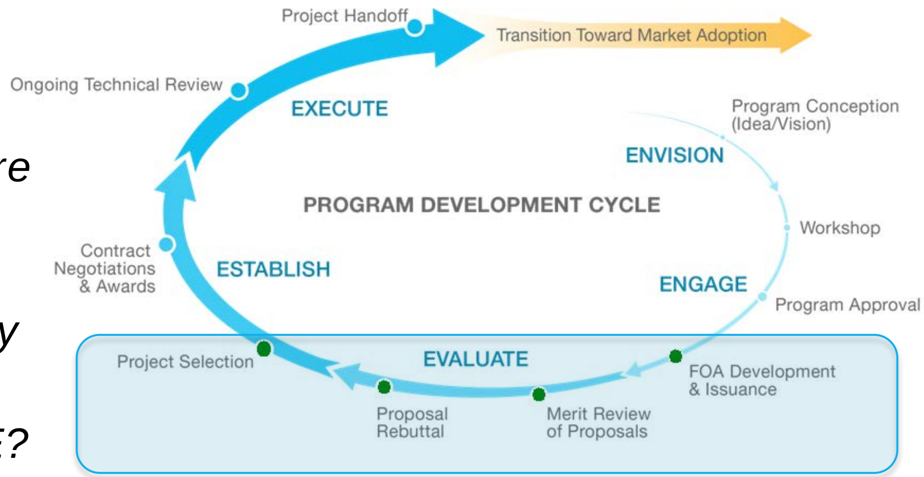
BREAKOUT Instructions Sheet:

Day 1: Why Now?

- Attendees pitch their quads
- 7 minutes total including:
  Intro, pitch, and Q&A.
- Audience follows up with questions by considering ARPA-E like criteria:
  - ***Impact***: *If project targets & metrics are achieved, will it matter?*
  - ***Transform***: *Is it a significant departure from the SOA? Are the risk factors fully outlined?*
  - ***Bridge***: *Is it uniquely suited for ARPA-E?*
  - ***Team***: *What set of capabilities and/or experiences are needed for execution?*



NOTE: Not all speakers will be detailing a specific approach but may focus on value-add content for the breakout.

Breakout Group #1

First Name	Last Name	Company/Organization
Eric	**Rohlfing**	**ARPA-E Moderator**
Dawson	**Cagle**	**Booz Allen Hamilton**
Ed	Arens	Berkeley
Bill	Carter	HRL
Jintu	Fan	Cornell University
Alon	Gorodetsky	UCI
Saul	Griffith	Otherlab
Maurice	Gunderson	Gentherm
Craig	Heller	Stanford
Jeff	Muhs	Witricity
Evelyn	Wang	MIT
YuHang	Wang	Univ. of Maryland
Joe	Wang	UCSD
Patrick	Williams	NIKE

Making Personal Comfort the Basis of Efficient Buildings

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This can save 30-50% of HVAC energy nationwide, ~5% of total US energy use …
(at 25% penetration over 5 years, 0.51–0.85 Quads, $5 -8 billion)

Problem Statement

- Buildings now uncomfortable to at least 20% of occupants
- Energy inefficiency: overcontrolled, oversized, open feedback loops
- Conservative industry, fragmented stakeholders, normal improvements are not scalable
- *But:* large reductions are possible in both retrofit and new construction

Approach

- Demonstrations in buildings of energy savings and comfort improvements
- Develop wireless sensor communications to central HVAC system, including occupant interaction via personal comfort devices and apps

Potential Solutions

- Personal comfort devices that are energy efficient and effective
- Decentralized ambient environmental control
- Web-based interaction between occupants and system
- Transparency in controls and data systems

Scientific & Technical Challenges

- Obtaining energy savings from personal comfort systems is still highly unproven
- Technology installation must bypass the multiplicity of trades
- Technology must solve who-pays versus who-benefits
- Commercialization may disrupt current interiors manufacturers

Personal Thermal Management Clothing System

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To develop a highly efficient thermal regulating underwear, capable of controlled heating or cooling of at least 15 Watts/m^2, without sacrificing wearing comfort and overall appearance.

Problem Statement

- How would you frame the problem?
  - Limited thermal regulation in existing material/clothing
  - Difficulty in creating cooling effect without sacrificing wear comfort and overall appearance.
- If success is attained:
  - Expansion of neutral-band of building by at least 4°F in each direction.
  - Save more than 1% of the total energy consumed in US.

Approach

- Integration of materials and functional apparel design.
- Use of micro-electronics
- Use of soft actuators
- Use of sweating fabric manikin technology.
- Building on the understanding of heat and mass transfer through clothing.
- Building on the understanding of clothing physiology.

