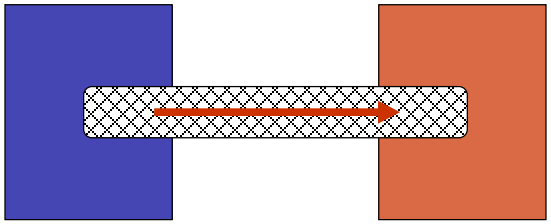
NSF Directorate for Engineering | Division of
Chemical, Bioengineering, Environmental, and Transport Systems (CBET)

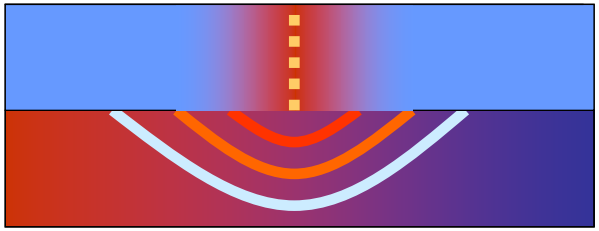
Transport and Thermal Fluids Cluster

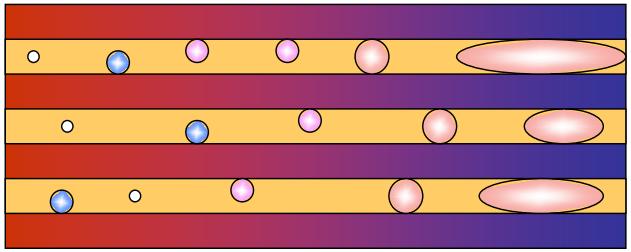
Thermal Transport Processes

Program Director – Sumanta Acharya- sacharya@nsf.gov
On IPA from Louisiana State University

Fundamentals

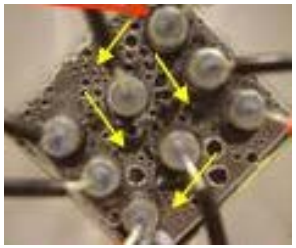


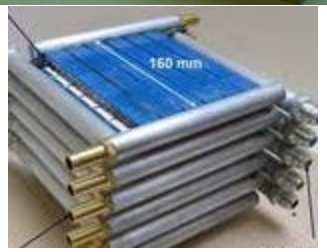




Unsolicited
(Spring Window, Jan 15-Feb 17)
CAREER (July window)
Targeted Initiatives
EAGER
Workshops
Travel

Applications *





~$10 million/year
~200 proposals/year
Success rate~12%

* Pictures taken from NSF reports

Program Scope

Technology Inspired, Focus on Fundamentals

- **Science:** Promote the fundamental understanding and application of thermal transport (heat and mass transfer and the associated fluids, materials and manufacturing processes) at different scales.
- **Tools/Methods**: Spatially & temporally resolved simulation and diagnostics exploiting high-performance computing; using highly-resolved data for upscaling/reduced order models; control and optimization for improved processes & products.

- **Innovation:** New & improved technologies for heating/cooling devices, systems, and infrastructure including the relevant materials processing and manufacturing technologies. Technologies for enhanced energy/power efficiency and generation and greater sustainability.
- **Outcomes:** Sustainable, energy-efficient heating/cooling systems and the science and tools for their design.

Current Program Portfolio

- Nano-scale Heat Transfer (1)
  - Phonon-transport: Carbon nano-materials, graphene, diamond
  - Material tuning: Thermoelectrics*, Photovoltaics
  - Devices: Thermal Interfaces, Heat Sinks
- Single and Two phase heat transfer (2)
  - Electronic/Device Cooling; Single phase; Two phase (Boiling)
  - Heat exchangers; Condensers**, Evaporators, HVAC
  - Engines (Internal Combustion***, Gas Turbine)
- Solar Energy (Solar-thermal, Solar-thermo-chemical, photovoltaics) (3)
  - Thermal storage: phase change materials
  - Working fluid: nanofluids**
  - Photovoltaics-near-field radiation
- Manufacturing & Material Synthesis(4)
  - Laser processing, CVD, self assembly
- BioTransport (5)
  - Cryopreservation, Thermally mediated treatments

~ (80-100) active awards

* NSF-DOE Partnership in Thermoelectrics ($9 million, ongoing)
** NSF-EPRI Partnership on Power Plant Cooling (Energy-Water Nexus) (planned)
*** NSF-DOE Partnership in Advanced Combustion Engine ($12 million, ongoing)

