P/O/E/T/S

CENTER FOR POWER OPTIMIZATION OF ELECTRO-THERMAL SYSTEMS

Overview

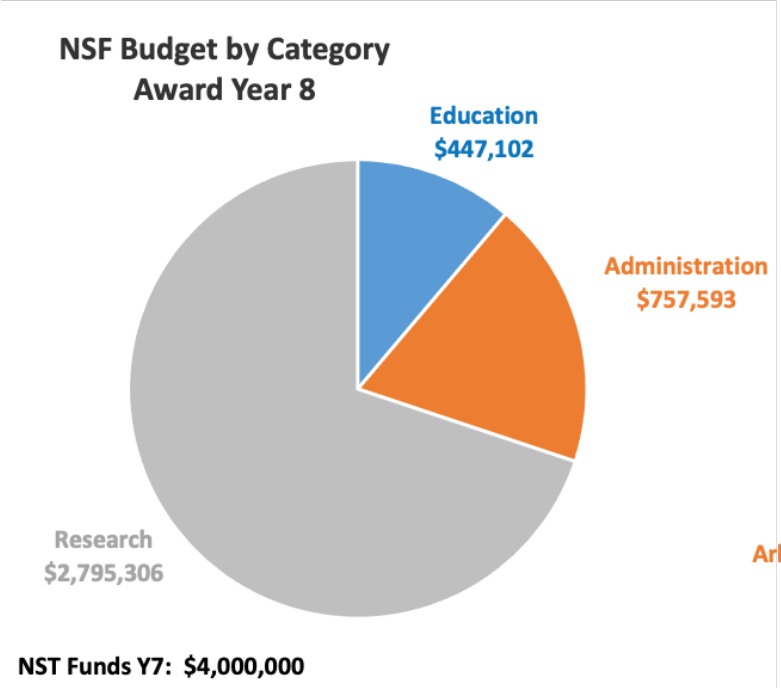
Kiruba Haran

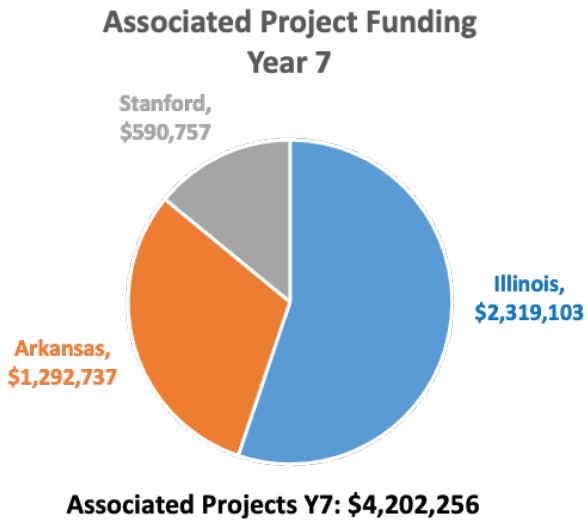
Outline

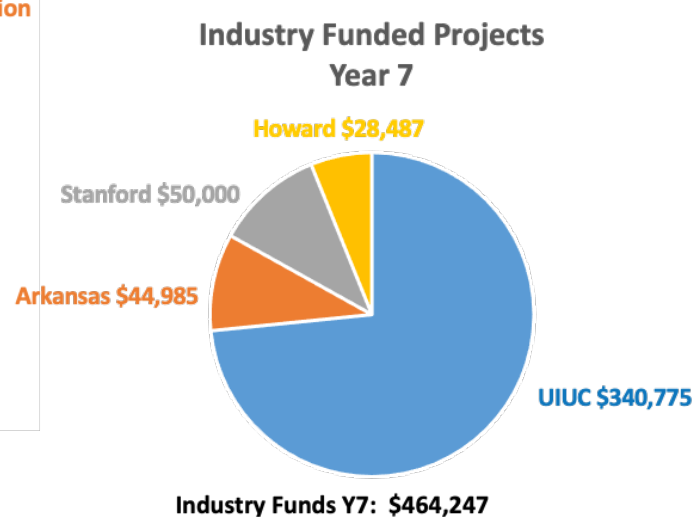
- Introduction
- State of the center
  - Research
  - Infrastructure
  - Technology Transfer
- New POETS Future Technical Leaders program
- Looking forward

POETS Financials

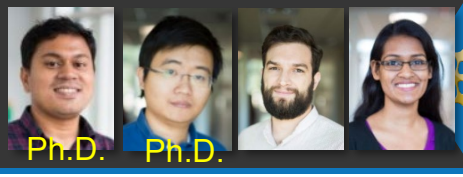
- Resource allocation in line with strategic planning
- Majority of resources to research
- Low administrative efforts





