Additively Manufactured Intensified Device for Enhanced Carbon Capture

Xin Sun, Lonnie Love, James Parks II
Energy and Transportation Science Division

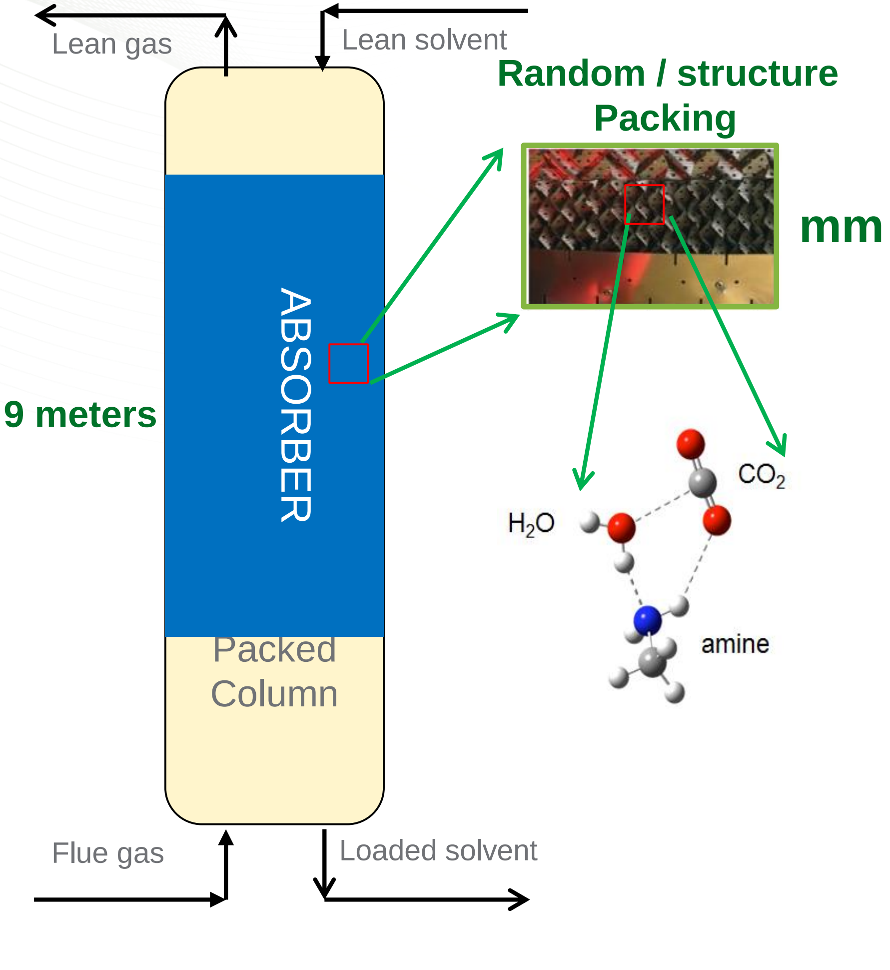
Oct. 19, 2017

Oak Ridge National Laboratory

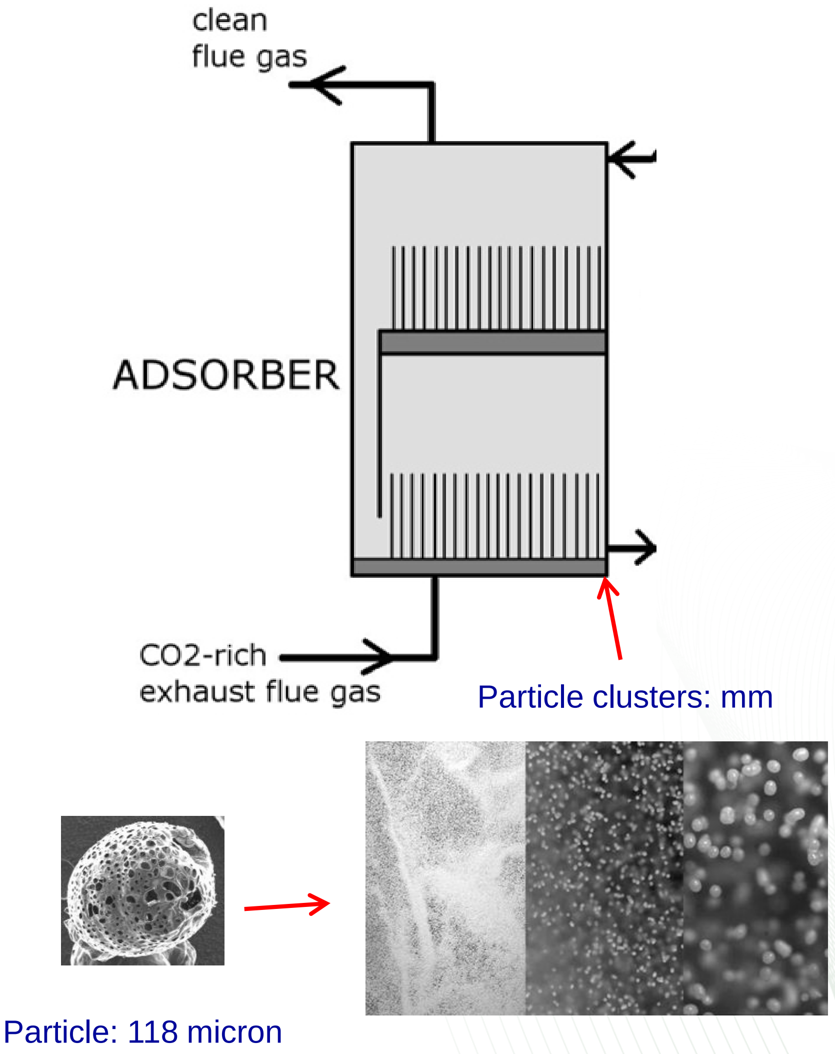
Project Kickoff Meeting

a. Project background
b. Project team/project organization
c. Project objectives
d. Technical approach/project scope
e. Project budget
f. Project schedule and associated milestones
g. Project risks/risk management

Carbon Capture: Solvent and Sorbent-based Technologies



Solvent-based capture



Sorbent-based capture

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Oak Ridge National Laboratory Organizational Update

Communications: David Keim
Counterintelligence: Selin Warnell
Chief Information Officer: Mike Bartell
Institutional Planning: Celia Merzbacher
Integrated Performance Management: Mike Baker

Oak Ridge National Laboratory
Thomas Zacharia, Laboratory Director

Michelle Buchanan
Deputy for Science and Technology

Jeff Smith
Deputy for Operations

Internal Audit: Gail Lewis
General Counsel: Rachel Blumenfeld
Operational Initiatives and Project Management: Jeff Ault
Research Excellence: Moody Altamimi

Computing and Computational Sciences Directorate: Jeff Nichols, Associate Laboratory Director

- **Computational Sciences and Engineering** — Shaun Gleason, Director
- **Computer Science and Mathematics** — Barney Maccabe, Director
- **National Center for Computational Sciences** — James Hack, Director
- **Oak Ridge Leadership Computing Facility Project** — Buddy Bland, Project Director

Energy and Environmental Sciences Directorate: Moe A. Khaleel, Associate Laboratory Director

- **Biosciences** — Tony Palumbo, Director
- **Electrical and Electronics Systems Research** — Rick Raines, Director
- **Energy and Transportation Sciences** — Xin Sun, Director
- **Environmental Sciences** — Stan Wullschleger, Director

Nuclear Science and Engineering Directorate: Alan Icenhour, Associate Laboratory Director

- **Fusion and Materials for Nuclear Systems** — Phil Ferguson, Director