Priorities & Focus

Technology Inspired & Fundamentally Focused

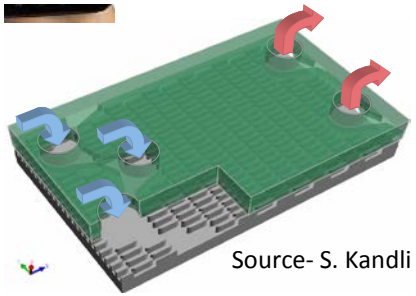
- Fundamentals of nanoscale heat conduction:
  - need to transition to improved materials, devices and systems, and to address fundamental problems needed in this transition.
  - Develop bridging models for meso-scale simulations
- Single and two phase heat transfer in channels for electronic cooling and heat exchangers (including boilers and condensers):
  - Need improved control of flow instabilities and regimes for desired heat transfer
  - Need improved strategies (e.g., super hydrophobic/hydrophilic/biphillic, nanostructured, coatings, etc.) for improved boiling (CHF), evaporation (thin-film), and condensation; high heat transfer coefficients
  - Improved predictive methodologies for interfacial, phase change and surface effects
- Manufacturing & Advanced Materials
- Energy Generation, Energy Harvesting, Propulsion

Recent Workshops/Conferences-Selected

- Materials for Energy Harvesting-- MRS meeting, San Francisco April 2011 (NSF)
- **ASME 2011 International Conference on Nanochannels, Microchannels and Minichannels, June 19-22, 2011, Edmonton, Canada (NSF)**
- **The first International Symposium on Thermal and Materials Nanoscience and Nanotechnology, May 29-June 3, 2011, Antalya, Turkey (NSF)**
- **Carbon Nano Materials and Applications Workshop, S. Dakota, October 2011 (NSF & Army)**
- **Workshop: The Seventh US-Japan Joint Workshop on Nanoscale Transport Phenomena, Izu, Japan, December, 2011 (NSF & ONR)**
- **3rd Microscale/Nanoscale Heat and Mass Transfer Conference, Atlanta, March 2012 (NSF & ONR)**
  - **Phonon Transport and Materials**
  - **Micro-channel flow and transport**
- **Workshop on Power Plant Cooling, November 2012, Houston (NSF & EPRI)**
- **Workshop on Micro- and Nano-Structures for Phase Change (NSF & ONR), 2013, Cambridge, MA**

Selected Outcomes from Workshops

- Nanoscale Heat Transfer (U.S Japan Workshop, Ga Tech Workshop, S. Dakota Workshop)
  - Materials-Phonon/electronic coupling, interfaces, assembly of nano-objects
  - Simulations & Diagnostics- Higher fidelity diagnostics at the nano scale & bridging of scales in simulations
  - Fundamental- Understanding & Controlling Spectral Nature of Phonons
- Nano/Micro Channel Flows (Edmonton, Ga Tech)
  - Improved analytical/numerical methods for boiling and condensation
  - Better heat transfer fluids
  - Flow instabilities and control
  - Critical Heat Flux in nano channels
- Electronics Cooling (discussions with DARPA & ONR)
  - Evaporating cooling
  - Embedded cooling-DARPA priority
- Power Plant Cooling (w/EPRI, ASME IMECE 2012)
  - ?



Source- S. Kandli

Leveraging & Partnerships

- NSF-DOE Partnership on Thermoelectrics ($9million)-ongoing (10 awards), last year
- NSF-DOE Partnership on Advanced Combustion Engines ($12 million), NSF12-559
  - Nearly 85 proposals received; in evaluation
- NSF-EPRI Partnership on Power Plant Cooling (planned, tentative)
  - Workshop jointly with EPRI at IMECE 2012

NSF-EPRI collaboration

- About 40% of fresh water withdrawl is used for power plants; 90% of this is used for cooling. Significant water consumption (~3%) for power plants.
- ✓ Advanced Power Plant Cooling with the goal for reduced water usage
- EPRI Office of Innovation has recently started an annual solicitation on innovations in power plant cooling for reduced water usage
- Advanced cooling is a priority for NSF CBET-Thermal Transport Program. Technologies developed are relevant to electronic cooling, and HVAC.
- ✓ Goal of the partnership is to promote integration of fundamental advances in condensation, and heat exchangers for wet, dry and hybrid power plant cooling.
- Workshop at the AME IMECE, Nov. 2012 for identifying priority areas for the solicitation planned for February 2013.

