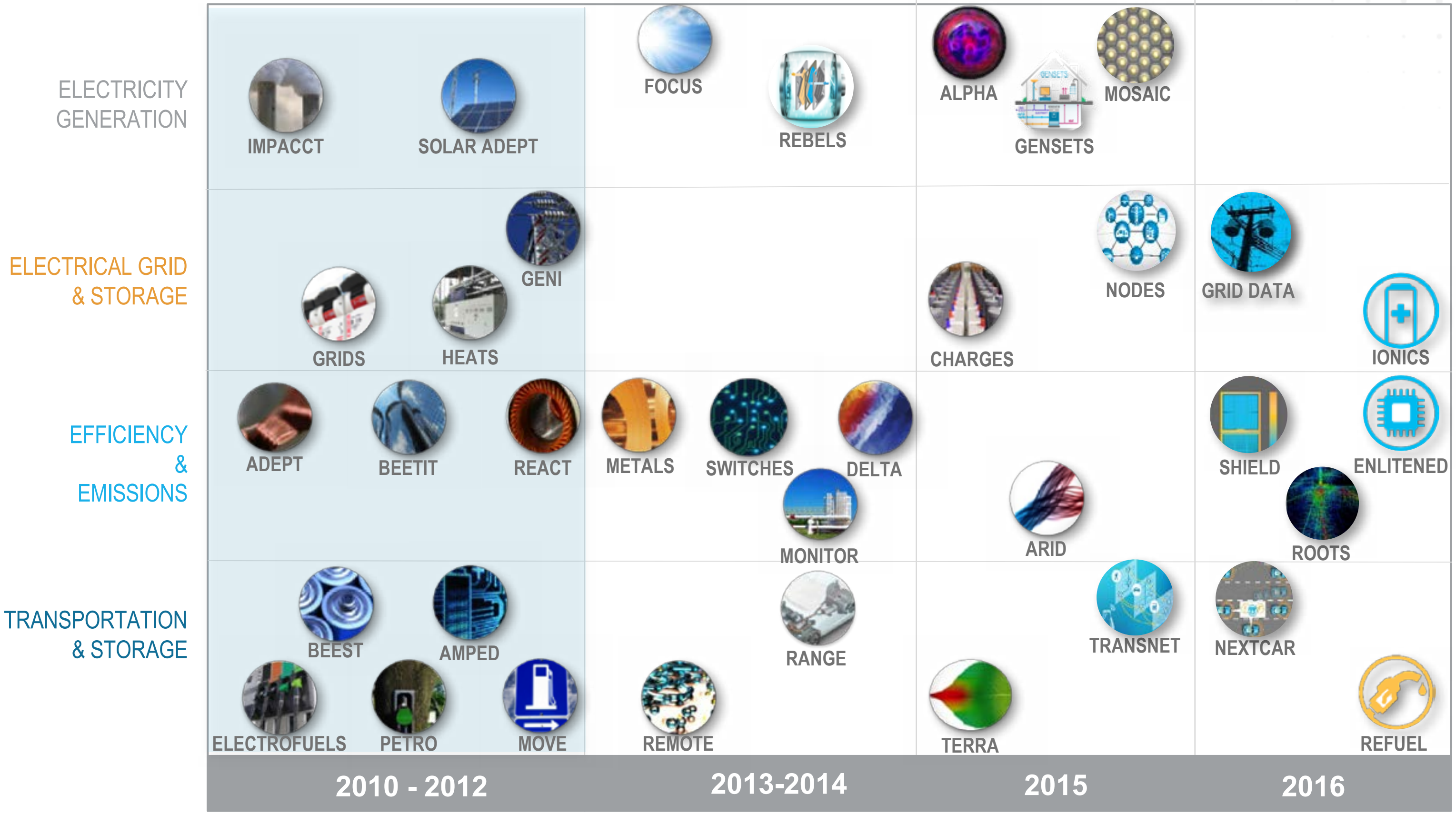
- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty

