



Energy, Power, and Thermal Research Overview

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Overview



- **AFRL**
- **Drivers and Applications**
- **Technologies**
- **Questions**



AFRL Mission



Leading the discovery, development, and integration of affordable warfighting technologies for our air and space force.





AFRL's Core Areas of Expertise





AFRL People & Facilities



- **5,764 Government Employees**
 - 4570 Air Force Civilian
 - 1194 Military
- **3,844 Onsite Contractors**



- **10 Major R&D Sites across US**
- **40 Sites World-Wide**
- **\$40B Real Property & Capital throughout AFRL**



Propulsion Directorate's Strategic Way Forward



- **RZ Portfolio addresses long-term AF capabilities**
 - Air-breathing High Speed Strike/ISR
 - Energy Security
 - Long Endurance ISR/Mobility
 - Energy Optimized Aircraft
 - Reusable Access to Space
 - Spacecraft Maneuverability



It's An Exciting Time!



TSSS



Hall Thrusters



X-51



HC Boost



Space & Missile

Hypersonics

Energy

Power & Thermal

Turbines



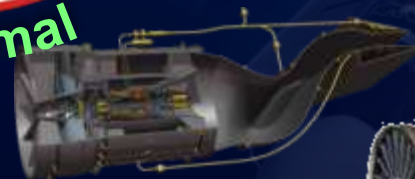
BRITES



INVENT



FUELS



HEETE



ADVENT



Sustainment



Key Planning Drivers



- **Energy**

- Make energy a consideration in all we do
- Ensure continued viability of propulsive energy sources
- Optimize efficiency at the platform level to increase capabilities by minimizing thermal limitations and also to reduce fuel used

- **Thermal**

- Address today's thermal challenges and prevent tomorrow's thermal limitations

- **System Integration**

- Deconflict subsystem interactions and define/demonstrate interfaces

- **Infrastructure**

- Invest in energy, power, and thermal research facilities to establish research foundation for the future

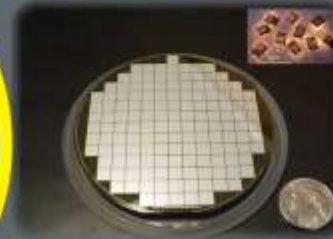
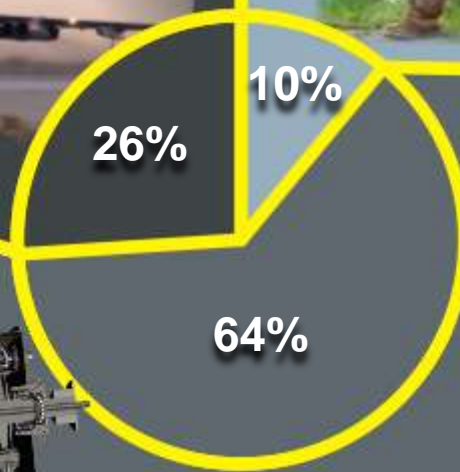
Energy, Power, and Thermal

(FY10-15 from FY11 PBR ~ \$54M/year)

Battlespace Fuels



Special Purpose Power



Energy Optimized Aircraft

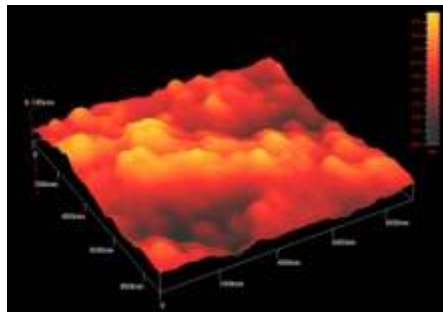
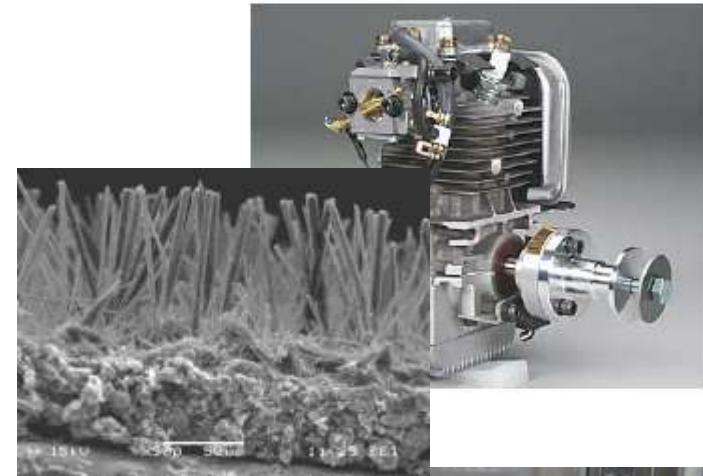




