Graphite-based Thermal Management System Components for Fuel Cell Power Systems

Edgar Lara-Curzio, J. G. Hemrick, N. Gallego, A. Zaltash, and C. Walls
Oak Ridge National Laboratory

Brian Thompson
University of Western Ontario

2004 DOE Hydrogen, Fuel Cell, & Infrastructure Technologies Program Review

This presentation does not contain any proprietary or confidential information

Outline

- Project Objective
- Budget
- Technical Barriers and Targets
- Approach and Timeline
- Technical Accomplishments/Progress
- Interactions and Collaborations
- Future Work

Objectives

To develop compact, low-weight, high-effectiveness thermal management system components for fuel cell power systems using carbon-based materials.

For FY04

- To design thermal management system components based on graphite foam and 3-D woven graphite fiber preforms.
    - Synthesize graphite foams with different pore sizes and assess the effect of pore size on heat transfer, permeability and mechanical strength.
    - Determine the feasibility of weaving high-stiffness graphite fibers into complex 3-D architectures.
    - Evaluate the effect of fiber architecture on the heat transfer and permeability of 3-D fiber preforms.
- To broaden industrial collaborations.

Budget

2004
$129K

- Project started in FY04

Technical Barriers and Targets

- DOE Technical Barriers for Transportation System Fuel Cells
  - Thermal management and heat utilization (C. and F.).
  - Vehicle size, weight, cost and durability.

- DOE Technical Targets for Transportation Related Fuel Cells
  - Ability to function over the full range of vehicle operating conditions (-40° to 80° C).
  - Smaller heat exchangers.
  - Smaller and lighter fuel cell systems which meet packaging requirements for automobiles.
  - Fuel cell systems with a cost of $30/kW.

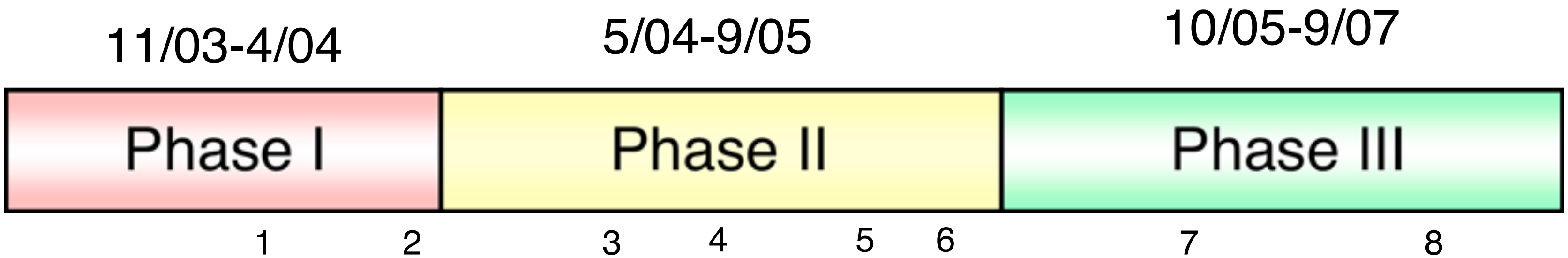
Approach

- Utilize woven preforms of high-thermal conductivity graphite fibers to develop compact thermal management system components (heat exchangers, radiators, evaporators) with low density, high surface area, high permeability, high thermal effectiveness and high damage tolerance.
- Utilize commercially-available graphite fibers and established manufacturing processes for fabrication of thermal management system components.
- Synthesize graphite foams with higher permeability utilizing low-cost precursors.
- Redefine geometry of thermal management system components.

Project Safety

- Project activities are covered by a formal, integrated work control process for each practice/facility.
  - Definition of task
  - Identification of hazards
  - Design of work controls
  - Conduct of work
  - Feedback
- Each work process is authorized on the basis of a Research Safety Summary (RSS) reviewed by ESH subject matter experts and approved by PI's and cognizant managers.
- RSS is reviewed/revised yearly, or sooner if a change in the work is needed.
- Staff with approved training and experience are authorized through the RSS.
- Activities involve the use of gases (< 100 psi), hot-surfaces (< 300°C), small-diameter fiber and low-voltage instrumentation.

Project Timeline



Phase I. Feasibility

1. Assess ability to weave high-stiffness fibers into 3-D architectures. (Go)
2. Fabricate woven fiber structure prototypes.