arpa·e CHANGING WHAT'S POSSIBLE

Transitions Toward Market Adoption



Portfolio Approach



Plus OPEN solicitations 2009, 2012 and 2015

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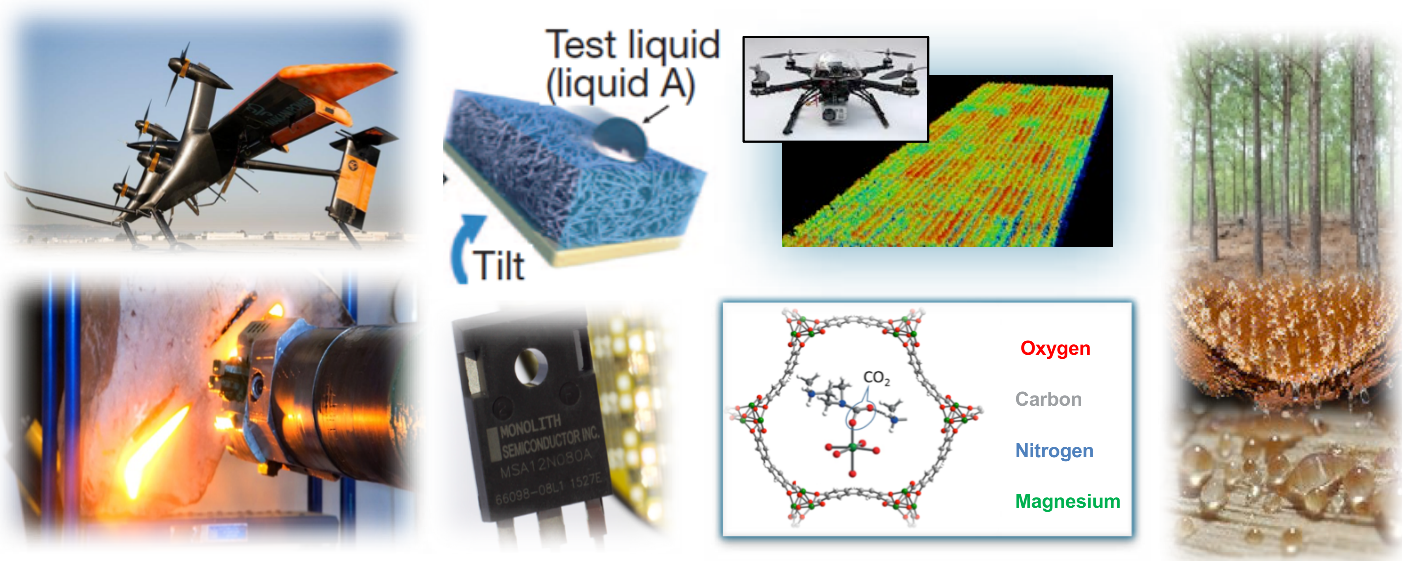
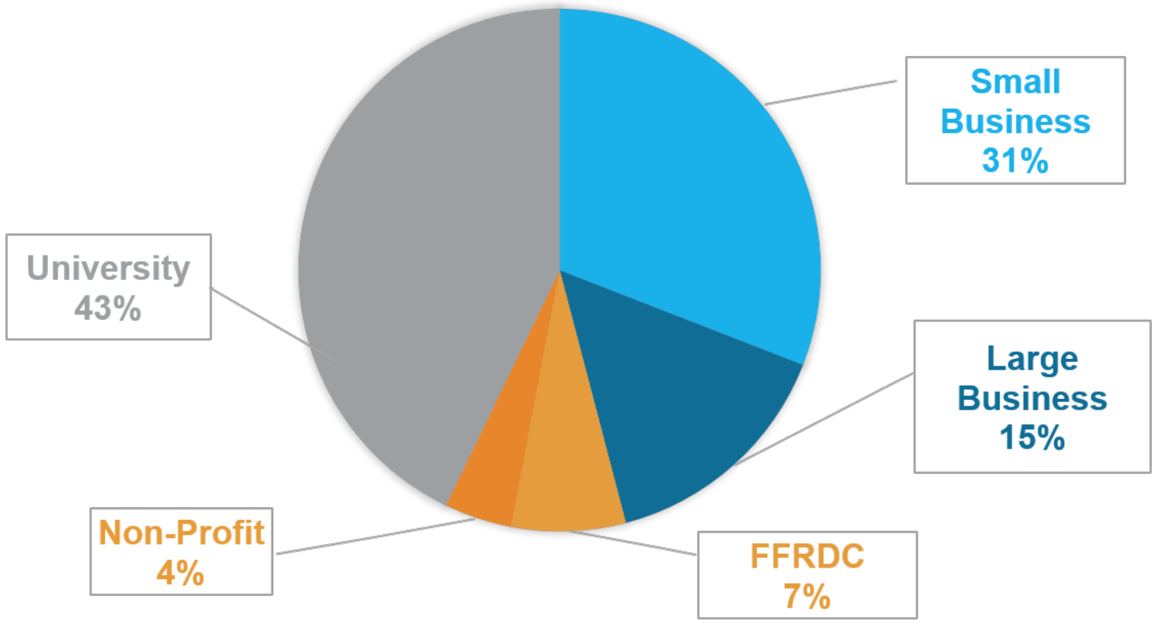
CHANGING WHAT'S POSSIBLE