Energy/Power/Thermal Core Technical Competencies



- Power distribution and electronics
- Electrochemistry
- Mechanical energy conversion
- Thermal management
- Fuel utilization and characterization
- System integration and optimization
- Power and thermal analysis and M&S

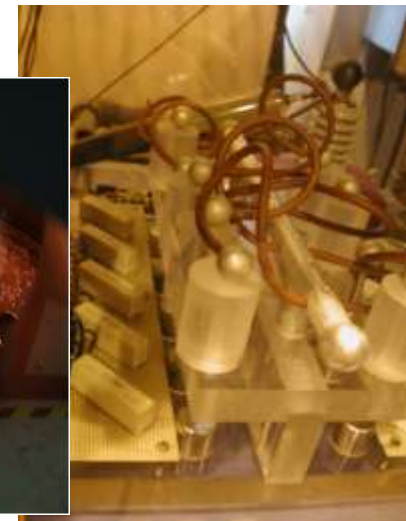
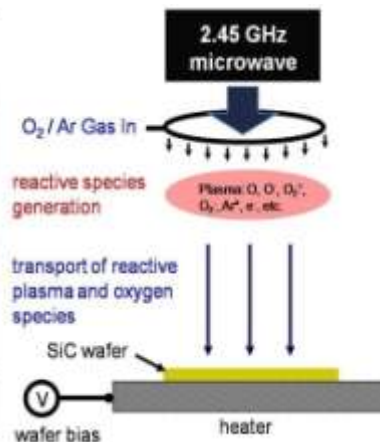




Power Distribution and Electronics

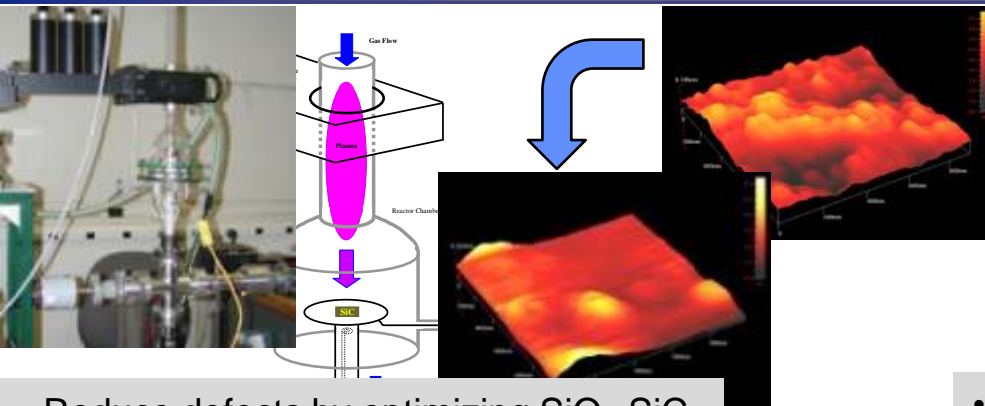


- Performance evaluation and advanced insulations
- Energy storage
- Dielectrics
- Carbon nanotubes for power applications
- SiC device and module reliability
- Plasma physics for defect-free high temperature wide-band gap electronics