Potential Solutions

- Temperature regulating fabrics (Fabrics with variable transport properties).
- Conductive yarns for heating
- Micro-electronics
- Soft actuators
- Direct heating from wireless source.
- Mechanisms to create air flow inside clothing to enhance mass and thermal transport.

Scientific & Technical Challenges

- Increased weight.
- Increased wearing discomfort.
- Unacceptable overall appearance.
- Consumer acceptance.
- Need for power supply.
- Limitation of temperature regulating fabrics.
- Development of mass production methods for new types of thermal regulating garments

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1 Problem Statement

- We currently use external energy to regulate human comfort in buildings over a very narrow range. The heat (or cold) is expensive.
- The great majority of synthetic textile fibers are monofilament and low in complexity.
- Biologically generated fibers are highly structured and multi-functional (eg. polar bear fiber light pipes, goose-down, hollow possum fibers)
- Active and more complex / multifunctional synthetic fibers and textiles will enable more human comfort over a broader range of temperatures.

2 Potential Solutions

1. Thermal Bimorph fibers increasing loft or insulation value with ambient temperature change.
2. Radiative carpet squares that localize heat delivery (and allow natural convection)
3. Self-inflating drapes (active or passive) for sealing windows and increasing insulation
4. RF inductive fibers in clothing for extreme localized heating.
5. Hollow fibers filled with phase change material for holding an isotherm.
6. Active-Dermis controlled fiber / textile lofting.

3 Approach(es)

1. Bi-material fibers slit from laminated films into topologies optimized for varying loft.
2. Locally addressable carpet squares with resistive heating elements.
3. Chambered and passively or actively inflated drapes that fill window cavities and vary insulation value.
4. Micro-antenna printed or stamped into filaments that are addressable by focussed RF for localized heating.
5. Micro-capillary fibers filled with paraffin wax or similar phase change material that are woven / incorporated into textiles.
6. Akin to "making the hair on the back of your neck stand-up" using two layers of "skin" (textile layers) that when moved relative to each other make the insulating fibers 'loft' up.

4 Scientific and Technical Challenges

- Materials challenge of high ΔCTE fibers.
- Automated micro-capillary filling without leakage
- Manufacturing issues of high throughput (roll-roll) structured fibers and downs.
- Human factors and product design.

Developing Markets for Personal Thermal Comfort

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Gross margin of 30% or greater.

Problem Statement

- Development of reliable, low-cost thermal comfort products, and growth and exploitation of markets for them.
- Energy savings are secondary and tertiary effects, and are difficult to quantify at this time.

Approach

- Fundamental molecular material design and system architecture paradigm change needed before laboratory-based physics demonstrations can flow into the commercial market
- Existing technologies and designs are only being dimensionally downsized and margin-tweaked, yielding sub-5% improvements in performance

Potential Solutions

- Thermoelectric heat pumps
- Rankine heat pumps
- Advanced air moving technologies
- Engineering fabrics and reticulated foams

Scientific & Technical Challenges

- Some current material selections are too fragile for commercial use
- Overall system efficiencies are too low for practical consideration in some applications
- Wireless power has not been pragmatically solved

Exploiting The Body's Natural Radiators to Develop Personal Heating/Cooling Systems

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Problem Statement

- Creating thermal comfort by heating and cooling ambient air is an inefficient use of energy
- Personal heating and cooling systems would increase the range of acceptable building temperatures necessary to maintain thermal comfort and it would accommodate variation in thermal needs of individuals.

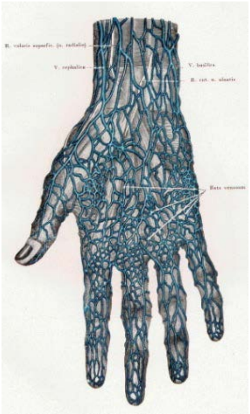
Approach

Build personal heat exchange systems that can heat or cool the palms of the hands or the soles of the feet.

Prototype systems have proven successful in rapidly restoring core temperature of hypo- and hyperthermic individuals and maintaining thermal comfort.

Potential Solutions

- Humans like all mammals have natural radiator structures underlying the non-hairy skin. These are vascular shunts that bypass the small capillaries and direct arterial blood into large networks of veins. These venous structures are the most direct way of exchanging heat between the body core and the environment.



Scientific & Technical Challenges

- Developing systems for sedentary subjects is rather straightforward, but developing wearable systems for ambulatory individuals is more difficult and would require:
  - Developing comfortable and functional heat exchange inserts for shoes.
  - Developing glove heat exchangers that enable manual dexterity.

Wireless Power – An enabling technology for PTMS

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A novel approach to eliminate the need for special clothing, user-worn batteries and or tethered power requirements in office environments.

Problem Statement

PTMS requires special clothing. Battery-powered clothing is size-specific, perceived as expensive, inconvenient and lifestyle-intrusive, and requires manual recharging or cell replacement. Outlet-tethered clothing has similar deficiencies. New methods are needed to eliminate these impediments.