- **Nonreactor Nuclear Facilities** — Mike Pierce, Director
- **Nuclear Security and Isotope Technology** — Cecil Parks, Director
- **Reactor and Nuclear Systems** — Ken Tobin, Director

Neutron Sciences Directorate: Paul Langan, Associate Laboratory Director

- **Neutron Scattering** — Richard Ibberson, Acting Director
- **Neutron Technologies** — Don Abercrombie, Acting Director
- **Research Accelerator** — Kevin Jones, Director
- **Research Reactors** — Tim Powers, Director
- **Proton Power Upgrade Project** — John Galambos, Project Director

Physical Sciences Directorate: Phil Britt, Acting Associate Laboratory Director

- **Center for Nanophase Materials Sciences** — Hans Christen, Director
- **Chemical Sciences** — Andrew Stack, Acting Director
- **Materials Science and Technology** — Jeremy Busby, Director
- **Physics** — David Dean, Director

Global Security Directorate: Brent Park, Associate Laboratory Director (James Peery, Chief Scientist)

- **Defense and Homeland Security Programs** — Nick Prins, Director
- **DOE-IN Programs** — Kendall Card, Director
- **Intelligence Programs** — J.D. Stauffer, Director
- **Nonproliferation Safeguards and Security Programs** — Larry Satkowiak, Director

Exascale Computing Project: Doug Kothe, Project Director (Stephen Lee, Deputy Project Director, LANL)

- **Application Development** — Doug Kothe, Director
- **Hardware Technology** — Jim Ang, Director (SNL)
- **Software Technology** — Rajeev Thakur, Director (ANL)

US ITER Project: Ned Sauthoff, Project Director (Suzanne Herron, Deputy Project Director)

- **Non-Nuclear Systems** — Graeme Murdoch, Director
- **Nuclear Systems** — Brad Nelson, Director

Business Services Directorate — Scott Branham, Chief Financial Officer

Environment, Safety, and Health Directorate — John Powell, Director

Facilities and Operations Directorate — Jimmy Stone, Director

Human Resources Directorate — Debbie Stairs, Director

Partnerships Directorate — Jim Roberto, Director

EESD Organizational Structure

Associate Laboratory Director
Mohammad (Moe) Khaleel
Shelia McClure, Executive Secretary