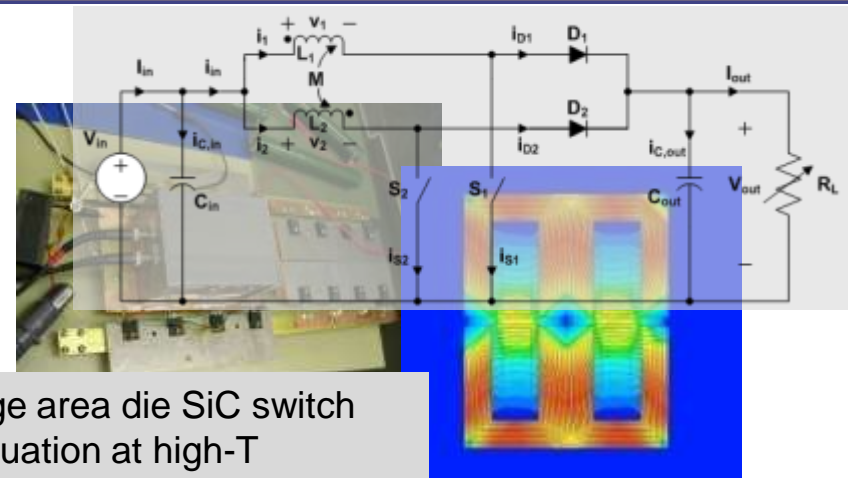




Power Distribution and Electronics

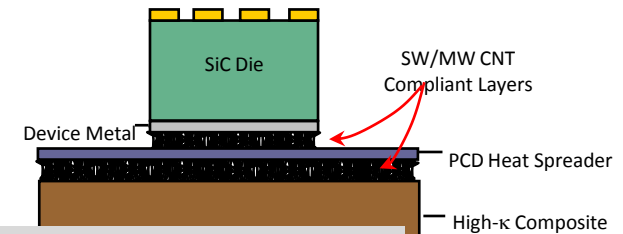
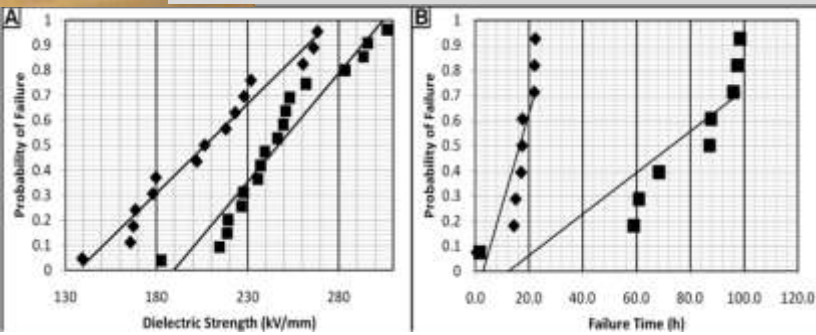


- Reduce defects by optimizing SiO₂-SiC interface using a low-T growth (300°C) process and atomic oxygen to remove C-atom (CO, CO₂)

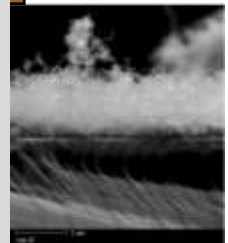


- Large area die SiC switch evaluation at high-T
- Inductor design comparison

- Effects of EM fields, corona, discharges on aerospace power systems
- High voltage discharge breakdown experiments



- Demonstrate PCD films for HV isolation and heat spreading layers in high-T power electronic packages
- CNT interface for stress compliancy for CTE_{PCD}~1-2 ppm/K