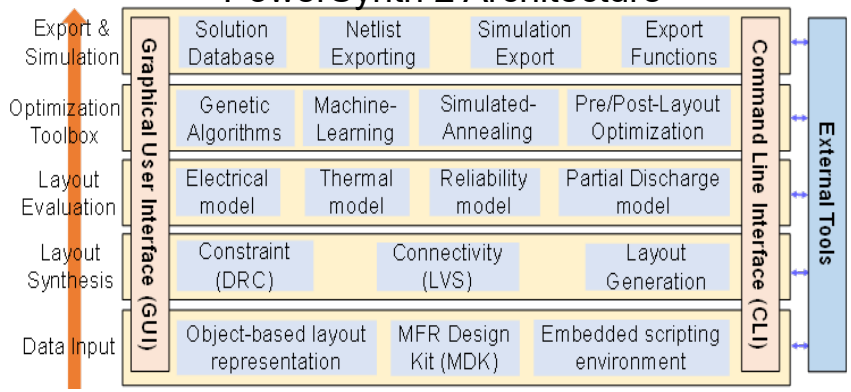


POETS Thrust 1 Effort - PowerSynth 3D

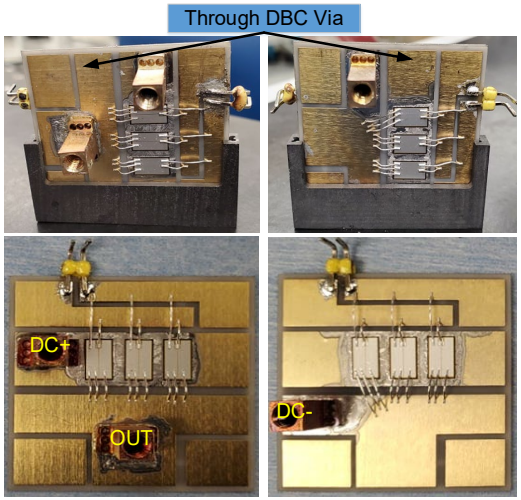


- PowerSynth v1.4 won the **First Place** Award in "ECCE 2021 Student Software Demonstration Competition". It will be open-sourced on github soon.
- State-of-the-art hierarchical 2D/2.5D/3D high-density power module optimization capability demonstrated with hardware validation through PowerSynth 2.
- Four conference, two journal papers published, two graduates since last October.
- Both Windows and Linux binary package available for PowerSynth 2, with manuals and design cases. **https://e3da.csce.uark.edu/release/PowerSynth/**
- **PowerSynth 3D** is our latest offering for power converter EDA. It incorporates domain-specific knowledge and data-driven models based on component libraries.

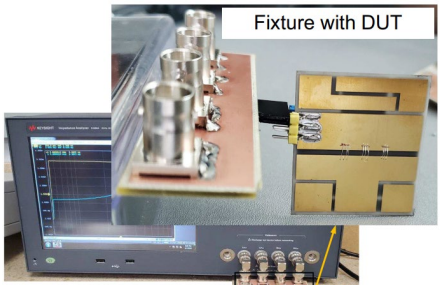
PowerSynth 2 Architecture



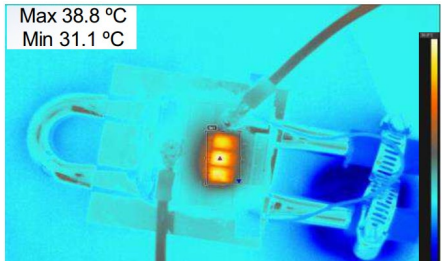
Methods	L_{Loop} (nH)	Runtime (s)	Netlist size	Speed up	Error
FastHenry	17.3	8.00	1	-	-
PEEC	16.1	0.835	1820	9.6 ×	6.9%
Loop Model	16.5	0.434	9	18.6 ×	4.6%



PowerSynth 2 designed high-density 3D power modules fabricated at HiDEC and validated at NCRPT [1]