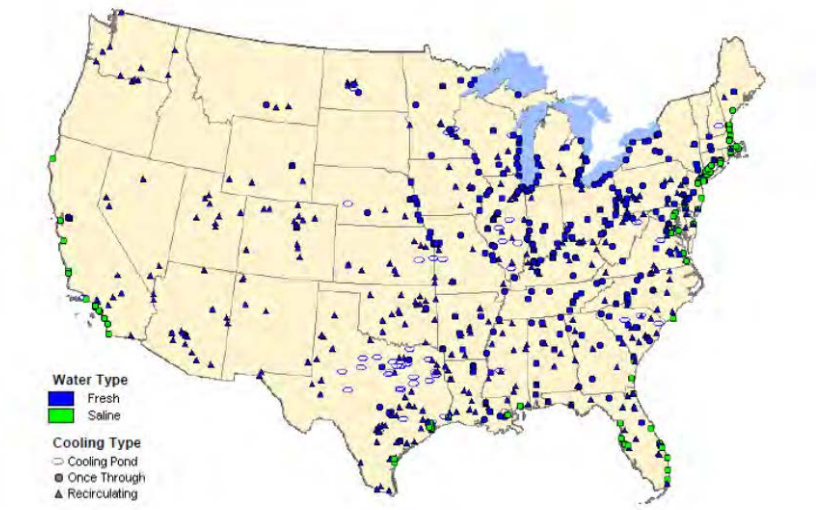
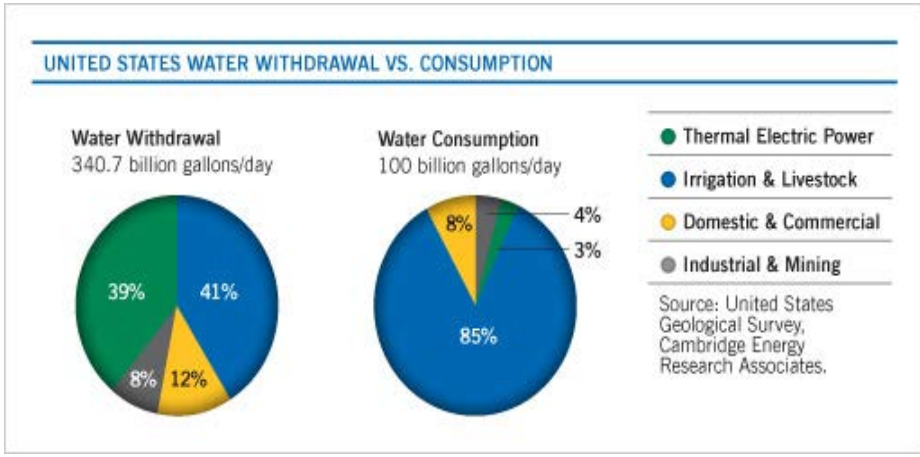


Figure 13. Cooling systems by technology and water source
Note: Dry cooling systems are not included in this figure.
Source: NETL 2010a.



http://sustainabilityreport.duke-energy.com/2008/water/withdrawal.asp

Research Highlights

Single- and Two-phase Heat Transfer

- Nano fluids and Nano-structured passages-RIT
  - Solar Thermal, Electronic Cooling, HX
- Phase change (condensation)- MTU, MIT
  - HVAC
- Phase change (boiling) for high heat flux removal
  - Electronic and device cooling, HX, (evaporation in thin film annular regime)

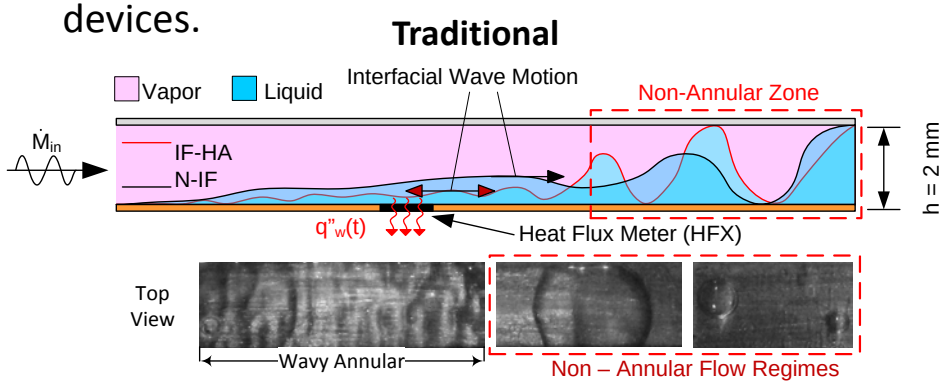
-Upcoming, NSF-EPRI Partnership on Advanced Cooling, 2013-2016, ~$6M