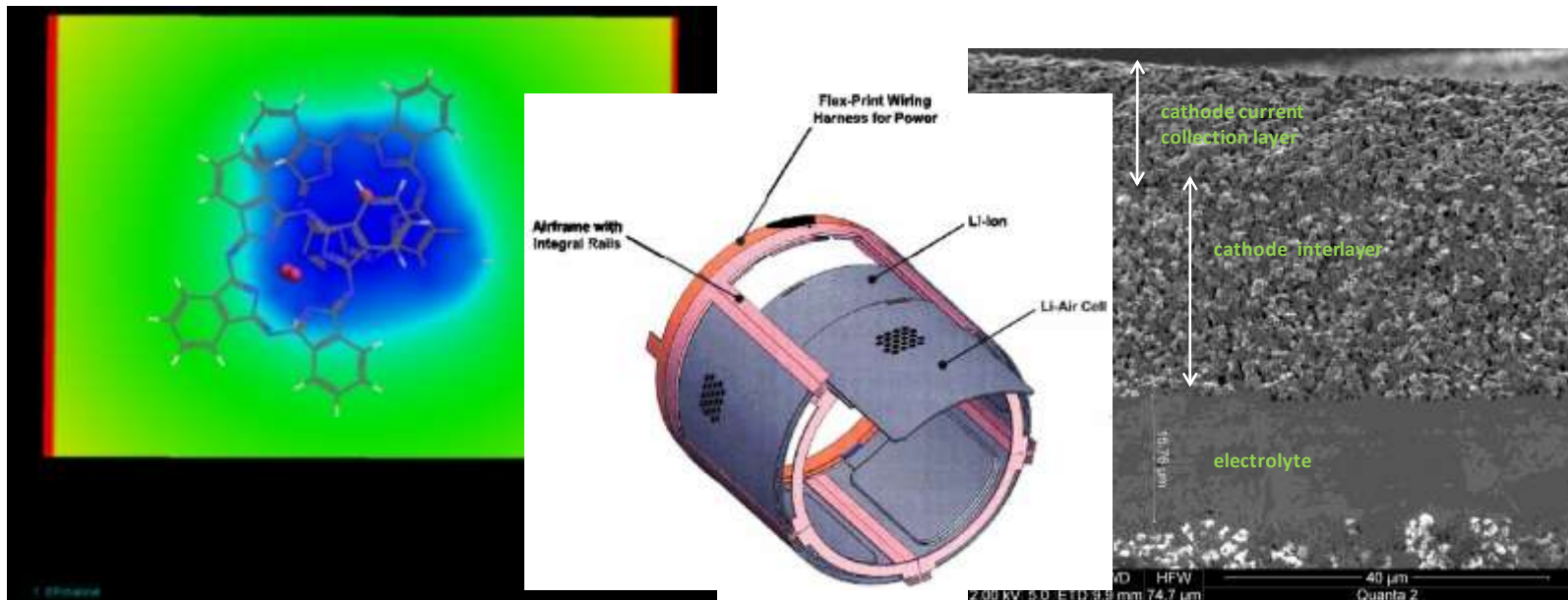




Electrochemistry

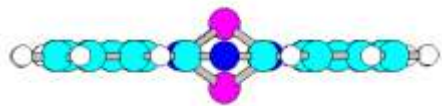
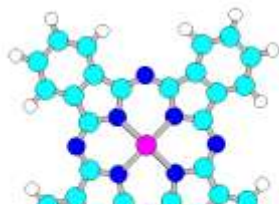
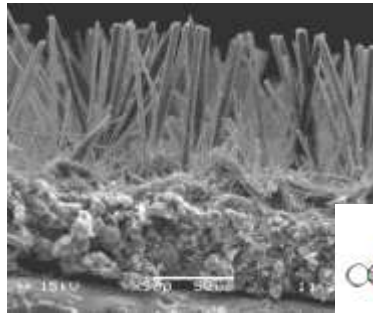


- Solid-state electrolyte for Li-ion batteries
- Li-air chemistries for high performance batteries
- High performance SOFCs
- Battery evaluation and analysis

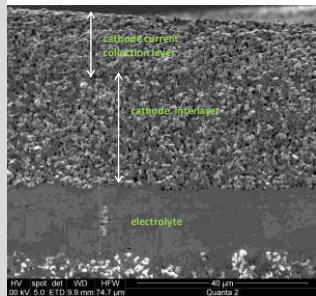




Electrochemistry



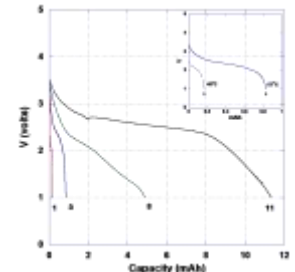
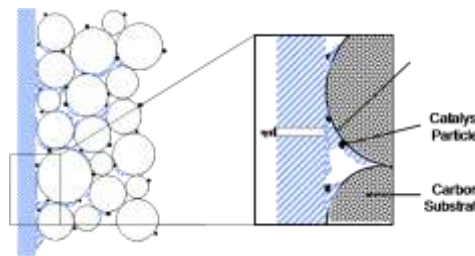
EXPANSION TO JP-8 REFORMATION WITH NEGLIBLE INCREASE IN WEIGHT/VOLUME



- Enable fuel-flexible capabilities to utilize energy-dense logistic fuels for SOFCs
- Optimize functional gradation to reduce interfacial impedance and increase fuel cell power density

- Evaluate and analyze electrochemical power technologies through simulation of mission profiles

- Investigate problem solution
- Recommend solutions
- Solve aircraft systems integration problems