Electrical testing at Zhao's lab

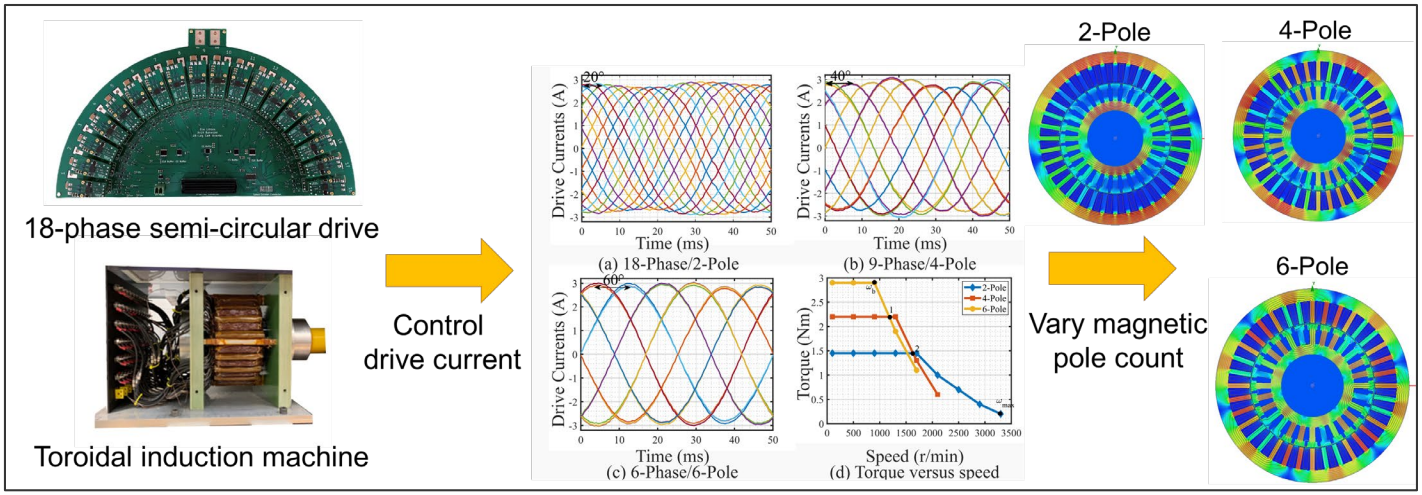


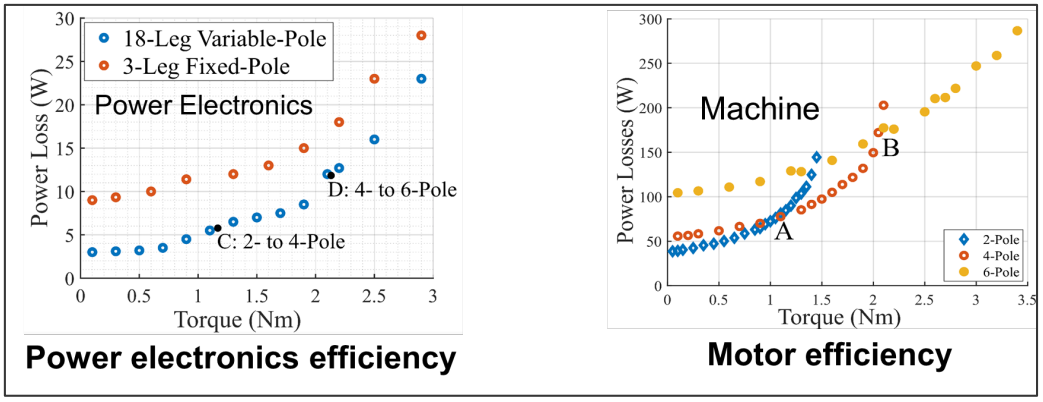
Thermal testing at Huitink's lab

[1] Imam Al Razi, Quang Le, Tristan Evans, Alan Mantooth, Yarui Peng, "PowerSynth 2: Physical Design Automation for High-Density 3D Multi-Chip Power Modules", (conditionally accepted) IEEE Transactions on Power Electronics

POETS Thrust 2 Effort

- Variable Pole Induction Machine increases efficiency over a wider operating range
  - Change magnetic pole count on the fly by controlling 18 phase currents



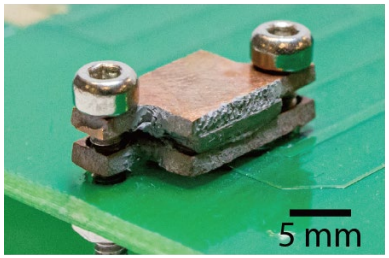


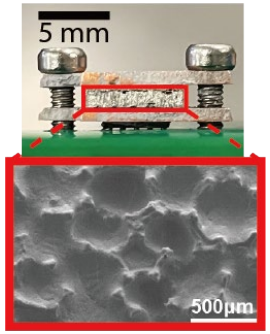
- Experimental validation on low power bench top system
- Also, losses spread out over more phases so total temperature rise is less than a 3 pole count motor

POETS Thrust 3 Effort - Phase Change Materials

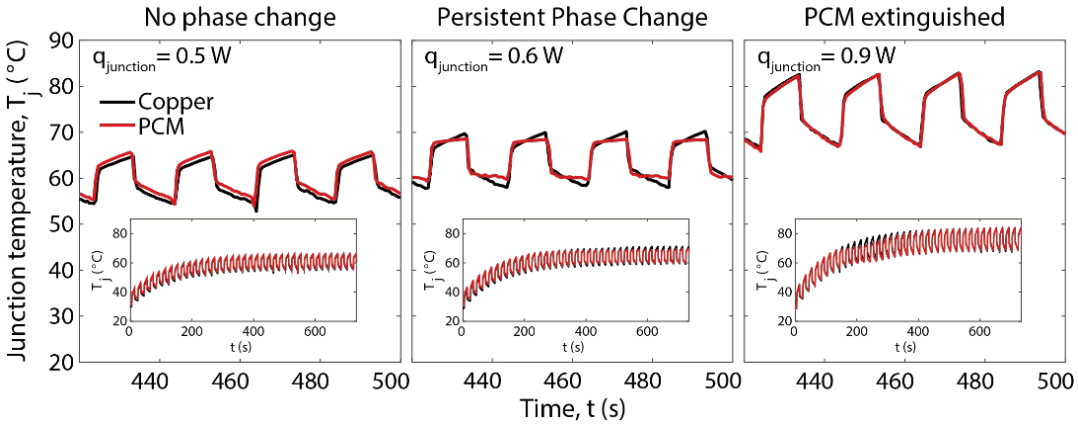
King/Miljkovic/Mantooth/Braun

- Phase change materials (PCM) for transient thermal buffering in electronics.

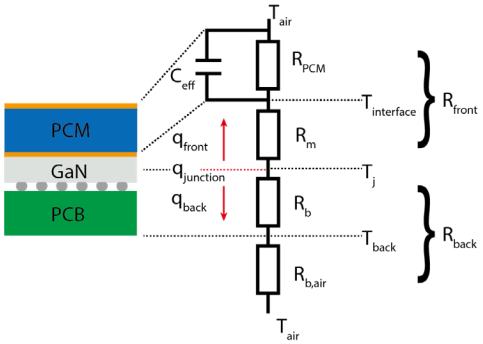


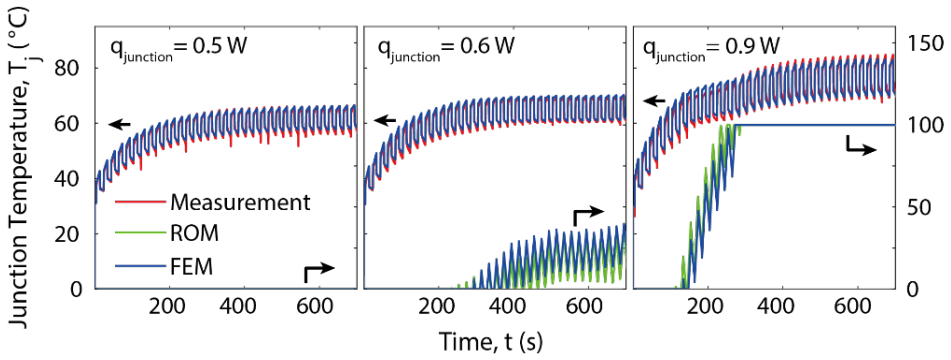


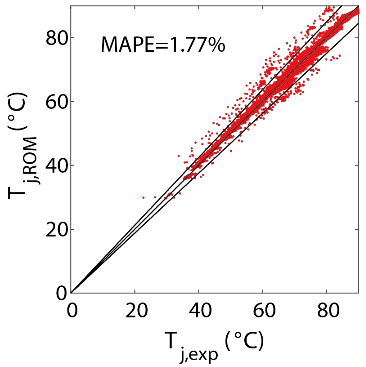
Field's metal/Cu foam composite



- Achieved up to **21% junction temperature swing reduction** compared to copper reference.