OBER Programs
Moe Khaleel

Applied Remediation and Subsurface Science
Eric Pierce

Climate Change Research
Stan Wullschleger

Biological Systems Science
Tony Palumbo

Applied Energy Programs
Moe Khaleel

Energy Efficiency & Renewable Energy
Craig Blue
- Advanced Mfg, Alan Liby
- Buildings, Patrick Hughes
- Transportation, Claus Daniel

Sustainable Electricity
Tom King

Fossil Energy
Yarom Polsky

Biosciences Division
Tony Palumbo, Director

Environmental Sciences Division
Stan Wullschleger, Director

Energy and Transportation Science Division
Xin Sun, Director

Electrical and Electronics Systems Research
Rick Raines, Director

Directorate Operations
David Fowler, Acting Manager

Communications
Jennifer Palmer, Manager

Institutional Veterinarian
Joan Richerson, DVM

Animal Care and Use Committee
Barbara Beatty, Chair

Matrix Support
Teddie Reagan, Business Manager
Amy Brown, Senior HR Manager
David Sims, Commercialization
Karen Sabo, Quality Manager

BioEnergy Science Center
Paul Gilna, Director

Joint Institute for Biological Sciences
VACANT

Carbon Fiber Technology Facility
Merlin Theodore

Climate Change Science Institute*
Stan Wullschleger, Director

Manufacturing Demonstration Facility
Bill Peter, Director

Urban Dynamics Institute*
Budhu Bhaduri, Director

Energy and Transportation Science Division Organizational Chart

Energy and Transportation Science Division
Xin Sun, Director
Ronald Ott, Deputy Director

- **UT-ORNL Governor's Chair, Advanced Manufacturing** – Suresh Babu
- **UT-ORNL Governor's Chair, Energy & Urbanism** – Philip Enquist
- **UT-ORNL Governor's Chair, Advanced Composites Manufacturing** – Uday Vaidya
- **Building Energy Efficiency Technologies**
  - **Building Envelope and Urban Systems Research** – Melissa Lapsa
  - **Building Equipment Research** – Brian Fricke
  - **Energy Efficiency Research and Analysis** – Sachin Nimbalkar
- **Transformational Energy Efficient Manufacturing**
  - **Manufacturing Systems Research** – Lonnie Love
  - **Roll-to-Roll Manufacturing** – *David Wood*
- **Intelligent, Clean, and Efficient Transportation**
  - **Applied Catalysis and Emissions Research** – James Parks II
  - **Fuels and Engines Research** – Brian West
  - **Transportation Planning and Decision Science** – *Xin Sun*[2]
  - **Vehicle Systems Research** – David Smith
- **Building Technologies Research and Integration Center** – Melissa Lapsa
- **National Transportation Research Center** – Robert Wagner

Additively Manufactured Intensified Device for Enhanced Carbon Capture

- Objective:
  - Design, rapid prototyping, demonstration and validation of enhanced CO_2 capture with intensified devices, i.e., unified devices combining multiple thermodynamic operations into one unit.
  - Traditional equipment design: Decoupled mass transfer and heat transfer with high equipment and space cost
- Project team and organization: Six technical tasks involving three disciplines
  - Design and optimization of heat/mass exchanger
  - Additive manufacturing
  - Core and device-scale experimental validation
- Two-year effort

Technical Approach/Tasks

- Task 1.0 – Project Management and Planning
- Task 2.0 – Design Realization of Intensified Device
- Task 3.0 – Manufacturability (3D Printability) Study
- Task 4.0 – Experimental Validation of Device Core Metrics
- Task 5.0 – Advanced Manufacturing of Device-scale Prototype
- Task 6.0 – Device-scale Validation through Design of Experiments

Project Approach/Timeline

- Three materials:
  - Mellapak 250 (commercial), printed Mellapak equivalent, printed intensified device
- Two scales:
  - Core scale, device scale

Project Timeline and Budget

Timeline in Quarters	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1 Project Management ($20K)								
Task 2 Design Realization of Intensified Device geometries ($150K)								
Task 3.1 Manufacturability of MellaPak 250-equivalent ($70K)								
Task 3.2 Manufacturability of Intensified Device Design ($70K)								
Task 4.0 Experimental Validation of Device Core Metrics: Commercial MellaPak 250 ($50K)								
Task 4.1 Experimental Validation of Device Core Metrics: Printed MellaPak 250-equivalent ($50K)								
Task 4.2 Experimental Validation of Device Core Metrics: Printed Intensified Device ($50K)								
Task 5.1 Printing of Device-scale Prototype of MellaPak 250-equivalent ($150K)								
Task 5.2 Printing of Device-scale Prototype of Intensified Device Design ($150K)								
Task 6.1 Prototypical Device-scale Validation with Printed MellaPak 250-equivalent ($120K)								
Task 6.2 Prototypical Device-scale Validation with Printed Intensified Device Design ($120K)								