- Li-air chemistries for high performance batteries
 - New cathodic formulations by enhancing triple phase boundaries
 - M&S using classical thermodynamics and chemical species mole balance



Mechanical Energy Conversion



- High temperature superconductors
- Mega-Watt power generation
- Magnetic materials
- Thermoelectric power generation



- Mega-Watt power generation
 - Superconducting and conventional generators
 - Short-circuit, open-circuit and low-load endurance testing
 - Used performance results and empirical analysis to modify generator to improve performance



Mechanical Energy Conversion



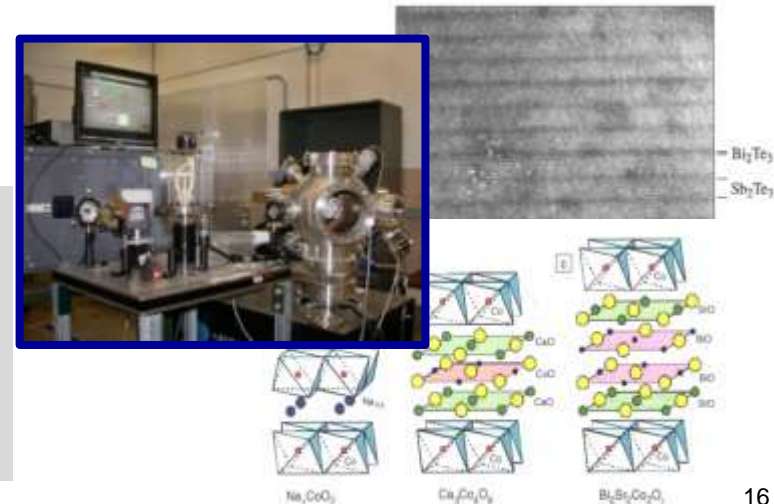
~60#, 12 T
NbTi-Superconductor Magnet



- Soft magnetic material composites
 - High-T up to 500°C
 - Operating frequencies up to 1 MHz
- Hard magnetic materials
 - High-T hybrid systems
 - Exchange spring systems with improved energy products (NdFeB, SmCo/Fe, FeCo)

- Develop YBCO superconductor properties for optimal performance
- Produce long lengths of YBCO coated conductors (DC and AC)
 - Minimize ac loss due to high power generation...lower heat loss
 - Stability and quench Issues
 - 1000A – 20,000A power transmission cables - lower weight and heat loss

- Multilayered structures for thermoelectric power generation
 - Oxide materials
 - Promote phonon scattering to inhibit thermal flow and increase efficiency
 - Nanostructure dispersions

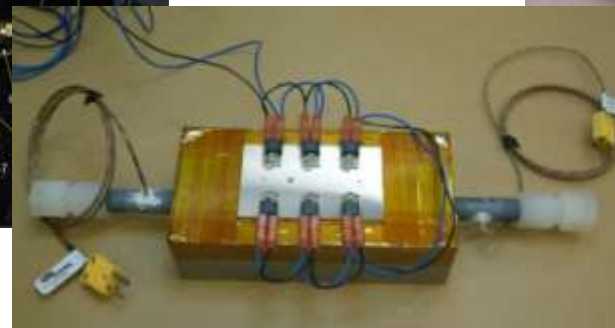
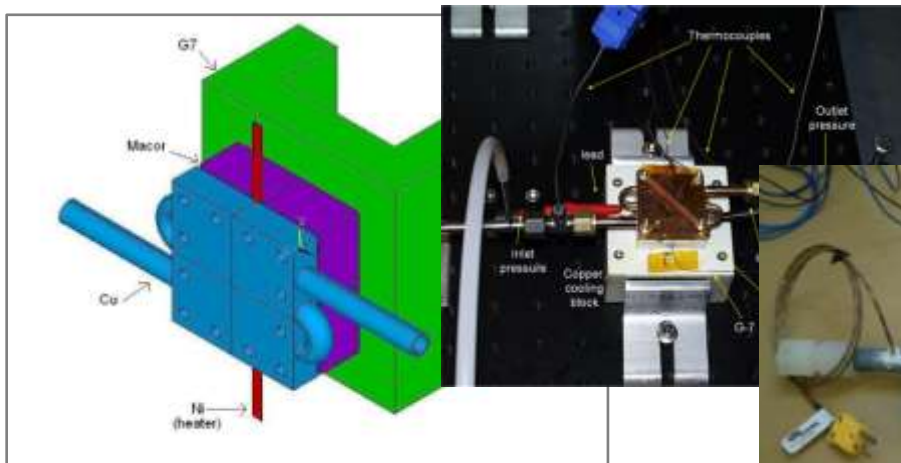
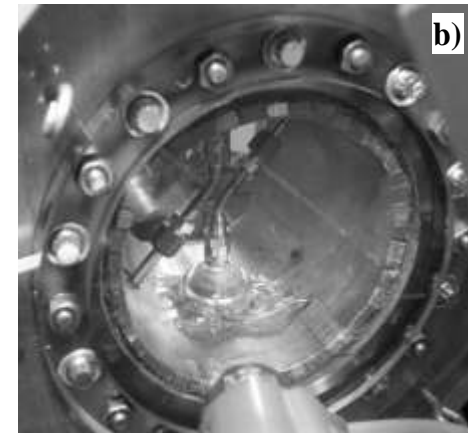