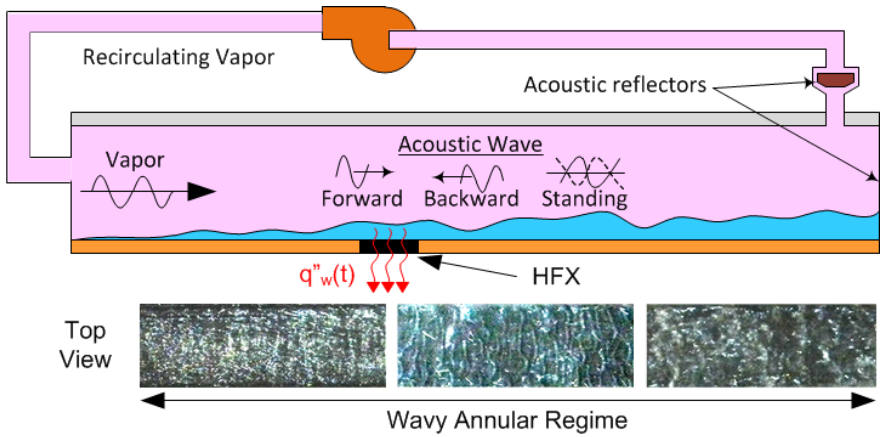
Condensers and Boilers for Innovative Micro-scale and Space-based Thermal Systems

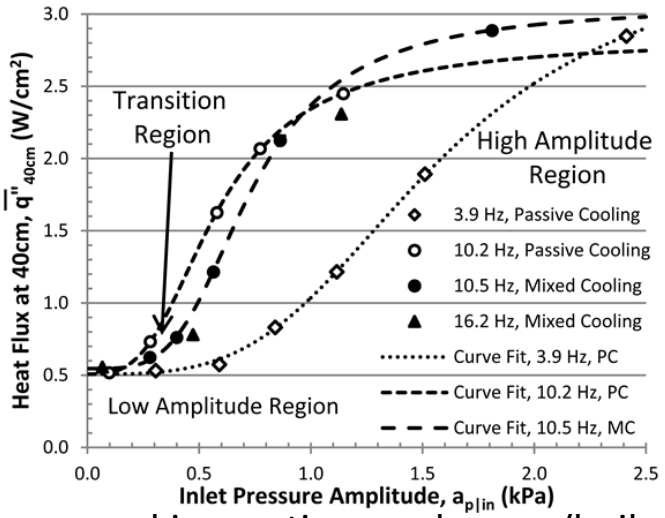
CBET-1033591

(A. Narain, MTU)

- Condensers/Boilers are components of traditional refrigerators, heat pumps, and other cooling systems.
- The poor performances in these applications are caused by unacceptable liquid-vapor configurations in the traditional devices.