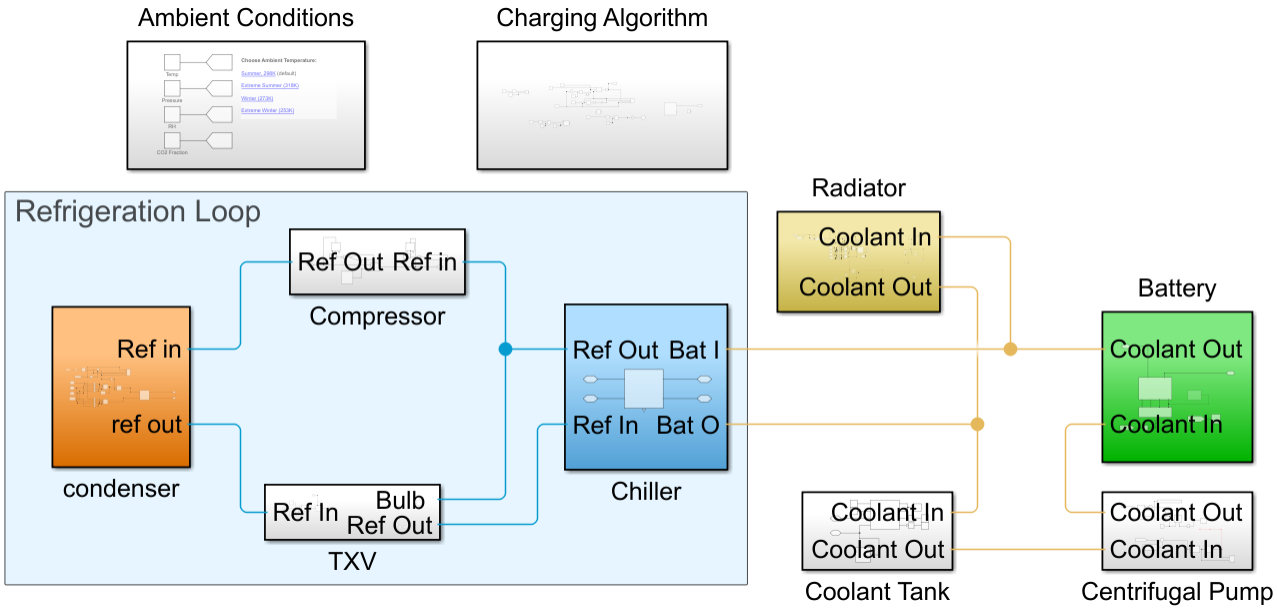




- Reduced-order model (ROM) provides expedited prediction tool for PCM integrated cooling optimization.
- ROM model solution takes **99.9% less time** when compared to finite element method simulations tools.

POETS Thrust 1 & 3: Virtual Testbed

Miljkovic/Goodson/Alleyne

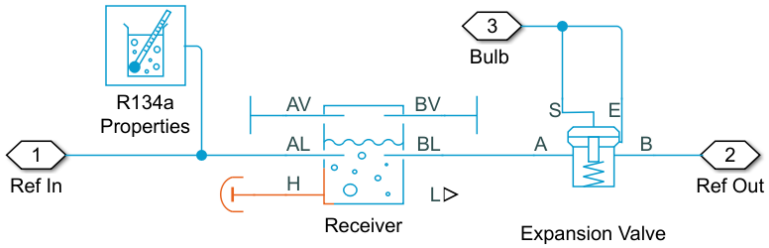


Virtual Testbed for System Level Analysis
e.g. EV Thermal Management

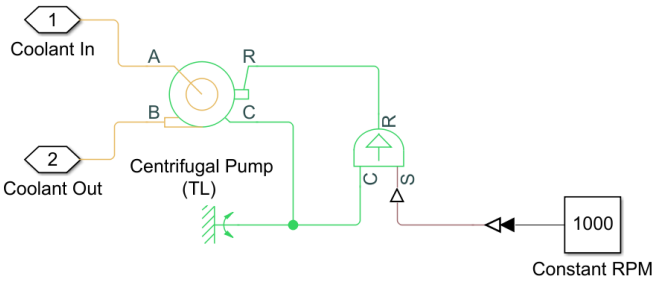
- Extendable to other electro-thermal applications (aircraft/naval/offroad)