Thermal Management

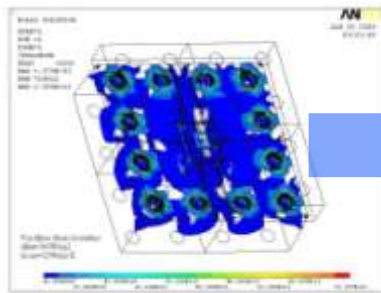


- Thermal management of SiC power modules
- Fuel cooling of turbo machinery
- Loop heat pipe for electronics cooling
- Thermal energy storage for mega-Watt applications
- Vapor cycle technologies for on-demand high-flux cooling applications

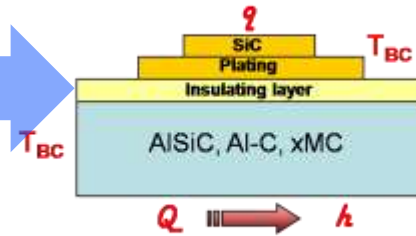




Thermal Management

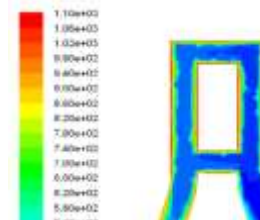


What is q and how will that drive our required " h ".

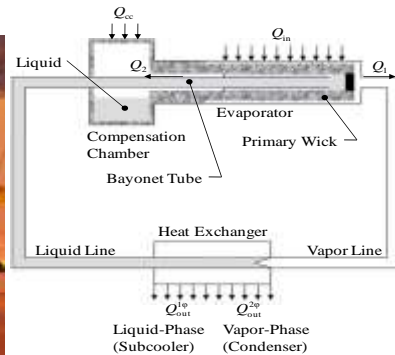


Modeled and empirical data can be used to focus development of cold plate technology needed.

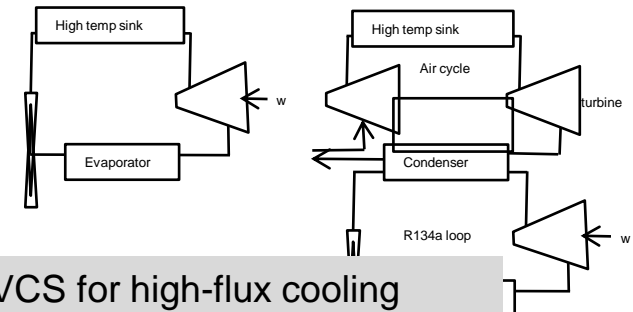
- Investigate and demonstrate SiC packaging technologies, target $R_{q,jc} = 0.15 \text{ cm}^2 \text{ K/W}$
 - Optimize heat transfer
 - Increase temp uniformity
 - Minimize CTE-related stress



- Investigate fuel cooling of rotating turbine components
- Combine experimental and modeling activities to understand fluid dynamics and thermal performance



- Dynamic LHP performance with time variant body forces for electronic component cooling



- On-demand VCS for high-flux cooling
- Time-accurate M&S and experimental validation (non-equilibrium physics, theoretical thermodynamics)