Early stage innovation



ARPA-E Project Portfolio by Lead Organization

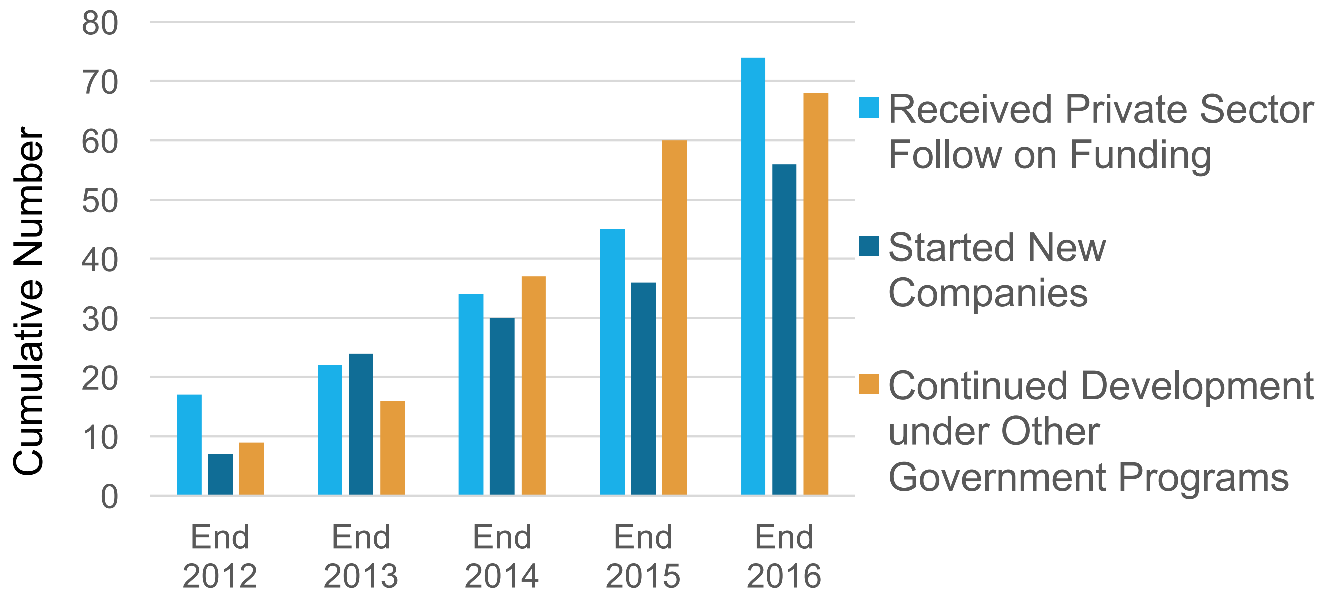


ARPA-E supports multi-institutional teams with substantial involvement from the private sector:
72% of projects involve more than one institution
84% of projects include the private sector, as leads or partners

Measuring the Transitions Toward Market

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 attracted more than $1.8 billion in private-sector follow-on funding (as of Feb 2017).