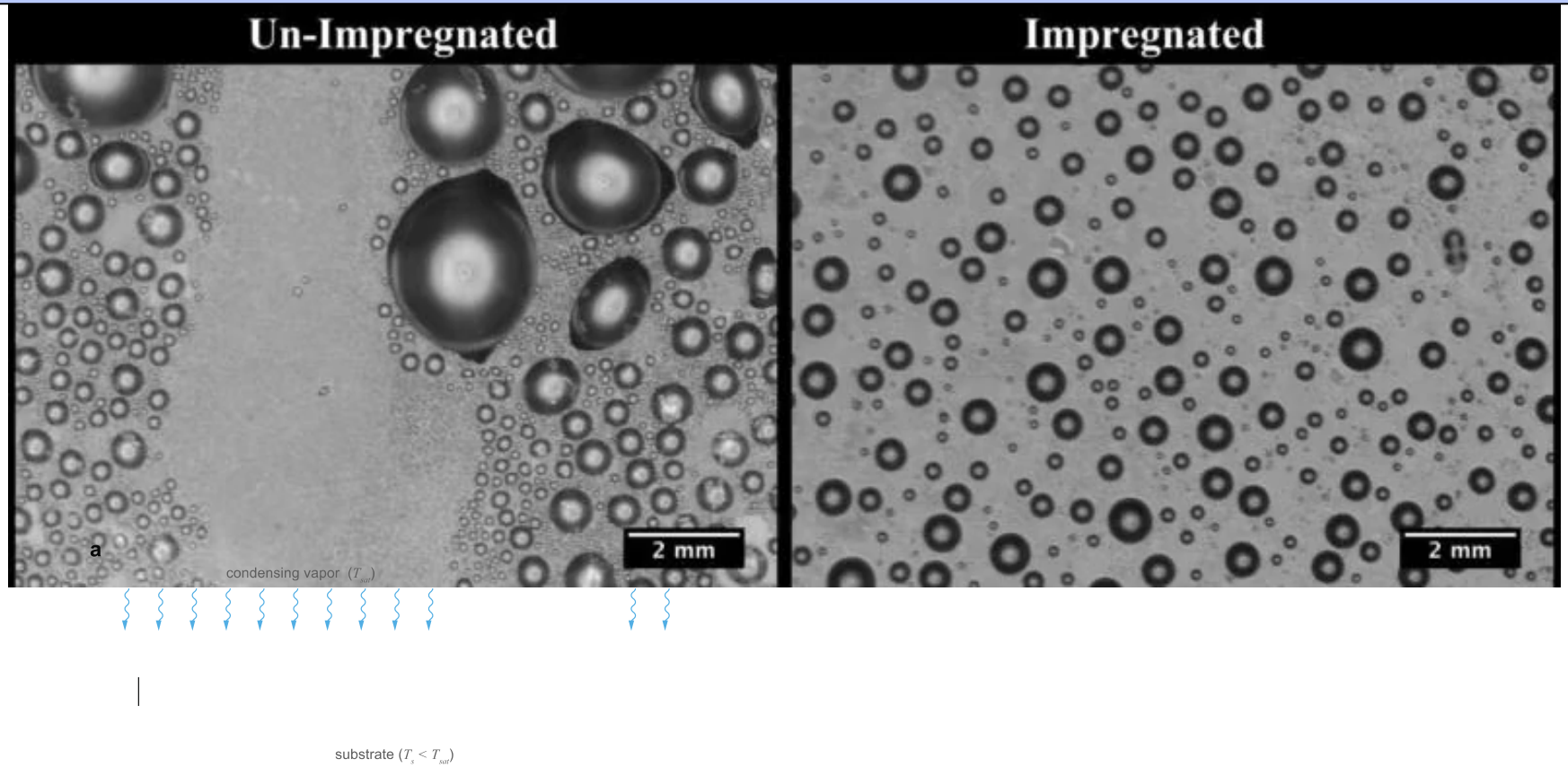




- The proposed innovative condensers/boilers use re-circulating vapor flows to ensure that thermally and hydrodynamically efficient annular flows are realized over most of the devices' heat-exchange surfaces.
- *Standing* acoustic waves are created to interact with *interfacia*l waves for beneficial time-averaged *texturing* of the interface at high amplitude imposed pressure pulsations. The amplitude-frequency effects on enhancements (200-400 %) measured is shown above.

Enhanced Condensation on Lubricant-Impregnated Surface vs Superhydrophobic (K. Varanasi, MIT)