Milestone Log

Project Year	ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	a	1	Updated Project Management Plan and Data Management Plan	09/30/2017		Project Management Plan file
1	b	1	Kickoff Meeting	10/19/2017		Presentation file
1	c	3	Baseline geometry (MellaPak 250) printed	3/31/2018		Quarterly Progress Report and corresponding data delivery
1	d	3	Intensified device design printed	6/30/2018		Quarterly Progress Report
1	e	4	Core metrics for commercial MellaPak 250 and for printed MellaPak 250 equivalent completed	9/30/2018		Quarterly Progress Report
2	f	4	Core metrics for printed intensified device design completed	12/31/2018		Quarterly Progress Report
2	g	5	Device-scale prototype of MellaPak 250 equivalent printed and delivered for testing and validation	9/30/2018		Quarterly Progress Report
2	h	5	Device-scale prototype of intensified device design printed and delivered for testing and validation	3/31/2019		Quarterly Progress Report
2	i	6	Device-scale validation experiments with printed MellaPak 250 equivalent completed	3/31/2019		Quarterly Progress Report
2	j	6	Device-scale validation experiments with printed intensified device design completed	9/30/2019		Quarterly Progress Report

Funding and Success Criteria

Planned Costs Fiscal Year	Fiscal Year (year in which the cost will be incurred, not appropriated)	Performing Organization	Planned Costs
			Federal Share
1	FY2018	ORNL	$500,000
2	FY2019	ORNL	$500,000
total	FY18-FY19	ORNL	$1,000,000

Fiscal Year	Date	Success Criteria
Project Year 1	Sept. 30, 2018	Successfully printed MellaPak 250-equivalent and intensified device design at 2'X2'X2' scale, ready for core metrics testing.
Project Year 2	Sept. 30, 2019	Successfully demonstrated the heat and mass transfer efficiency of the printed intensified design vs. printed MellaPak 250 at the device scale.

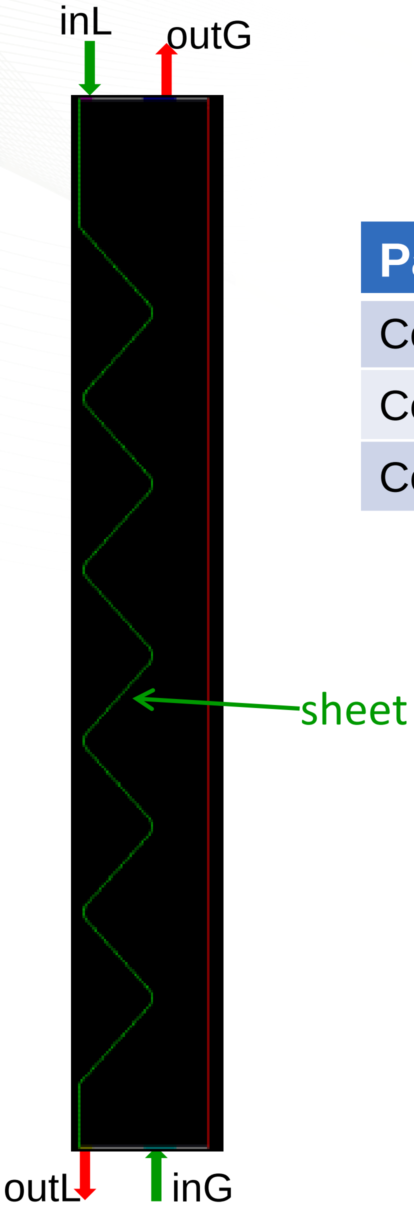
Risks and Risk Mitigation

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Technical Risks:			
Subtask 3.1 Baseline Geometry- MellaPak 250-equivalent - Since commercial Mellapak baseline is made from stacks of thin metal sheets with intricate geometric features, additively manufactured baseline from subtask 3.1 may deviate slightly from the intricate geometric features. In addition, the additively manufactured part will also have surface undulations intrinsic to the metal deposition process. These deviations from the commercial baseline, however, may or may not influence the overall capture performance of the packing.	High	Low	As a risk mitigation, ORNL will first document the quantitative differences of the printed and the commercial MellaPak in terms of surface measurements. Then pressure drop and wettability will be measured in Task 4 for both the commercial packing and the printed packing. Decisions will then be made on whether further improvements on printing techniques and parameters will be necessary to reduce the geometric discrepancies between the printed and the commercial baseline of MellaPak 250.
Task 5.0 Advanced Manufacturing of Device-scale Prototype - The size of the prototype device-scale may be too large such that the printed structure might not withhold its own weight as the device height increases.			As a mitigation, mechanical strength characterization for the intensified design will be carried out in Subtask 3.2 and a bound analysis will be performed to limit the device build height.
Resource Risks:			
Y2 Task 6 on Device scale validation - This is the last task of the project mostly scheduled for Year 2. If the device scale validation needs more funding than anticipated due to its complex nature, the project would not be able to accommodate this resource shortage at the end of the project.	Medium		Reducing the size of the device-scale validation may be considered as a mitigation technique.
Management Risks:			
Timely coordination of the three disciplines in the project	Medium	High	The execution of the project requires seamless integration of three different disciplines/capabilities residing within two divisions at ORNL. Any problems/delays in a particular task will cascade down to impact the delivery of the subsequent task. The PI is experienced in leading a multi-disciplinary team as such. Interdisciplinary communication is key to the success of this project. The staff within ETSD are collocated at NTRC. Daily technical progress exchange will be encouraged. Project specific shared drive will be used to update technical progress. A bi-weekly face to face project meeting will be used to further improve technical communications, identify issues early and to mitigate risks with team consensus.