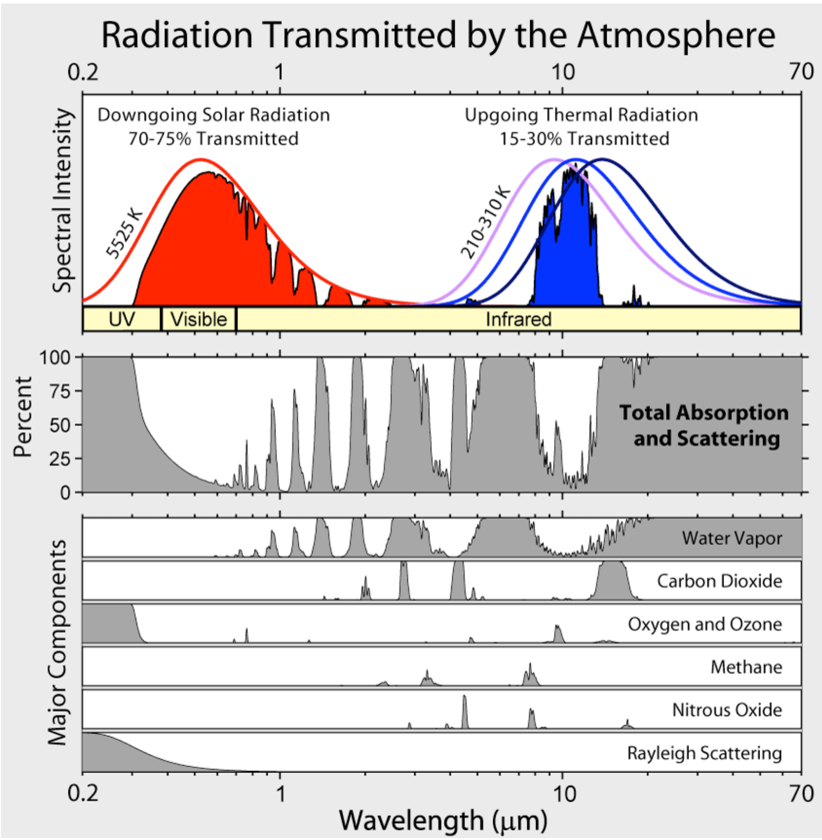


Assessment criteria

- Potential impact on Energy Mission and Goals
- Technical Challenge
  - what are the barriers to creating the desired impacts
- Technical Opportunity
  - what new approaches provide an opportunity for transformation
- Innovation Demonstration*
  - what was accomplished, how much has the technology advanced from the start to end of the project
- Pathway to Economic Impact*
  - Status of project at end of ARPA-E funding (or present status for alumni)
  - Next steps in commercialization pathway, demonstrations underway or planned (or commercialization status, early products for alumni)
  - Partnerships and funding
- Long Term Impacts
  - Value of the prototype technology
  - Assessment of broader impacts of the new technical approaches
  - Estimates of the scale of potential impacts on Energy Sector goals

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

Fundamental Understanding . . .



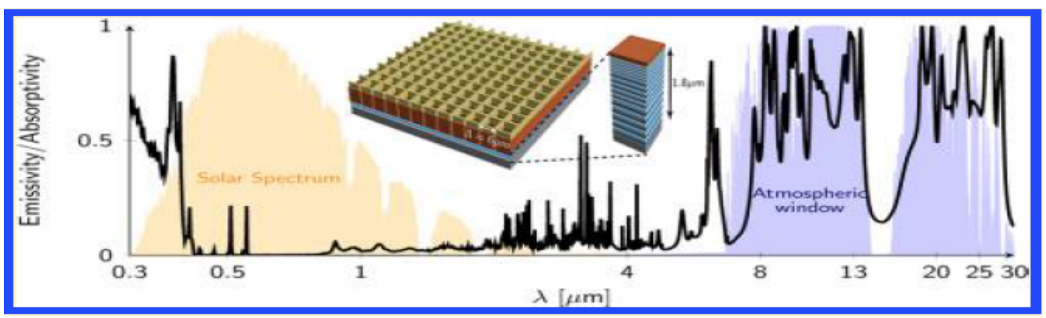
Radiative cooling to low temperatures: General considerations and application to selectively emitting SiO_2 films
C. G. Granqvist and A. Hjortsberg
Journal of Applied Physics 52 , 4205 (1981);