Phase II. Development, Testing and Evaluation

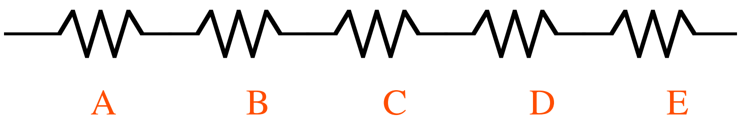
3. Evaluate effect of precursor on pore size and microstructure of graphite foam.
4. Evaluate effect of fiber architecture or microstructure on permeability and heat transfer of woven fiber structures and modified graphite foams.
5. Complete numerical models of effect of fiber architecture or microstructure on permeability and heat transfer characteristics of woven fiber structures and graphite foams.
6. Develop hybrid woven fiber structures to optimize cost, transport properties and mechanical durability.

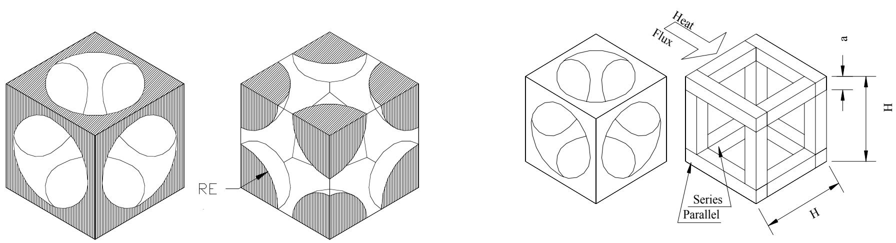
Phase III. System Design and Testing

7. In collaboration with fuel cell developers and users, design and fabricate pilot versions of thermal management system components for testing and evaluation.
8. Transition technology to industry.

Technical Accomplishments

Modeling





$$K = \frac{\varepsilon^3 DE^2}{147(1-\varepsilon)^2} \qquad K = \frac{36\varepsilon^3}{147\beta^2}$$

$$ke = \frac{\left(4a^2 + H^2(1-t)^2\right)\dfrac{\sigma + \left(\frac{1}{t}-1\right)^2 k_f}{1+\left(\frac{1}{t}-1\right)^2} + 4aH(1-t)\dfrac{k_s}{(1-t)\sigma + t}}{H^2(1+t)}$$

A	Convective resistance of water
B	Conductive resistance due to the metal tubing
C	Conductive resistance due to tube/HTM contact
D	Conductive resistance due to HTM
E	Convective resistance of air

- Collaboration with Professor Brian Thompson of the University of Western Ontario (through a DOE-DER sponsored project).
- Engineering model provides thermal resistance and pressure drop in air-water heat exchangers with plate-fin and annular-fin configurations.

Technical Accomplishments

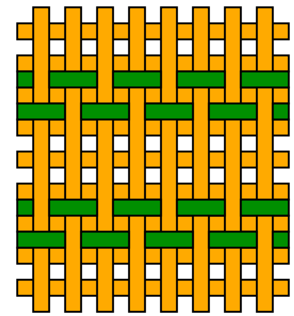
High Thermal Conductivity Fibers

- Several commercial fibers with thermal conductivities greater than that of current heat exchanger materials such as aluminum (K ≈ 237 W/mK) and comparable to that of graphite foam ligaments have been identified.

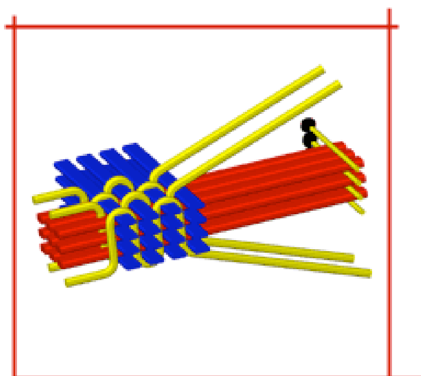
Fiber (Manufacturer)	Thermal Conductivity (W/mK)	Elastic Modulus (GPa)
K-100 (Cytec)	1000	965
K-800X (Cytec)	900	896
P-120S (Cytec)	640	827
YS-95A (NGF)	600	920
P-100S (Cytec)	520	758
YS-90A (NGF)	500	880
CN-90 (NGF)	500	890
YS-80A (NGF)	320	785
CN-80 (NGF)	320	800

