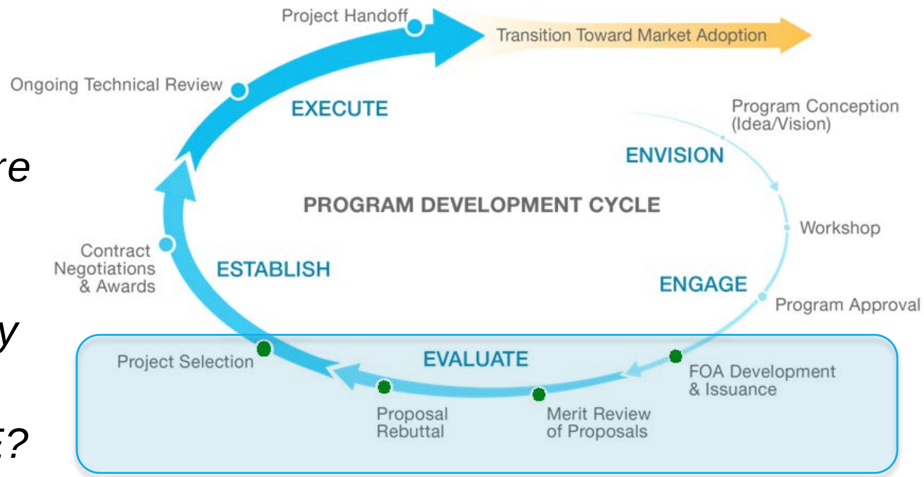
BREAKOUT Instructions Sheet:

<u>Day 1</u>: 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?*



arpa·e
CHANGING WHAT'S POSSIBLE

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

Breakout Group #2

First Name	Last Name	Company/Organization
Dane	**Boysen**	**ARPA-E Moderator**
Amul	**Tevar**	**ARPA-E**
Ashwin	**Salvani**	**ARPA-E**
Christine	Cole	Clemson
Allen	Curran	Thermoanalytics, Inc.
Steve	Fossey	Natick Soldier RD&E Center
Lei	He	UCLA
George	Hernandez	BTO/PNNL
Bing	Hu	University of Maryland
Byron	Shaw	Gentherm
Girish	Srinivas	TDA Research, Inc.
Dan	Steingart	Princeton University
Diane	Warren	VFC
Xiaojiang	Xu	US Army Research Institute of Environmental Medicine
Ronggui	Yang	University of Colorado

The Personal Impact of Thermal Control Systems

Dr. Christine W. Cole
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Problem Statement

- How to reduce energy consumption used to provide ‘human comfort’ in the work place through individual solutions which have minimal impact on individuals?
- Success = immediate impact through widening of control settings for general environment, 68 – 72F becomes low 60s – 78F, for cold/hot weather

Approach

- Examine the psychological and physiological barriers to a given solution

Jones NY

A. Madeline.de

Ann Taylor

Potential Solutions

On-the-body solutions need to be evaluated relative to personal choices – ex:solutions that may alter choices by professional women regarding attire will encounter resistance

Changes in general environment must consider medical conditions which may be impacted, such as Reynaud’s Syndrome, menopausal ‘hot flashes’

Individual solutions that are off the body may be impacted by synergistic general environment changes, such as a ‘cooling chair’ will not address personal discomfort in hot general environment when not seated.

Scientific & Technical Challenges

- Ability to design for the ‘lowest common denominator’ may impact success of any solution
- The form of energy required by solution needs to lower than the form used in general heating and cooling, ie, the actual energy tradeoff is not sufficient

Physiology-Based Human Comfort Prediction Methodology

Al Curran
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An efficient, physiology-based human comfort prediction methodology that emphasizes simulation and minimizes human subject testing will improve PTMS designs and save time and money.