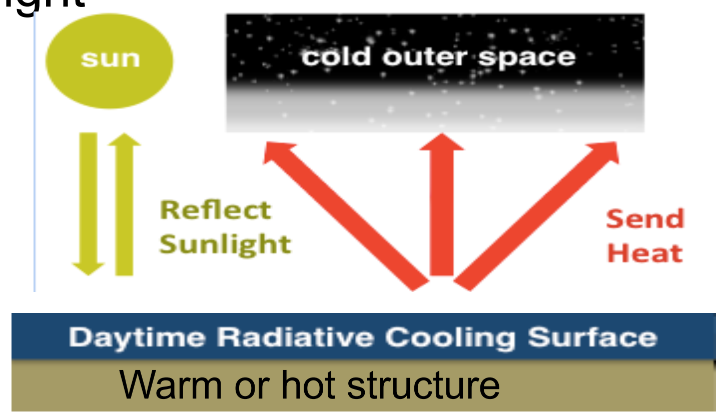
Radiative cooling occurs because the atmospheric emittance is low in the wavelength interval 8-13 μm particularly if the air is dry. . . The key factor is infrared selectivity with low reflectance in the 8-13 μm "window" but high reflectance elsewhere. Considering only radiation balance, ideal surfaces of this type can yield temperature differences of -50·C while the cooling power at near-ambient temperatures is -100 W/m^2 . . . However, nonradiative exchange limits the practically achievable temperature difference

. . . may require time to reach practical impact
Stanford – Photonic tailored structure

- **Technical Challenge:** Technological innovations in cooling systems are needed to improve energy and water use in buildings, and reduce CO_2 and other harmful emissions associated with cooling.
- **Technical Opportunity:** New advances in materials science and engineering now make it possible to create structured materials tailored to reflect sunlight very strongly while simultaneously emitting infrared light

P.I. Shanhui Fan



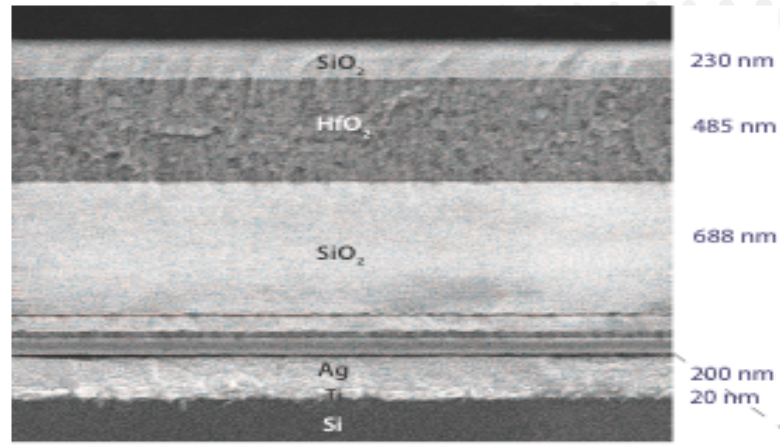


Nano Letters 13, 1457 (2013) – Laboratory performance 100W/m^2

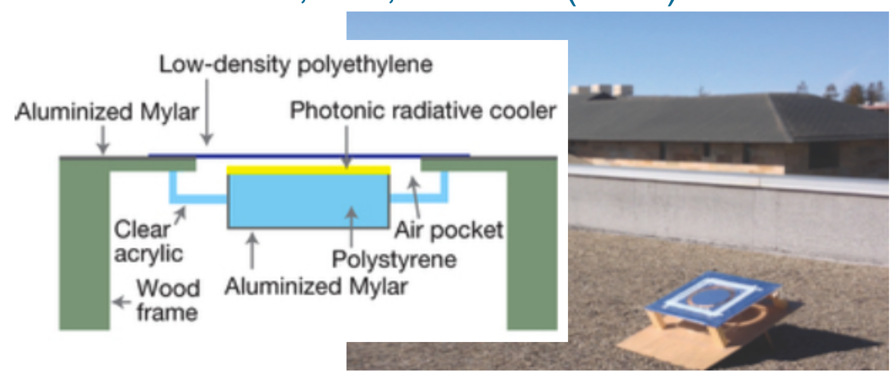
Radiative Cooling: Team Progress

- **Technical Accomplishments**
  - Designed & fabricated a layered structure with the desired optical properties, compatible with low-cost manufacturing approaches.
  - Scaled up to 8" wafer and demonstrated cooling in roof-top installation
    - 40 W/m^2 heat rejection
    - Cooling 3-5^{o}C below ambient