Reconfigurable System Blocks

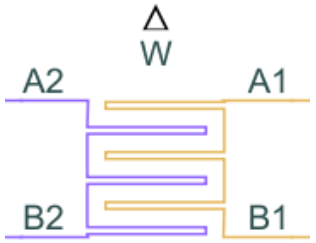
Expansion Valves and Refrigerants



Pumps

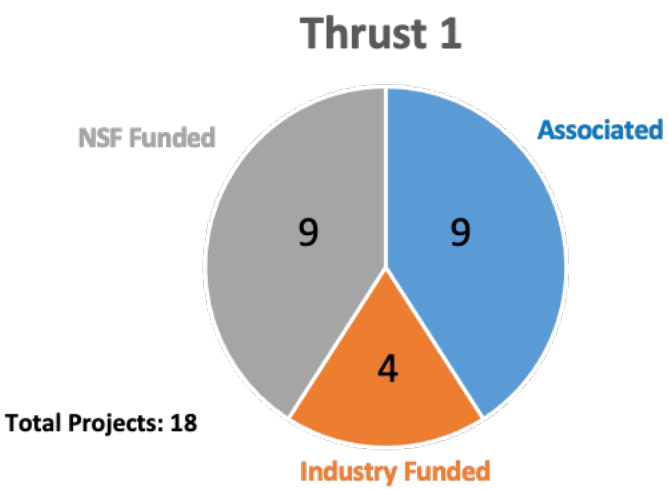


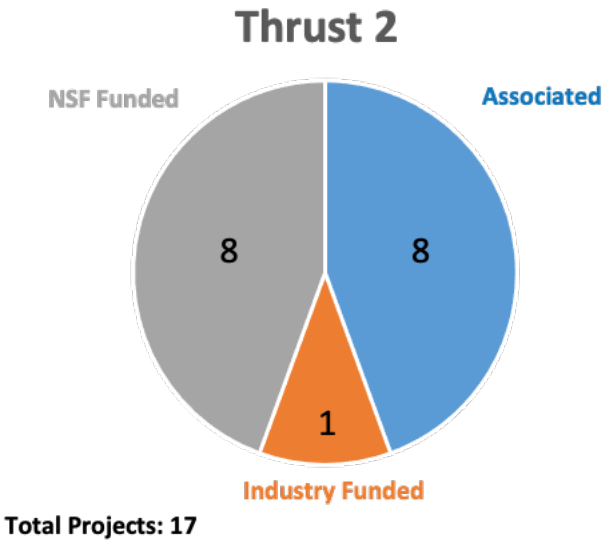
Heat Exchangers:
Radiator/Cond/Evap/Chiller

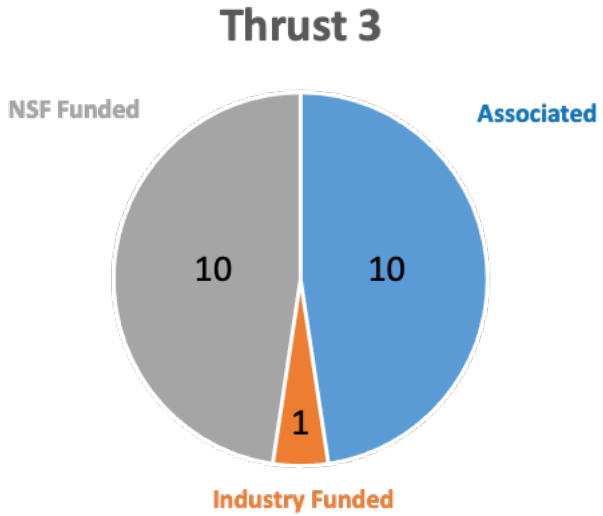


POETS Research Projects

- Research activity is spread across the center

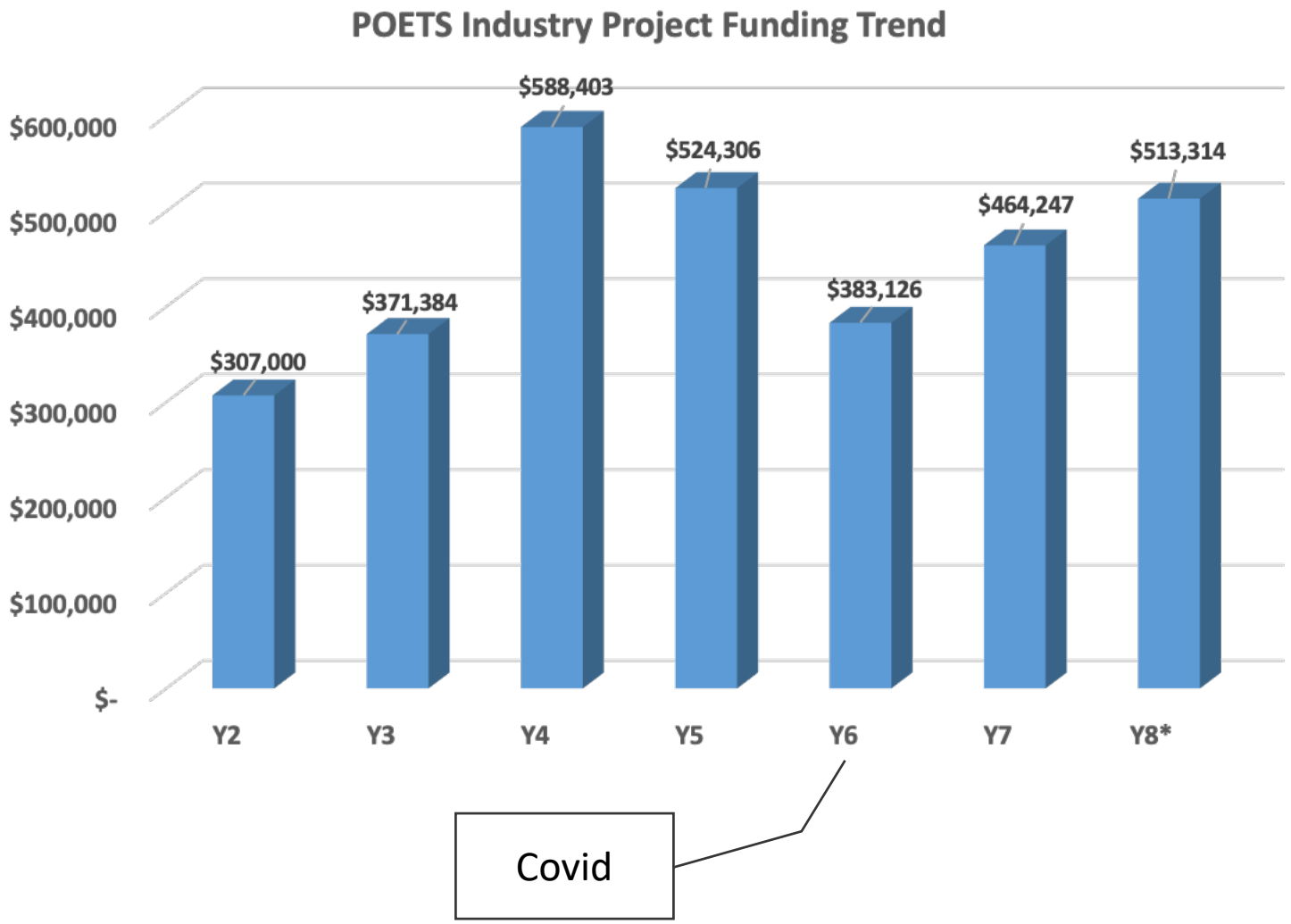






- Thrusts 2 and 3 are similar in project activity
- Well balanced
- This is in line with prior strategic planning