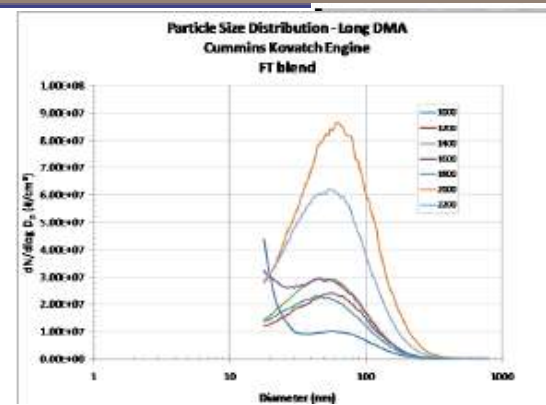
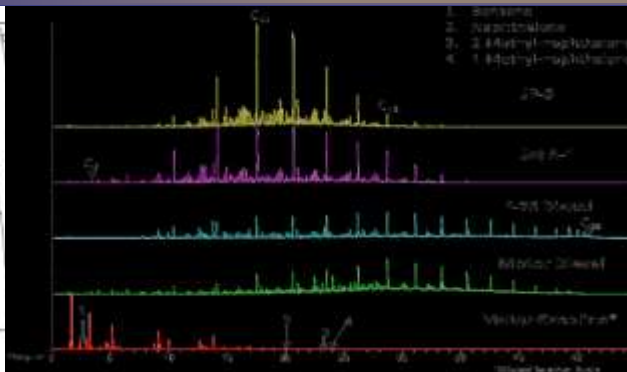
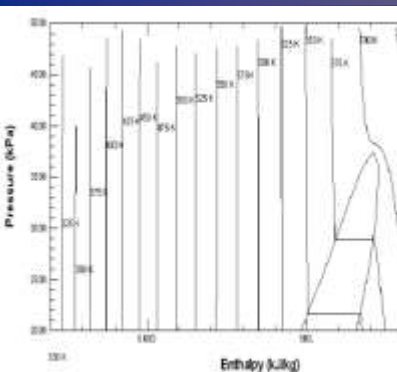
Fuel Utilization and Characterization



- **Endothermic fuels and hydrocarbon propellants**
- **Develop and optimize alternative fuels technologies (AAFRF)**
- **Microbial activity in fuels**
- **Emissions reduction via fuel technologies**
- **M&S of fuels technology**
- **Fuel characterization and fundamental studies**
- **Small engine fuel testing**
- **Nanofuels**

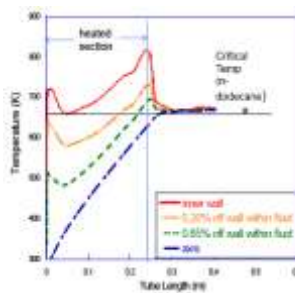
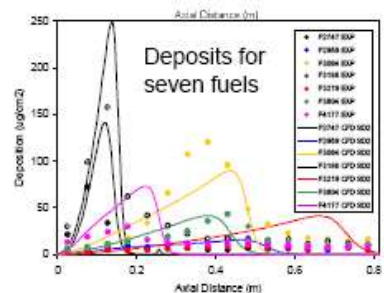


Fuel Utilization and Characterization



- Develop composition-based physical property models for endothermic fuels
- Thermal-oxidative deposition model enhanced

- Emissions evaluation with alternative fuels
 - Research combustor
 - Military and commercial engines
- Conventional techniques
 - Particle size, mass, and number
 - Chemical analysis of particulates
 - Gaseous emissions



- Fuel system modeling tools for fuel system design
- Realistic heat flows
- Modules for various fuels
- Complex geometries
- Oxidation and deposition