- **Pathway to Economic Impact**
  - Manufacturing partnership to produce large areas of material cost effectively
  - Likely first application in chilling water
    - Pre-cooling for air conditioner efficiency
    - Direct use in chilled water use

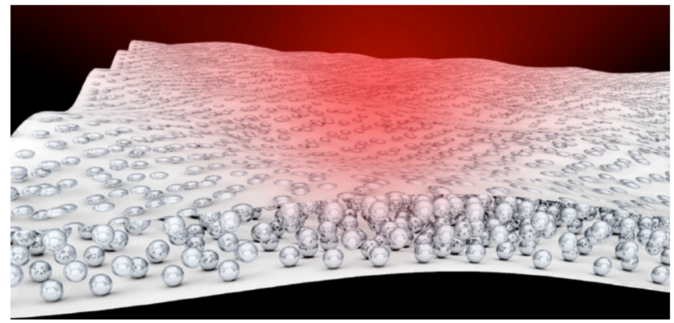


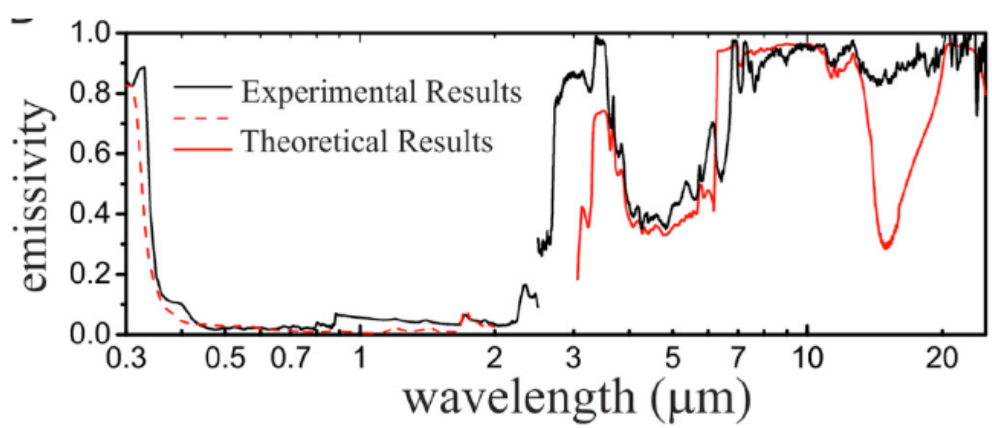
Nature, 515, 540-544 (2014)