Started Discussions with CCSI2 Team on Core Design Optimization

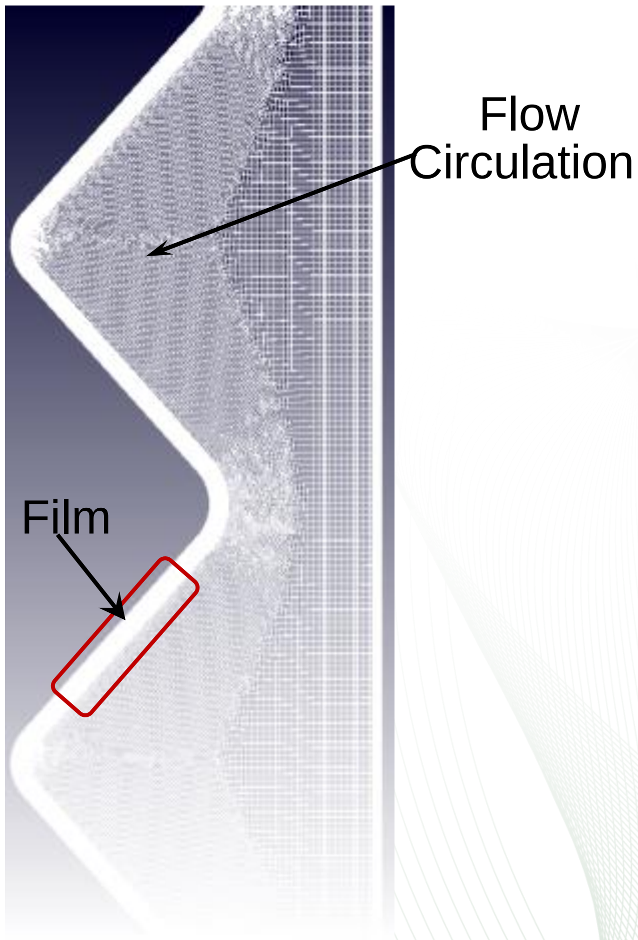
- Device scale:
  - MFix simulation to derive optimized column temperature profile for capture efficiency (cm scale)
- Corrugation scale:
  - VOF-based coupled mass and heat transfer with heat sinks within the corrugation