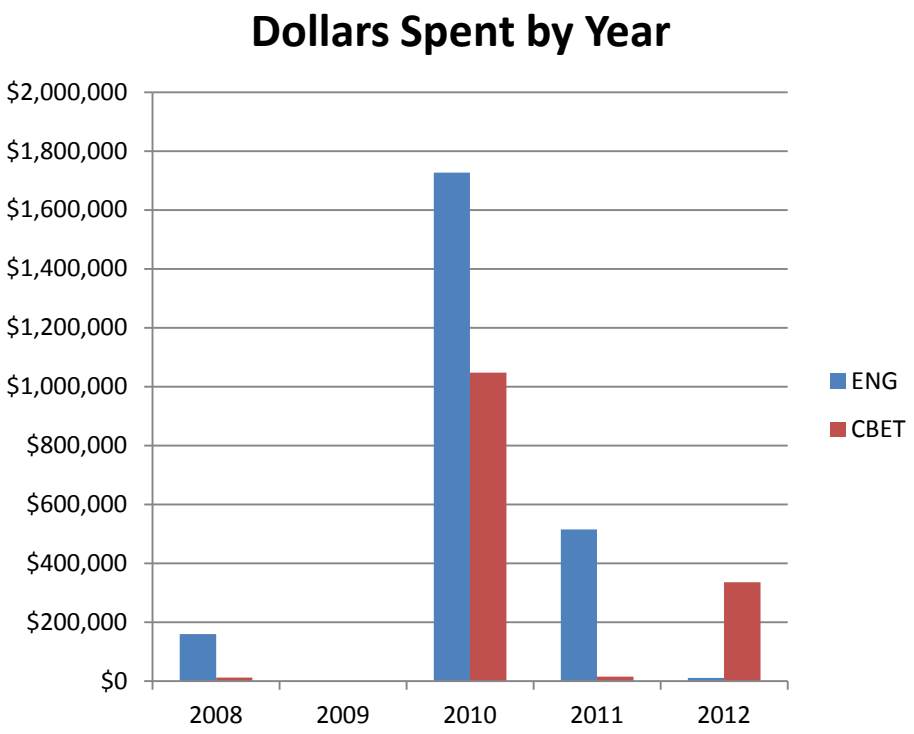
Small drops are mobile with more than 4-orders of higher mobility than dry superhydrophobic surfaces and create a sweeping effect for fresh condensation
Applications: Energy, Desalination, HVAC, etc…