Competition in Technical Innovation

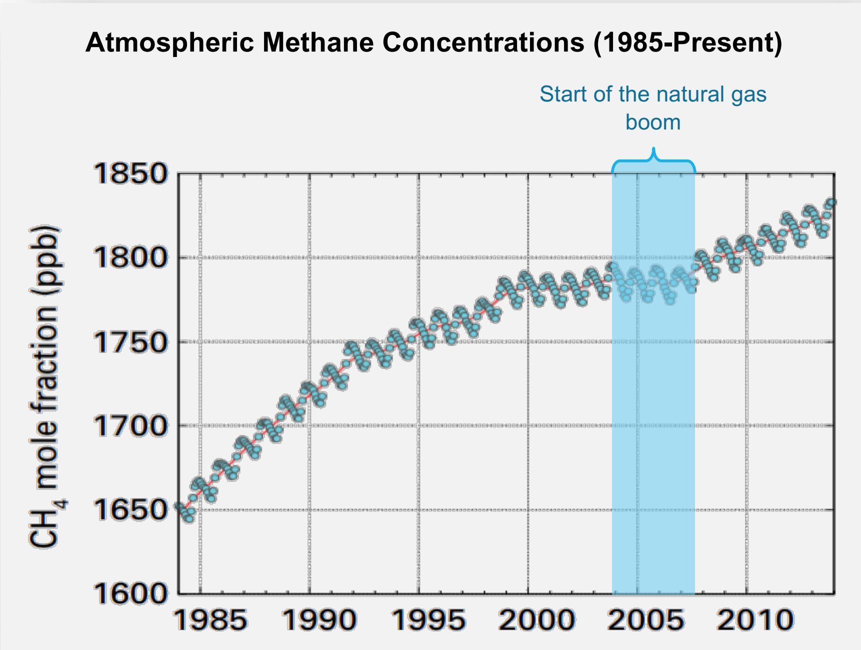
- Metamaterials approach to selective emission
- Micron scale SiO_2 spheres embedded in transparent polymer matrix, designed for a broadened plasmonic resonance around 10 µm
- **Long-Term Impacts:**
  - Maintain efficiency in power generation plants even when cooling water is restricted





Y. Zhai, Science, February 2017 – Laboratory performance $100W/m^2$

Natural Gas Challenge

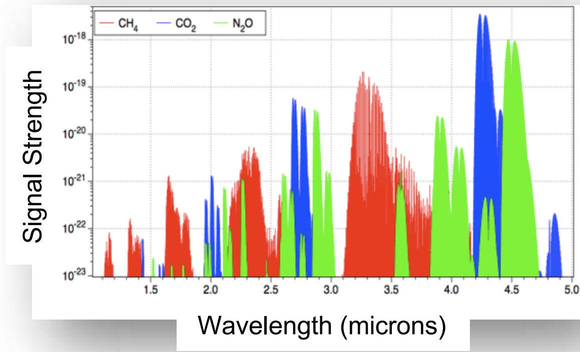


- About 2% of US natural gas resource is wasted due to leaks
- Leaks in natural gas and petroleum systems add about 5% to US greenhouse gas emissions

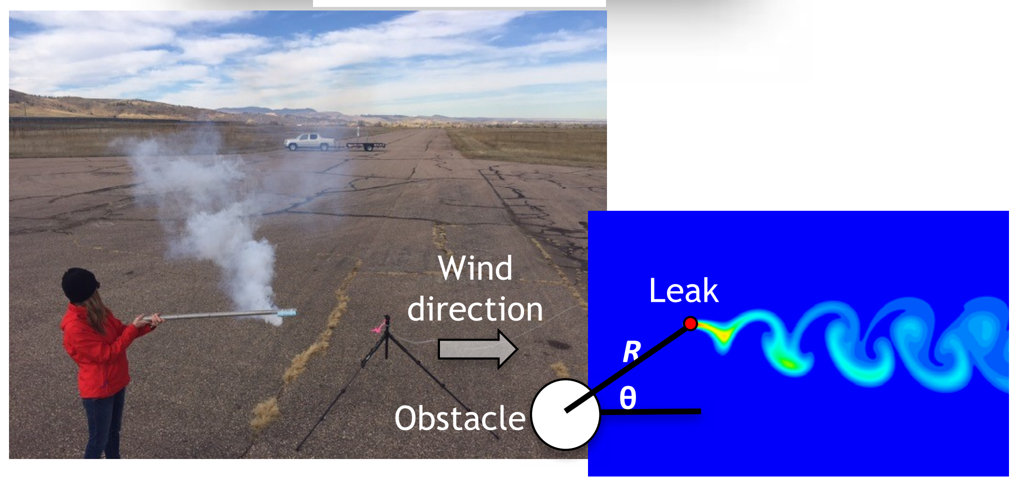
Source: WMO Greenhouse Gas Bulletin (Sept. 2014), Rhodium Group, Untapped Potential (April 2015)

Technical Challenges

- Measurement:
  - Small gas quantities (ppm) in a complex background
  - Sensing at distance, through large volume of air



- Identifying source location
  - Discrete measurements at small number of locations
  - Analyze trajectory through complex air currents