IPAB Funding

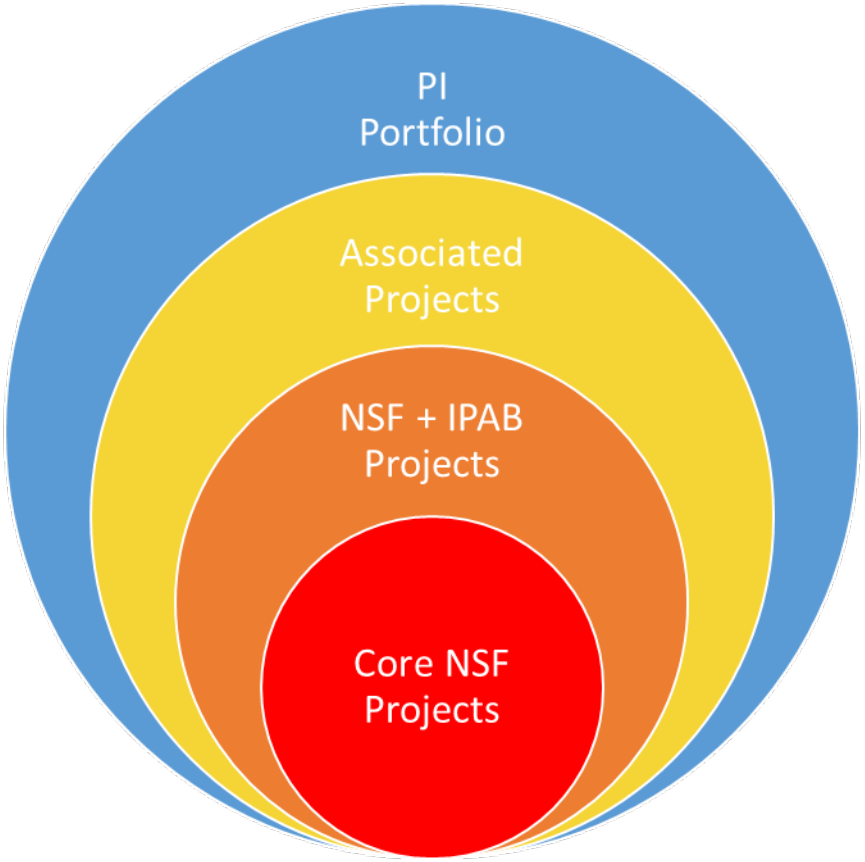


* Note, Y8 is a *projection* and has assumptions built in

POETS Research Projects

- Strategy of core plus associated projects is still sound
  - Y7 core NSF research was about $2.8M
  - Y7 IPAB research was about $0.43M
  - Y7 Associated Project expenditure were about $4.2M

- Several new Associated Projects received and applied for in Y8 to date



Overall, the POETS research portfolio is strong

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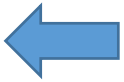
  - Research
  - Infrastructure 
  - Technology Transfer
- New POETS Future Technical Leaders program
- Looking forward

POETS Infrastructure

- POETS infrastructure is maturing

- Investing in new equipment
  - ~500K equipment supplement in 2021 from NSF
  - Both at UIUC and Arkansas

- Brunswick Marine Testbed

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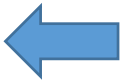
  - Technology Transfer 
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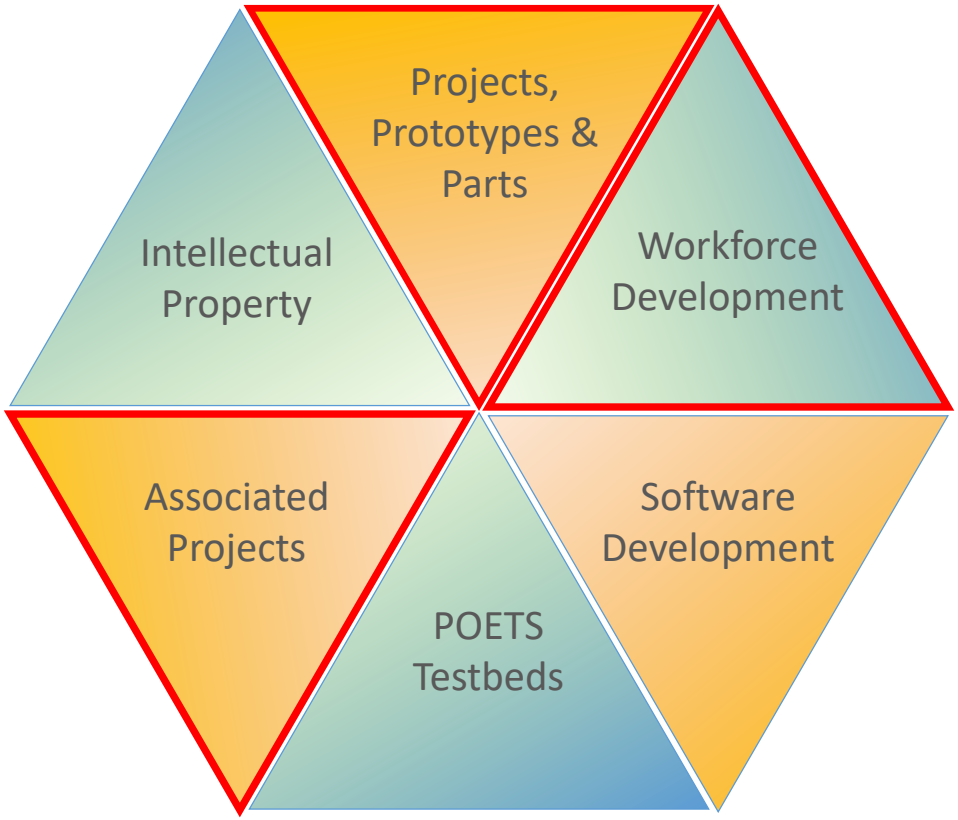
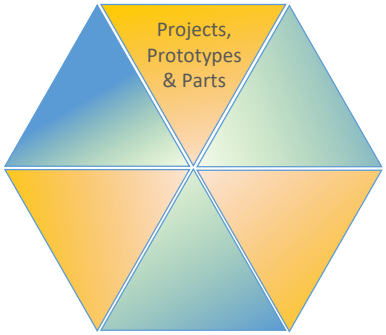
Technology Transfer - Dimensions