Absorption in Structured Packings

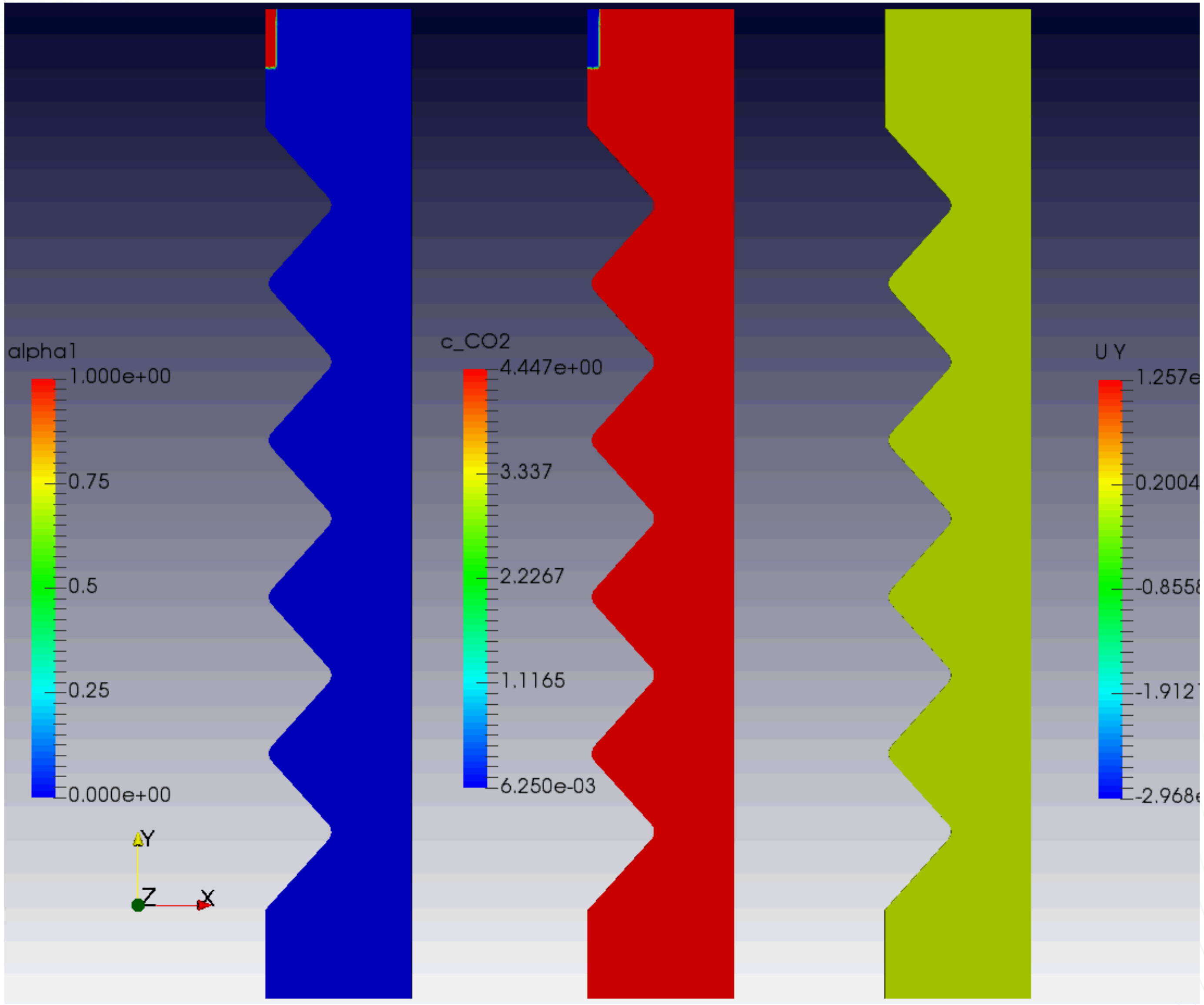


Problem setup

Parameter	
Corrugation base (B)	26.7 mm
Corrugation height (h)	12.0 mm
Corrugation side (s)	17.0 mm



Animation for Solvent Absorptions



Significant Awards and Achievements: Manufacturing

Development of Metal BAAM for Printed Excavator at CONEXPO: Mark Noakes, Brad Richardson, Andrzej Nycz, Brian Post, Matthew Sallas , Srdjan Simunovic, Ralph Dinwiddie

Navy's Admiral Award: 3D Printed Submarine

-- Lonnie Love

Guinness Book World Record for Largest 3D printed part: Partners Cincinnati Inc, Boeing, Techmer, Ford

-- Brian Post

Design Miami 3D printed bamboo pavilion: Partner ShoP and Techmer

-- Lonnie Love

Federal Laboratory Commission Regional Partnership Award:
Sandia and TPI Composites on Blade Manufacturing using Advanced Manufacturing
CAMX Ace Award Finalist: Bio-Composite Printing

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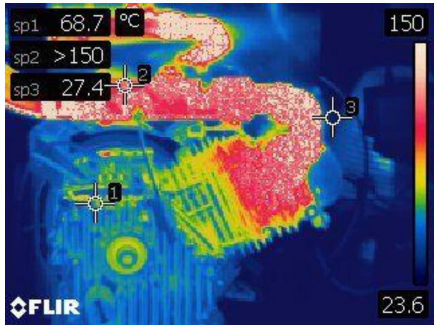
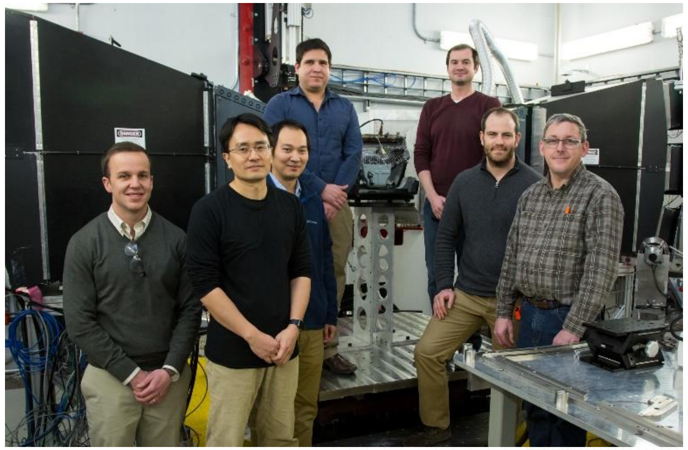
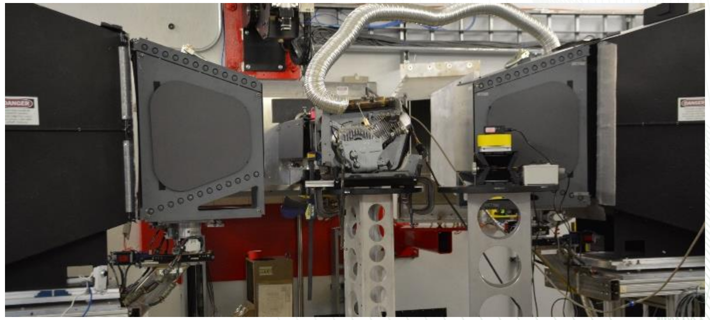
First-of-a-kind experiment uses neutrons to evaluate new alloy during engine operation