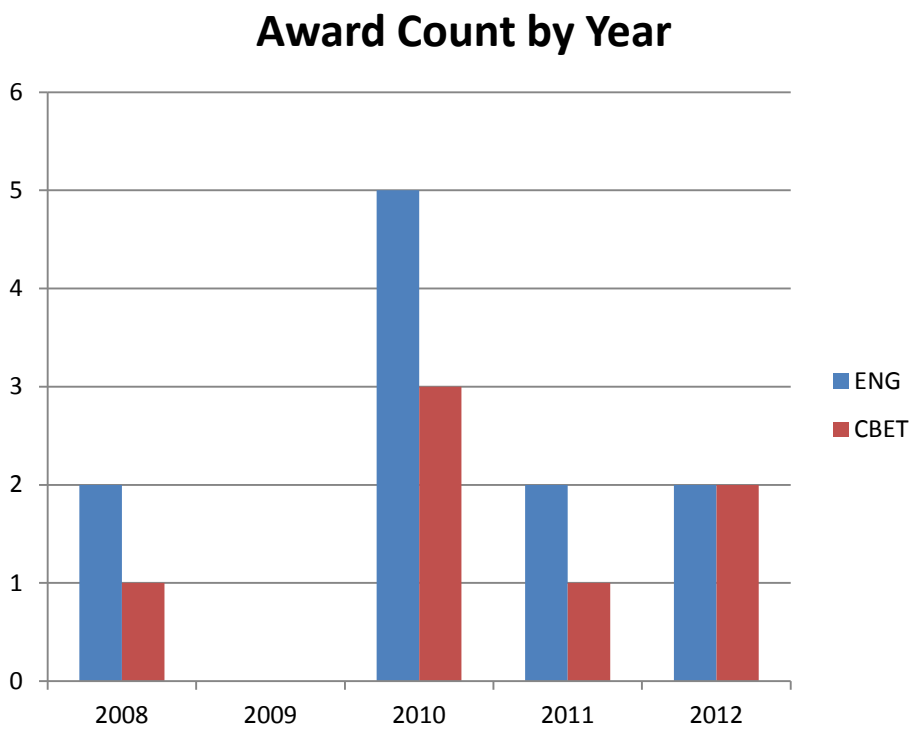


Low mobility on superhydrophobic surfaces due to Wenzel pinning

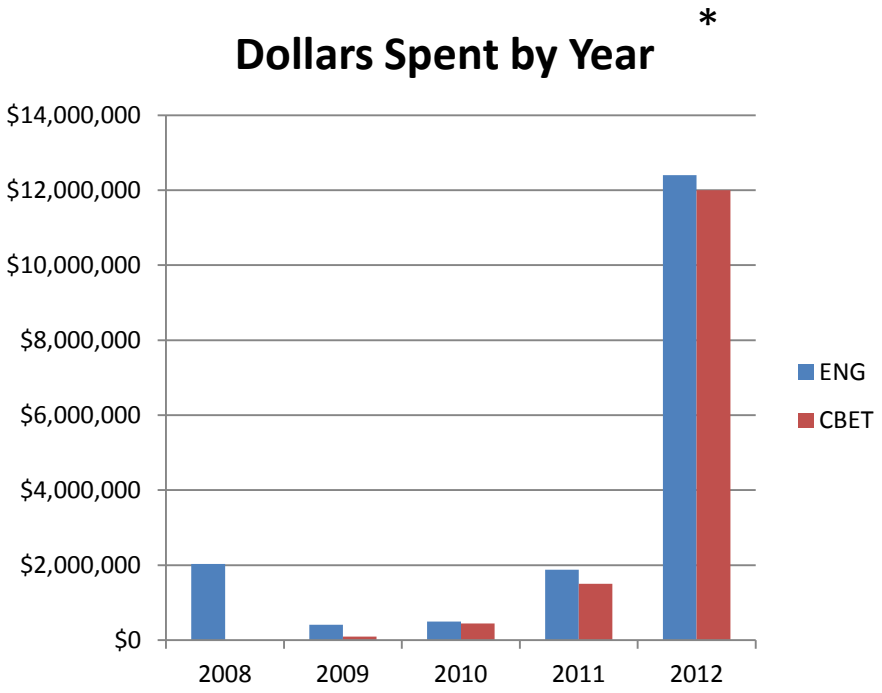
High mobility of sub 100um drops observed – creates UFO droplets

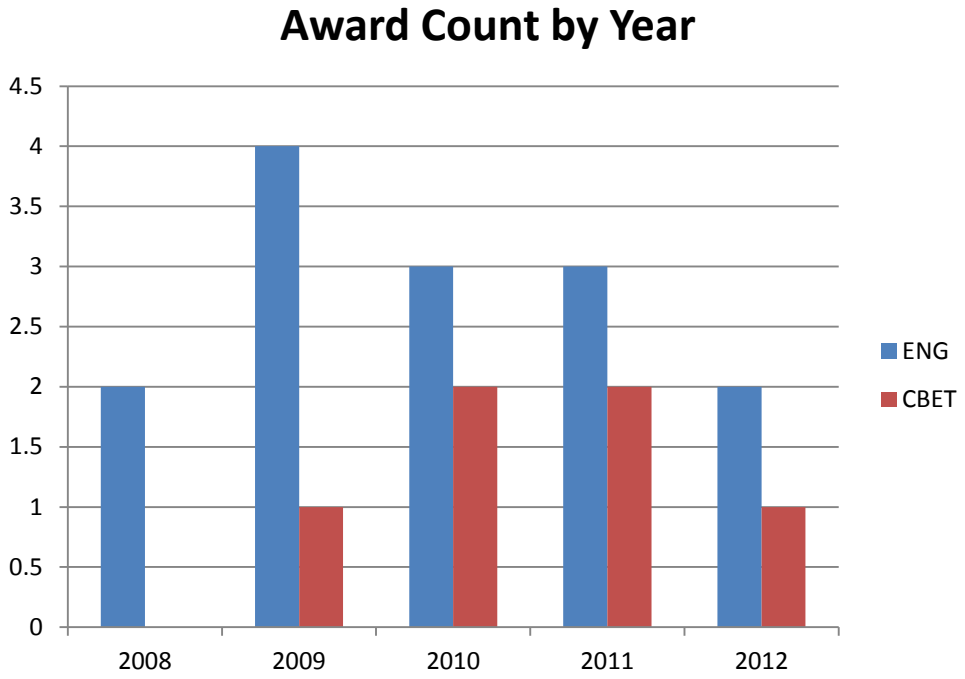
Award Data in Power Plant Cooling





Award Data for Water-Energy Nexus





* SRN Award in 2012

Possible NSF-EPRI Joint Solicitation
on Advancing Water Conservation Cooling Technologies

- **Potential Funding Level:**
  - Max. $500k for a up to three year project
- **Tentative Timing**
  - Solicitation Releasing Time:
  - Proposal Due:
  - Award Time:
- **Funding Approach**
  - Coordinated but independent funding
    - NSF awards grants
    - EPRI contracts
  - Joint funding for most proposals
  - Independent funding for a few proposals if needed

Memorandum of Understanding on this effort established between NSF/EPRI

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Questions?

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gure.