Innovative Teams: Different Approaches

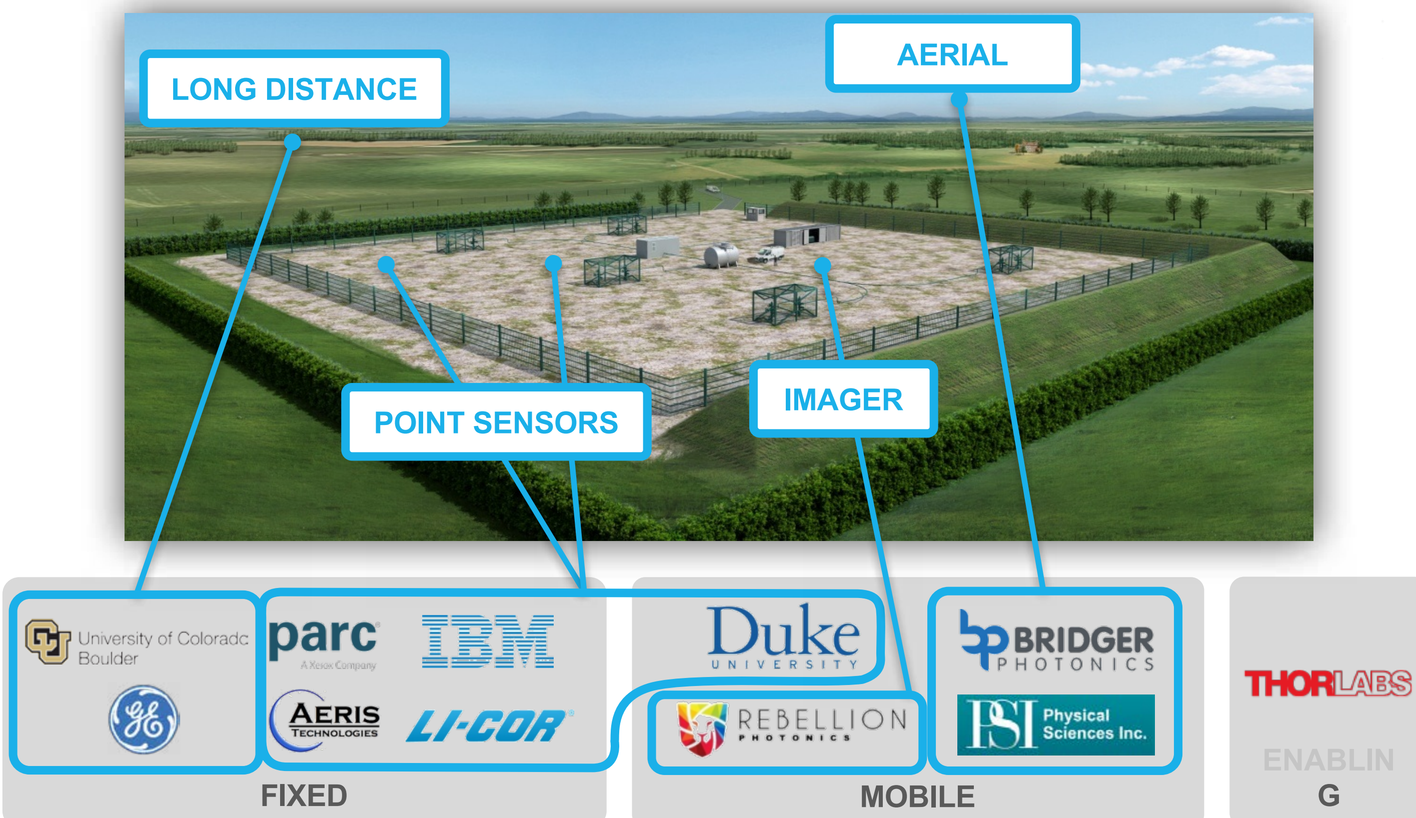


Image courtesy of Cuadrilla Resources

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: Basic or curiosity driven research does create opportunities for social impact, but those opportunities are too early stage and too high risk for commercial investment.

- Engagement: We cannot afford to naïvely 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.

Background slides