- **The cylinder head for a small engine was cast with a new ORNL alloy and characterized with neutrons on a running engine to investigate alloy performance**
  - Multi-disciplinary research team included experts in neutrons, materials, and combustion science
  - Experiment conducted on the SNS Vulcan beamline
  - Neutrons used to measure stress and strain on the alloy during engine operation
- **Experiment demonstrated that the new alloy outperforms other aluminum alloys at high temperatures**
- **Successful proof of principle for in-situ neutron analysis of engine components during actual operating conditions**







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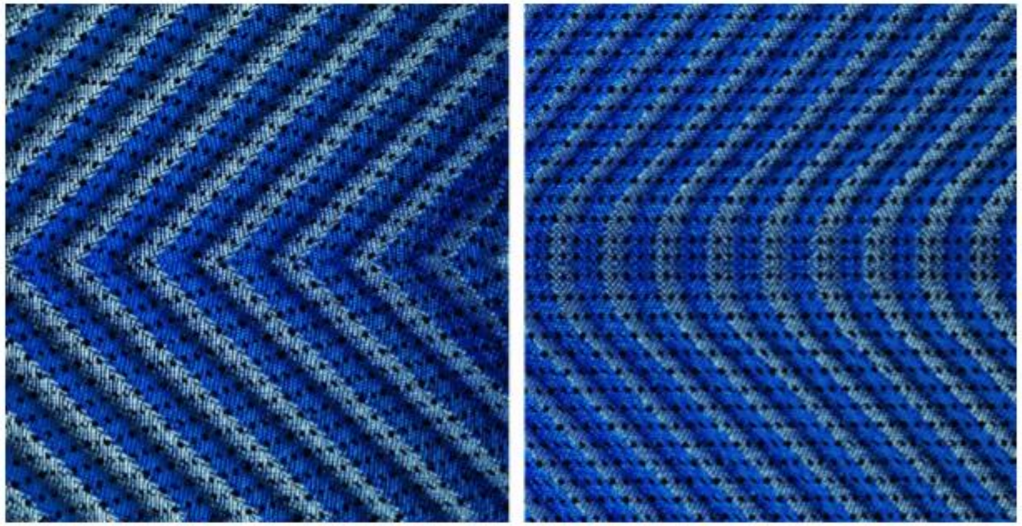
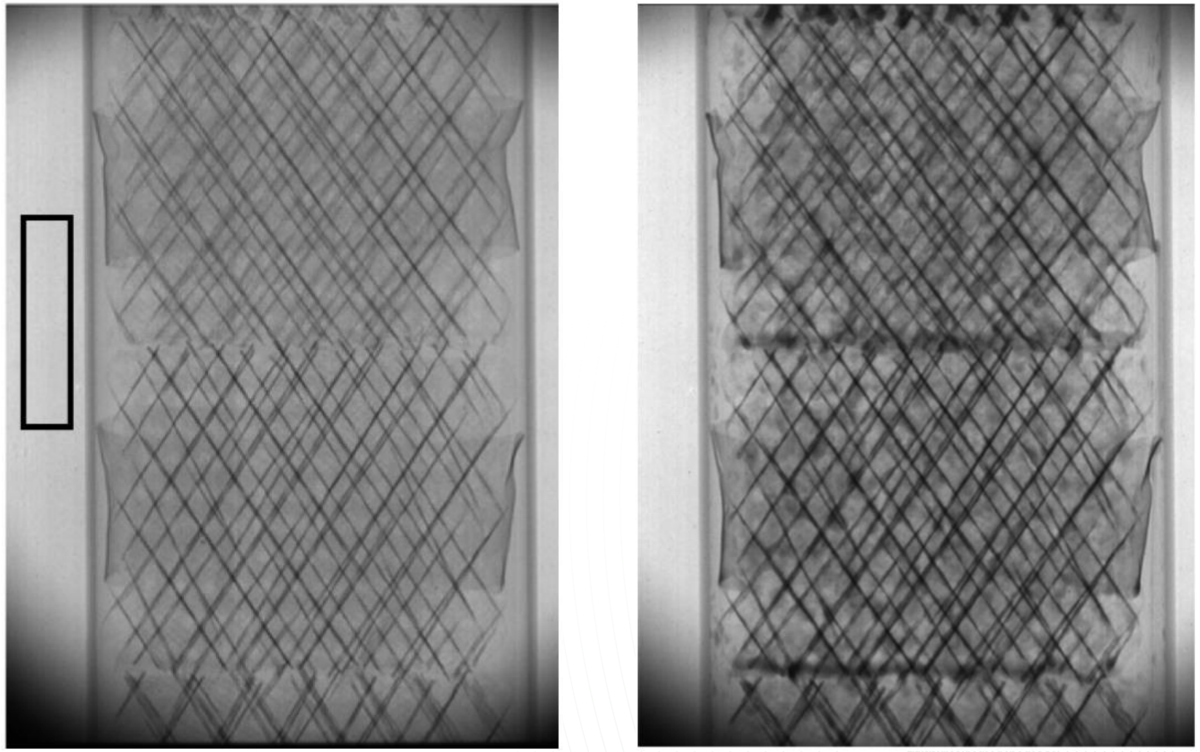
Possibility of Using Neutron Radiography on Wetting Comparison