Problem Statement

- Local cooling and heating solutions (PTMS) can be employed as opposed to conditioning the entire space of a building.
- The designers of these solutions don't have easy access to appropriate simulation or evaluation techniques that predict thermal comfort for building occupants.
- Impact: Reduced building energy consumption due to expanded use of PTMS

Approach

- Extend the Human Thermal Model (HTM) in RadTherm thermal simulation software to incorporate:
  - Advanced clothing models (e.g, active clothing, phase change material)
  - Advanced environmental models (e.g., heated/cooled seats)
  - Advanced comfort models (e.g, local (sub-segment) heating/cooling)

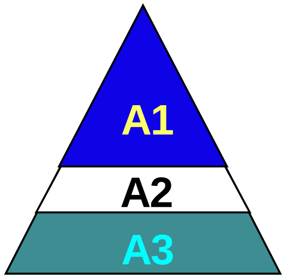
Potential Solutions

- Segmental physiological models (e.g., Berkeley, Fiala, RadTherm HTM)
- Physiologically-controlled sweating thermal manikin.
- Passive sensor manikin
- Two-node thermoregulation models
- Environment-based comfort metrics (e.g., equivalent temperature)

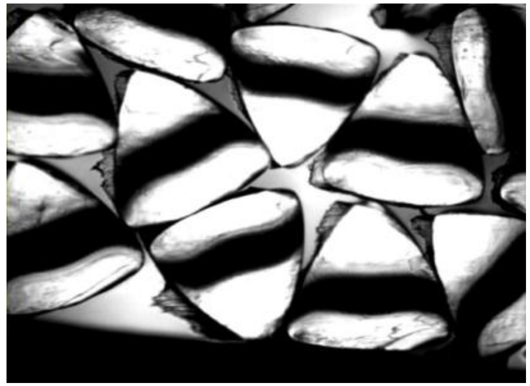
Scientific & Technical Challenges

- Getting simulation and evaluation tools into the hands of the designers at the time when it's useful to them.
- Simulation tools must incorporate the technologies of interest for PTMS.
- Simulation tools must model human thermo-physiological response.

Multi-component Fibers for Temperature Adaptive Insulation



Concept


Actual fibers

As temperature decreases, batting thickness increases

Applications:
- Cold Weather Clothing
- Sleeping Bags
- Blankets

3 different polymers - Fibers curl, batting gets thicker.

3 components using the same polymer - No curling or change in thickness

Personalized, Wearable Thermal Comfort Sensor

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Problem Statement

- Accurate thermal comfort sensor is missing and challenging to design because the current practice is based on: subjective, uni-model, general model, lack of direct evidence;
- Accurate thermal comfort sensor is the pivotal figure in building personal thermal management systems

Approach

- Aims: build a personalized thermal comfort sensor:
- Wearable system to capture evidence;
- Multi-modal model (metric) for thermal comfort analysis;
- Key technologies:
- E-textile, MEMS sensors: design, modeling and calibration;
- Human Physiopsychological Model;
- Machine Learning;

Potential Solutions

- **Research plan:**
- Developing a wearable system to monitor individual physiological responses, physical activity signals, mental status, ambience;
- Design and model a heterogeneous multi-modal metric to estimate the human thermal comfort;

Scientific & Technical Challenges

- It is an interdisciplinary research, including:
- **Engineering**: material, system integrating, sensor model and calibration;
- **Phycology:** Physiopsychological modeling;
- **Computer Science:** machine learning to build personalized thermal modeling.

UNIVERSITY OF MARYLAND 1856

Core-Shell Textile Fibers With Phase Change Materials

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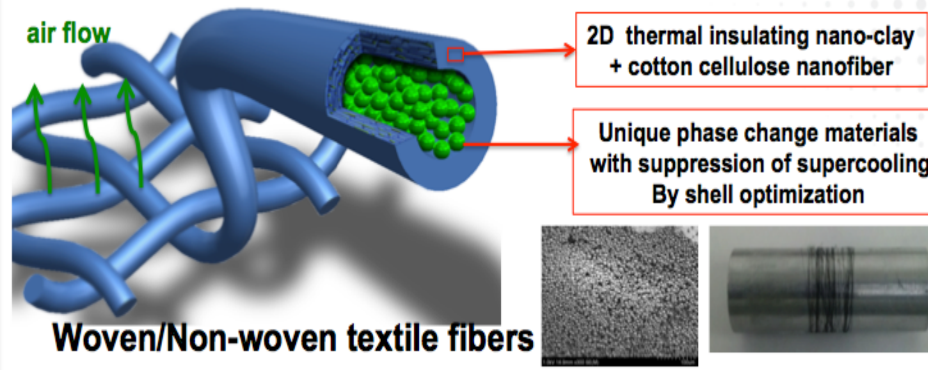
Design innovative, safe, comfortable textile fibers with scalable wet spinning process that incorporate PCM