Success of a center is often measured by how the technology and knowledge is transferred across industry, government, and academia. While intellectual property and patents are both tangible metrics to measure tech transfer, POETS is also tracking 5 additional metrics that we believe provide a broader and more complete picture of the impact POETS is having in the electrified mobility space.



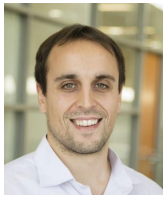
Technology Transfer – Projects, Prototypes & Parts



Directed Projects

Dr. Alleyne

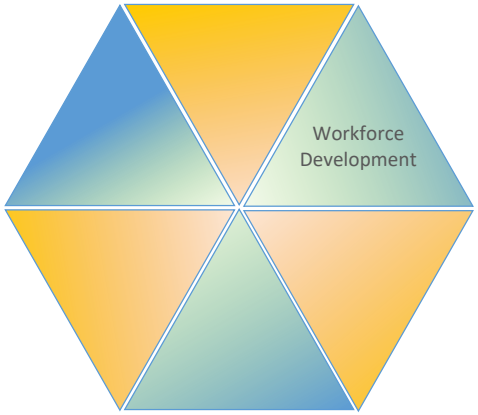
Dr. Haran



Dr. Miljkovic

Project Leader	Collaborators	Project Title	IAB Project Liaison
Dr. Pingfeng Wang (UI)	Dr. Nenad Miljkovic (UI) Dr. Sonya Smith (HU)	Battery Pack Power-Thermal Co-Management System Design Optimization for Enhanced Reliability and Safety Performances	BRUNSWICK, JOHN DEERE
Dr. Ken Goodson (SU)	Dr. Mehdi Asheghi (SU), Dr. Nenad Miljkovic (UI)	Virtual Testbed for Fast Charging Battery Systems	BRUNSWICK, Ford
Dr. Debbie Senesky(SU)	Kiruba Haran (UI), Pingfeng Wang (UI)	Data-Driven Reliability Monitoring and Fault Diagnostics of High-Power Density Motors via Embedded Magnetic Field Sensors	PCKA, NASA
Dr. Nenad Miljkovic (UI)	Dr. Juan Balda (UA) Dr. Yue Zhao (UA)	Additive-Manufacturing-Enabled High-Temperature and High-Density Power Electronics	Raytheon Technologies
Dr. Pingfeng Wang (UI)	Dr. Nenad Miljkovic (UI) Dr. Sonya Smith (HU)	Reliability-Based Co-Design of a Battery Power-Thermal Coupled Management System	PCKA, JOHN DEERE
Dr. Yue Zhao (UA)	Dr. Nenad Miljkovic (UI)	A High Density Isolated High Voltage (800V) DC-DC Converter for Aux Power Supplies in Automotive and Off-Road Applications (Figure 1)	JOHN DEERE
Dr. James Allison (UI)	Dr. Kai James (UI)	Optimal 3D Spatial Packaging of Interconnected Systems with Physics Interactions	Raytheon Technologies, PCKA, Ford
Dr. David Huitink (UA)	Dr. Nenad Miljkovic (UI) Dr. Alan Mantooth (UA)	Enablement of High-Voltage, High-Power Modules via Performance and Durability Validation of Direct Cooling, Voltage Blocking Technologies	CAT, Rolls-Royce, NASA
Dr. Debbie Senesky(SU)	Dr. David Huitink (UA) Dr. Greg Salamo (UA)	Reliability of GAN Magnetic Field Sensors Under Industry-Relevant Conditions	JOHN DEERE, CUA
Dr. Eric Pop (SU)	Dr. Fang Luo (UA), Dr. Debbie Senesky (UA)	"Smart TIMS" (Thermal Interface Materials) for Power Electronics (Figure 2)	Rolls-Royce, CUA
Dr. Kai James (UI)	Dr. James Allison (UI)	Novel Solution Methods for Optimal 3D Spatial Packaging and Routing of Electro-Thermal Systems	Raytheon Technologies, CUA
Dr. Fang Luo (UA)	Dr. David Huitink (UA) Dr. Eric Pop (SU)	Advanced Co-packaged Si-IGBT and SiC-MOSFET Hybrid Switch Power Module	JOHN DEERE
Dr. Alan Mantooth (UA)	Dr. Ken Goodson (SU)	Feasibility Study of Tight Integration of Power Electronics and Micro-Cooler around DBC Platform	Ford