- Commercial vs printed core on wetting

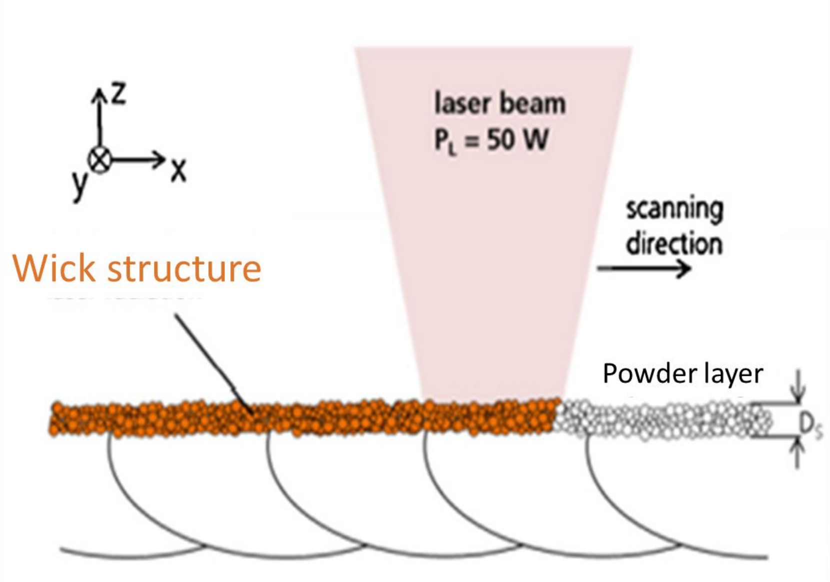


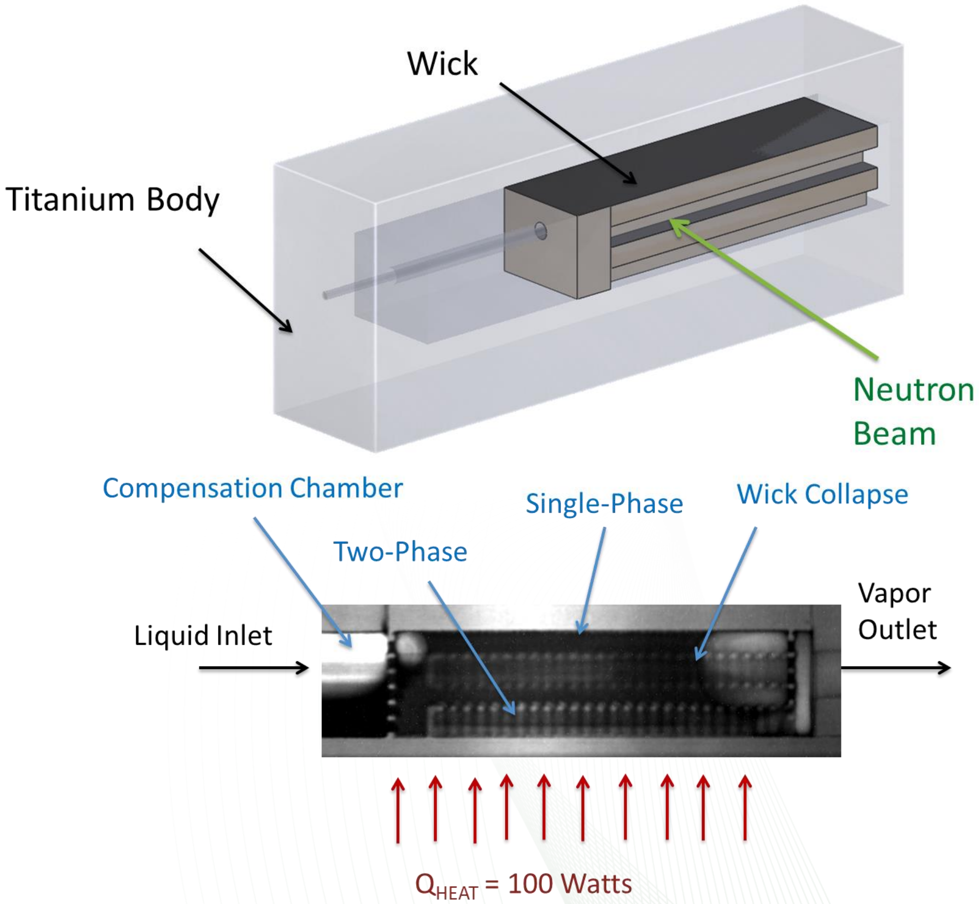


M. Basden, et al. Liquid Holdup Profiles in Structured Packing Determined via Neutron Radiography, dx.doi.org/10.1021/ie402574x| Ind. Eng. Chem. Res. 2013, 52, 17263−17269.

Creating 3D Printed Heat Pipe Porous Wick Structures by lowering EBM/laser intensity

- Heat Pipes offer heat transfer rates orders of magnitude greater than conduction
- AM primarily uses low thermal conductivity materials
- **Embed heat pipes into 3D printed parts**
- Neutron image to optimize design





Peak Temperature 45°C

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Q & A