Technical Accomplishments

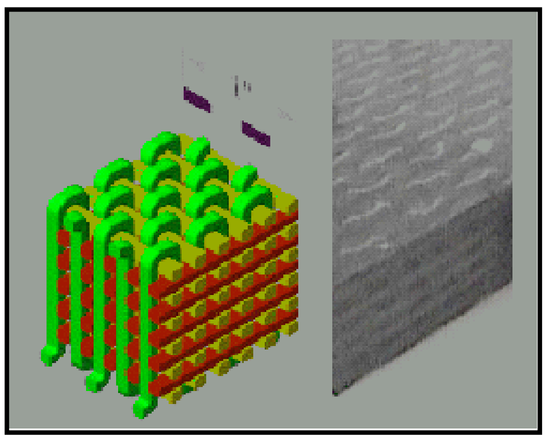
Graphite Fiber Weaving

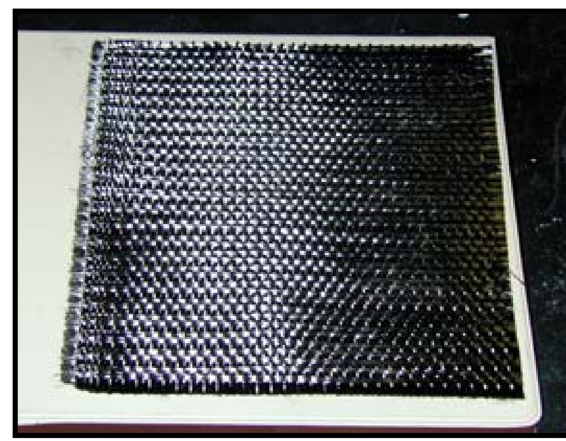


- Technologies have been identified for weaving graphite fiber preforms with complex three-dimensional architectures*.
- These technologies will be utilized to produce tailored preforms with controlled pore structure, permeability and thermal properties.