Problem Statement

- Safety issues of PCM materials
- Health, safety, and environmental concerns of nanomaterials
- Mass production of nanomaterials

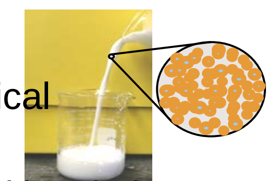
Approach



Potential Solutions

- Incorporating fire retardant materials;
- Incorporating PCMs by coating or lamination.
- Porous shell materials to reduce weight and improve thermal insulation
- Porous nano-clays form barrier between the flammable PCM microcapsules and air, reducing the rate of burning

Scientific & Technical Challenges



- Cost may be higher;
- Optimization of thermal and mechanical properties of textile fibers
- Durability of textile fibers with thermal insulative, fire retardant shell and PCM microcapsule core.
- Challenges to fabricate core-shell textile fibers with enough mechanical strength.

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

TDA Research

Microclimate Cooling Shirt for Energy Savings

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TDA estimates that total energy savings possible if TDA's personal cooling garment were fully implemented could be approximately 2 quad/yr (~2% of US energy use)

Problem Statement

- Developing a personal system is a challenge because current technologies such as liquid cooling, AC and large fans require considerable power, are heavy, and not very portable. Thus, these are unlikely to be used by workers that must be mobile (inside and outside of building)
- Our technology eliminates these problems using a cooling garment that permits cooling by the body naturally.
- Importantly our technology permits this to happen *even in very hot and humid conditions*.

Approach

- TDA proposes to develop a personal cooling shirt that works even in hot *and humid* climates
- Our design is based on well established textile technologies and long known engineering principles of heat and mass transfer.
- We propose to develop a small, lightweight, (~3 lb.) system that can be used to remove as much as ~750 Btu/hr. of heat from the body

Potential Solutions

- Competing technologies include phase change materials (such as ice) and liquid cooling systems
- Phase change systems are heavy and require refrigeration for regeneration
- Liquid systems require a portable cooling device that is heavy and power hungry that is connected to the wearer with tubing.
- TDA's technology is light, requires minimal power and there are no regeneration requirements or ancillary units because we do not use phase change or liquid cooling

Scientific & Technical Challenges

- The risk is minimal; the textile technology we use is mature and the engineering design principles are very well established
- Technical challenges include fabrication of the proprietary, patent pending technology; however our industrial textile manufacturing collaborator has evaluated our technology and feels that this will not be difficult to address.
- Several iterations of the design may be needed to optimize cooling.

Fabric Embedded Batteries for Personal Thermal Management

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We will expand upon our stretchable batteries for medical and novelty applications to develop cost effective garment energy storage for personal temp ware

Problem Statement

- Making large area, safe, long lasting maintainable batteries capable of providing 2-6 W of power to heating/cooling devices for 2-5 hrs
- 10 Whr per person should save more than 1 kWhr of heat per day.

Approach

- We would work with clothing designers to specify the qualities of a fabric embedded battery for lay applications.
- We will exploit newer safe, high rate, high current density long cycle life chemistries for embedded applications.

Potential Solutions

- Encapsulated Phase Change Materials
- Efficient Thermoelectrics
- Basic Flexible Logic/Sensors

Scientific & Technical Challenges

- Efficiency and durability of thermoelectric devices
- User acceptance of garments: if it's "under wear", or "not normal" uptake will be difficult
- Cost efficacy of garments
- Weight of PCMs
- Fundamental Durability of a battery in this application