Technology Transfer – Workforce Development

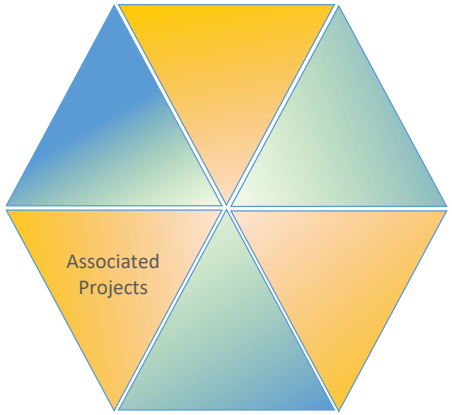


Conversions

- 3 Full-Time Employees
- 1 Full-Time Employee
- 1 Internship
- 2 Internships
- 4 Full-Time Employees
- 2 Internships
- 4 Full-Time Employees
- 1 Full-Time Employee

Technical Seminars Attendees	Dr. Balda, Dr. Zhao, Dr. Huitink SiC Component Design	Dr. Asheghi, Dr. Gupta Thermal Mgmt – Embedded Systems	Dr. Zhao, Dr. Huitink Reliability Considerations
AFRL	3 Employees	1 Employee	
Brunswick	7 Employees	2 Employees	4 Employees
Caterpillar	4 Employees	2 Employees	1 Employee
CUA	1 Employee		
Deere	5 Employees	2 Employees	16 Employees
Ford	3 Employees	3 Employees	3 Employees
NASA	4 Employees	5 Employees	5 Empoyees
PcKA	1 Employee	1 Employee	1 Employee
Raytheon		6 Employees	6 Employees
Rolls-Royce	1 Employee	1 Employee	
	29 Total Employees	**23 Total Employees**	**36 Total Employees**

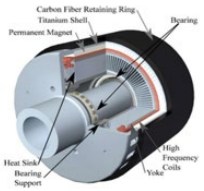
Technology Transfer – Associated Projects



High-Efficiency Electric Machines (Multiple Projects)

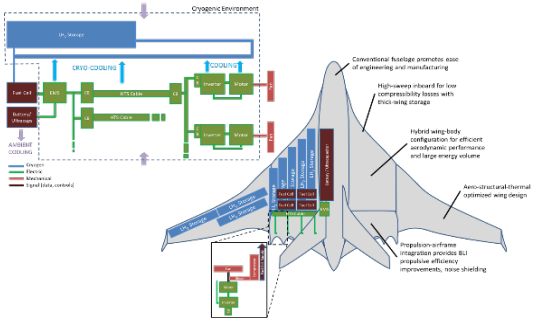
Hinetics
Innovation Through Engineering

Dr. Haran



AFWERX

Cryogenic High-Efficiency Electrical Technologies for Aircraft



NASA

Dr. Haran

Flow Boiling Experiments for Cryogen Transfer for Aerospace

Dr. Miljkovic

Raytheon Technologies

NASA

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
VEHICLE TECHNOLOGIES OFFICE

Dr. Zhao

JOHN DEERE

Articulated Dump Truck Electrification

High-Power Density Inverter

Dr. Zhao

Dr. Mantooth

Dr. Miljkovic

Dr. Huitink

CAT

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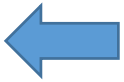
- Workforce Development 
- Looking forward

POETS Workforce Efforts Perform Well to Date

Short Courses and Training

- **Responsive** to IPAB member suggestions and needs
- 3 Short Courses Delivered
  - SiC Design
  - Automotive Thermal Management
  - Reliability Considerations
- Over 50 IAB members attended

Cross-Institution Technical Events

- Student Technical Conference
- Single day, 3 track event
  - >30 student technical talks

3 Industry talks in Year 7

- Brunswick
- GE Research
- Raytheon

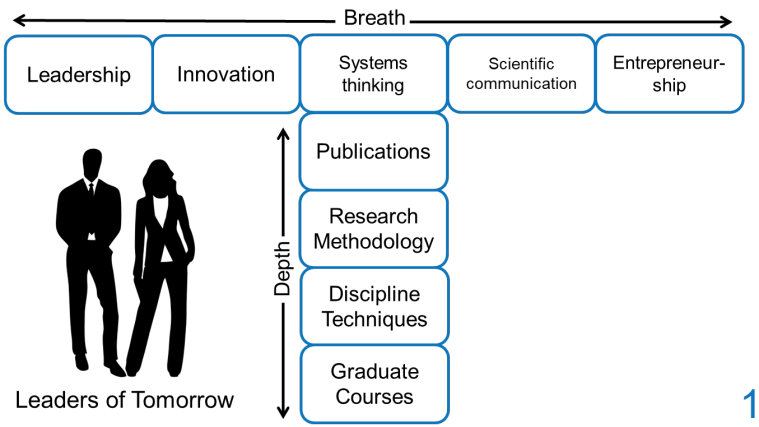
Workforce Development

Since 2016, 45 POETS Master's & PhD students graduated

- 13% postdocs
- 17% faculty
- 55% industry
- 7% gov/other

We currently have over 100+ graduate students and 50 undergraduate students in the pipeline

Training Approach



New--POETS Future Technical Leaders

- Universities typically train students to *do* research
- POETS is now training a select group of students to *lead* research in industry in the future
  - 11 students graduated in first cohort
  - All 4 core partners
- Target is to help launch future group leaders, and beyond, in corporate R&D

Industry Support

Raytheon Technologies
BRUNSWICK
PCKA
JOHN DEERE

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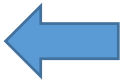
- Looking forward 

Looking forward

- We have come back relatively strong from Covid-19
- IPAB membership recovering after dip in the last two years
- We are growing the research program significantly through associated projects, and transferring technology well
- Overall, things are in good shape now

- Looking forward:
  - Continue building and refining the teams for external opportunities
  - Maintain the core + Associated Project model
  - Everyone lean in to assist in the transition

- Keep an eye on 2025
  - A little over 1000 days away
  - Primary goal - sustainability and continued impact on the electrification industry