Approach

Leverage existing WPT technology but add:

- Optimized custom resonators
- Tiled, intuitive passive repeater arrays
- Flexible & conformal topologies
- Improved efficiencies over much wider dynamic range (power, device orientation, positional misalignment, load impedance)

Potential Solutions

Use wireless power transfer to eliminate special clothing, batteries or tethered power by integrating WPT transmitters into special floor mats that transfer power to untethered thermally-adaptive, and WPT-equipped office chairs and shoe insoles that, in turn, provide thermal comfort. If necessary, integrate WPT into chairs & transfer power user-worn batteries in clothing.

Scientific & Technical Challenges

Needed Novel Capability	Risk
Dynamic power control	L/M
Device Design for wireless	M
More Ubiquitous charging	M/H
Conformal resonators	H
Intuitive, passive repeaters	VH

Phase-Change Devices for Personal Thermal Management

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Thermally dissipate 100 W with 0.05 clo and 1 kWh to reduce >1% of energy consumption and CO_2 emissions

Problem Statement

- Develop personal garments for thermal comfort
- Sustained cooling and heating for >8 hours, power consumption <33 W, with added weight < 2 lbs, thickness of < 1 cm and garment cost of <$40/m^2
- If successful, potential reduction in >1% of energy consumption and CO_2 emissions in near term. Even larger energy savings with the projected increased need of energy in the future.

Approach

- Develop integrated passive flexible phase-change device with localized thermoelectric modules for temperature control
- Phase-change devices such as heat pipes currently exist commercially for electronics thermal management
- Thermoelectric modules are also commercially available in various form factors

Potential Solutions

- Phase-change solutions include:
  - Flexible heat pipes
  - Adsorption device
  - Phase-change materials
- Integrated with thin film thermoelectric modules

Scientific & Technical Challenges

- Heat pipes: development of fluid with operating temperature range and thin flexible form factor with sufficient liquid/vapor transport
- Adsorption device: adsorption materials for operating temperature range and desorption temperature, sufficient operation time without recharging, control
- Phase change materials: latent heat and other thermophysical properties, operational time
- Thermoelectrics: high COP, thin form factor

Adaptive Clothing from Thermally Responsive, Conductive Yarns

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Insert value proposition statement for your technical approach = *X* clo/°F, *Y* Watts Thermally dissipated, *Z* kWh saved per year…

Problem Statement

- How can one design and produce advanced clothing that can provide personal comfort over a broader range of building temperature?
- If success is attained, such advanced clothing will significantly advance energy materials technology and system integration and, for the long term, it will provide substantial savings on energy consumption in buildings and improve human adaptability to server environment.

Approach

- Integrate carbon nanotubes (CNTs) as heat absorber in expandable fabrics such that it expands to reduce body heat loss and increase absorbance of radiation when cold and contracts to facilitate heat dissipation and increase emission when hot. Thermometer can be directly integrated into the conductive yarn and weaved into the cloth for personal comfort triggered local control.
- The body emits and absorbs heat primarily by radiation (up to 50%). CNTs are nearly ideal blackbody absorbers that can be seamlessly integrated into yarns.

Potential Solutions

- Produce CNT fibers as electrically and thermally conductive yarns that will allow seamless integration of electronic and thermal management functions in advanced textiles.
- Develop thermally responsive, multifunctional composite yarns that integrate carbon nanotubes as heat absorber and thermally responsive polymers for integrated thermal management capabilities.

Scientific & Technical Challenges

- The fabrication of a thermally responsive and conductive yarns for advanced clothing has never been established. Effectiveness (or ineffectiveness) of the thermal management functions has never been established. To meet this challenge, we have proposed an experiment to correlate the mechanical, thermal, and electrical response of the composite yarn with the structure.
- The yarn technology has to be compatible with conventional clothing and textiles, highly scalable, and cost effective.

ARPA-E Personal Thermal Management Workshop
Raleigh, NC, November 12 &13, 2013

Smart Textiles with Active Cooling (STAC)

Joseph Wang (UCSD)

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Expertise and Alignment

Microfabrication, Advanced Screen Printing
Wearable Body-Worn Devices
Electrochemistry
Advanced Flexible Materials

Relevant Research

Textile-based Screen Printed Electrodes (NSF)
Wearable Electrochemical Sensors (various industrial sponsors)
Fuel Cells and Biofuel Cells (NSF)
Advanced Energy Materials (DOE)

Collaboration Outlook

Thermoelectric Materials and Thermo-Management- Renkun Chen (UCSD)
Intelligent Adaptive Materials – Sungho Jin (UCSD)
Solid-State Energy Storage - Shirley Meng-(UCSD)

Contact Info

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