* 3-Tex 3Weave

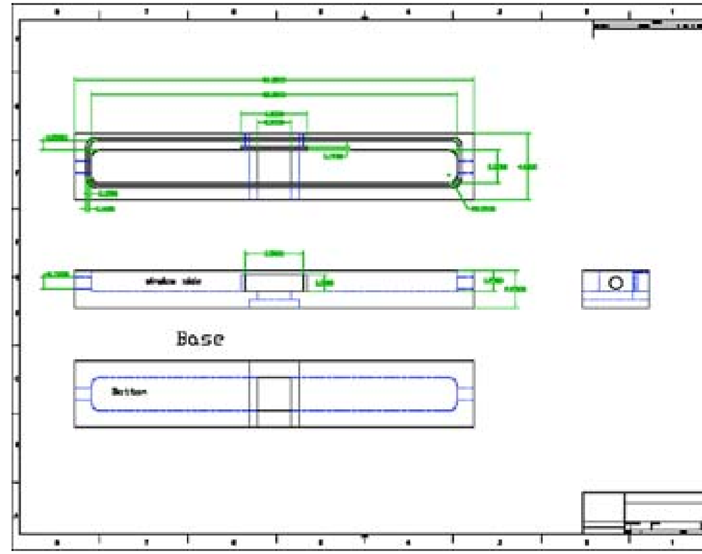


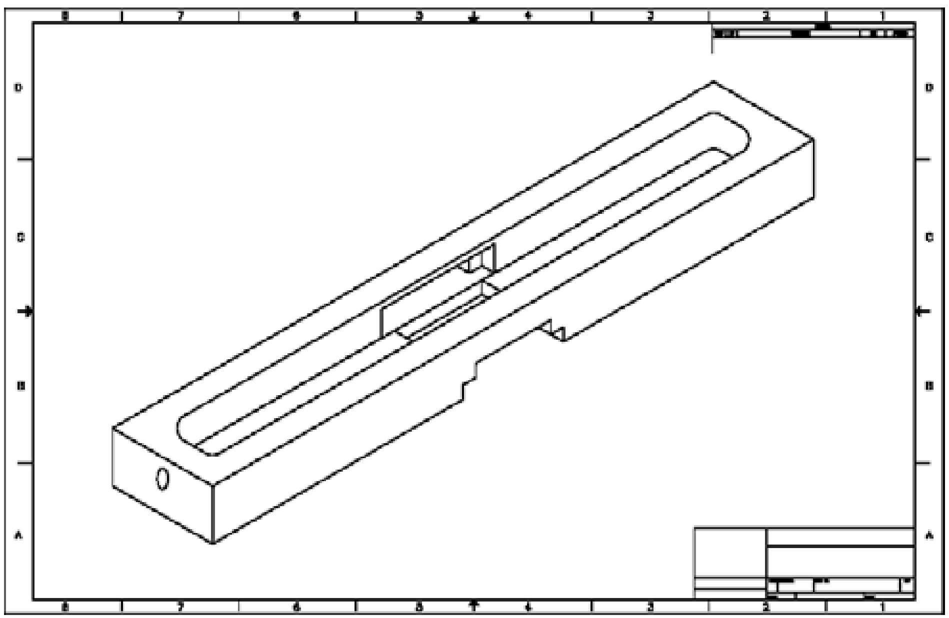


Technical Accomplishments

Testing of Heat Transfer and Pressure Drop

- A test rig has been designed and built to evaluate heat transfer and permeability of graphite foams and woven fiber preforms.





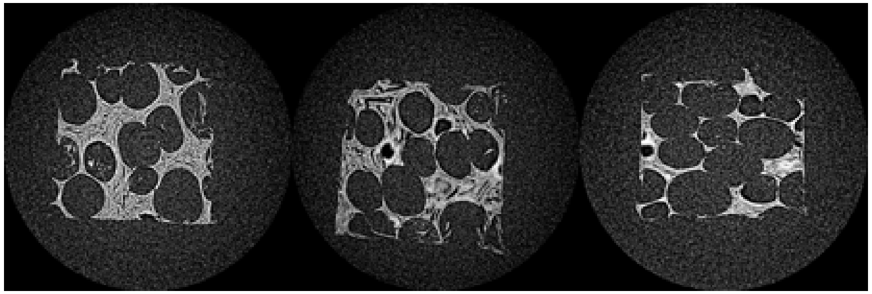
- Results will be used to optimize the pore structures of foams and fiber preforms to maximum performance and to verify model predictions.

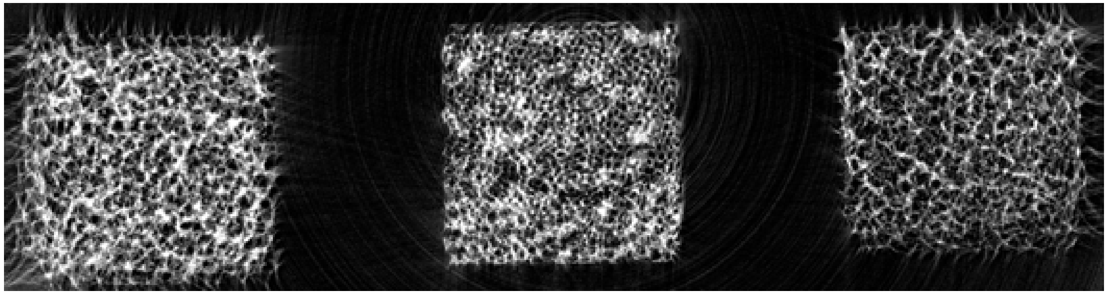
Technical Accomplishments

X-ray Tomography

- The role of pore geometry and mechanical properties of individual foam ligaments on the macroscopic mechanical properties of foams will be evaluated with the aid of models produced through X-ray tomography and rapid prototyping techniques.
- CT scans performed on foams at 26 and 3 μm resolutions

- Scan data will be used for Layer Object Manufacturing (LOM) of enlarged ligament structures





Interactions and Collaborations

- Graphite fiber supplier: *Cytec Engineered Materials*
- Fiber weaving technology : *3-TEX, Inc., Albany International (Techniweave)*
- X-ray tomography of graphite foam and fibrous structures: *Argonne National Laboratory*
- Heat Transfer Modeling*: University of Western Ontario*

Pioneering Science and Technology

ARGONNE NATIONAL LABORATORY A U.S. Department of Energy laboratory operated by The University of Chicago

Future Plans

- Remainder of FY 2004:
  - Weaving of high-modulus fibers.
  - Weaving of 3-D fiber preforms containing tubing.
  - Synthesis of graphite foams with larger pores.
  - Heat transfer and permeability testing of modified graphite foams and woven preform structures.
  - Production of enlarged ligament models based on X-ray tomography and mechanical testing of models.

- FY 2005:
  - Complete numerical models of effect of fiber architecture or microstructure on permeability and heat transfer characteristics of woven fiber structures and graphite foams.
  - Develop hybrid woven fiber structures to optimize cost, thermal properties, permeability and mechanical durability.