- Leverage small engine technologies for alternative and heavy fuels

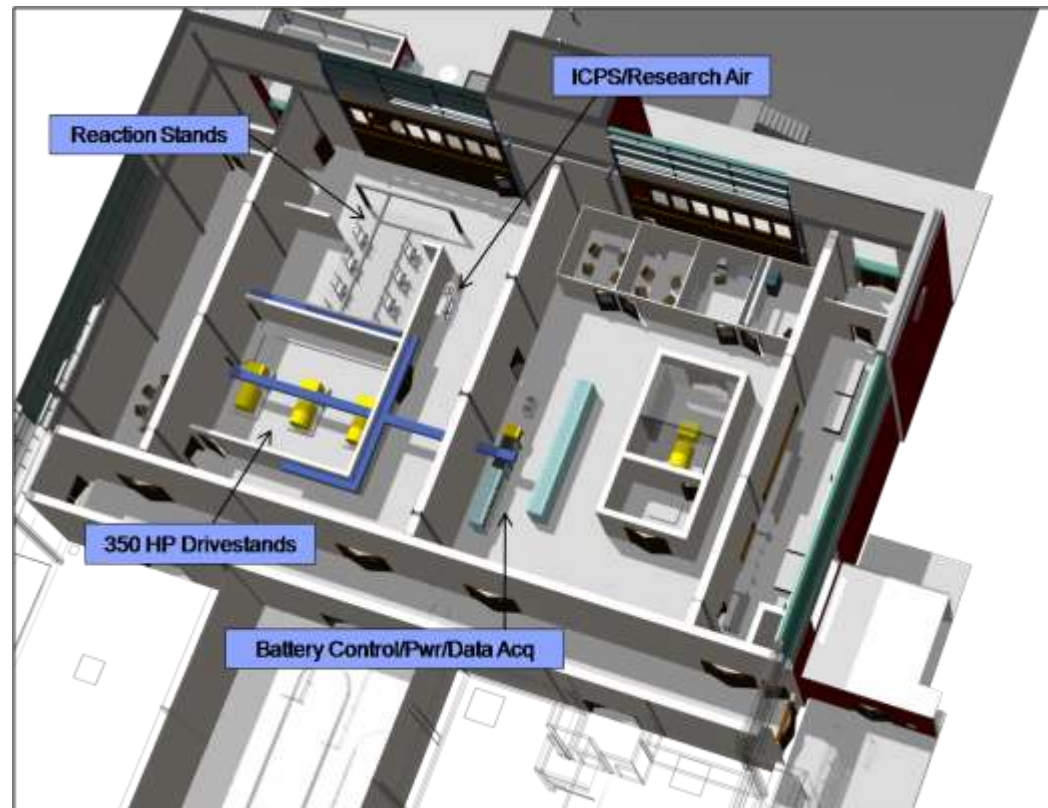
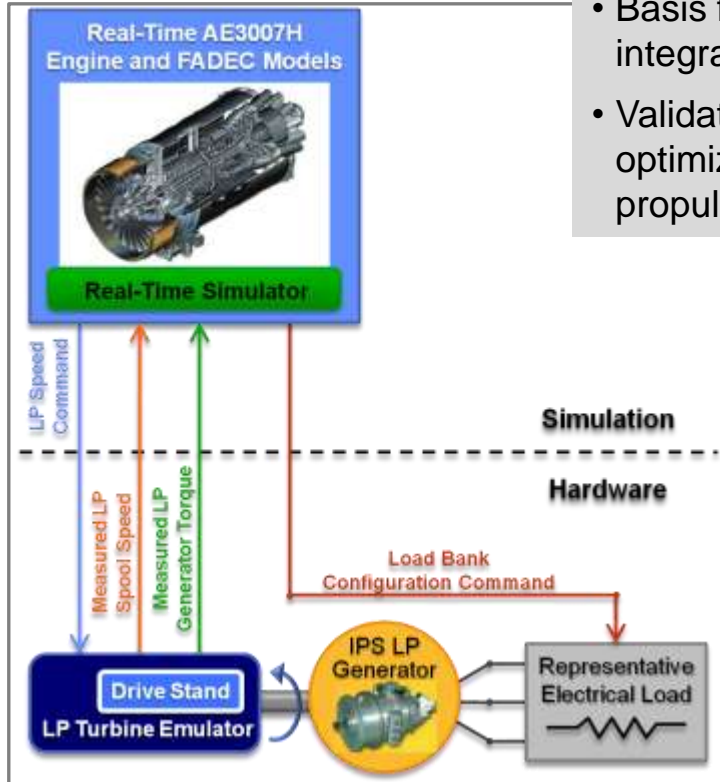




System Integration and Optimization



- Basis for SIL/HIL approach to system integration and energy optimization
- Validate HIL concepts for SIL approach to optimize power, thermal management, and propulsion from an energy perspective





Power and Thermal Analysis and M&S

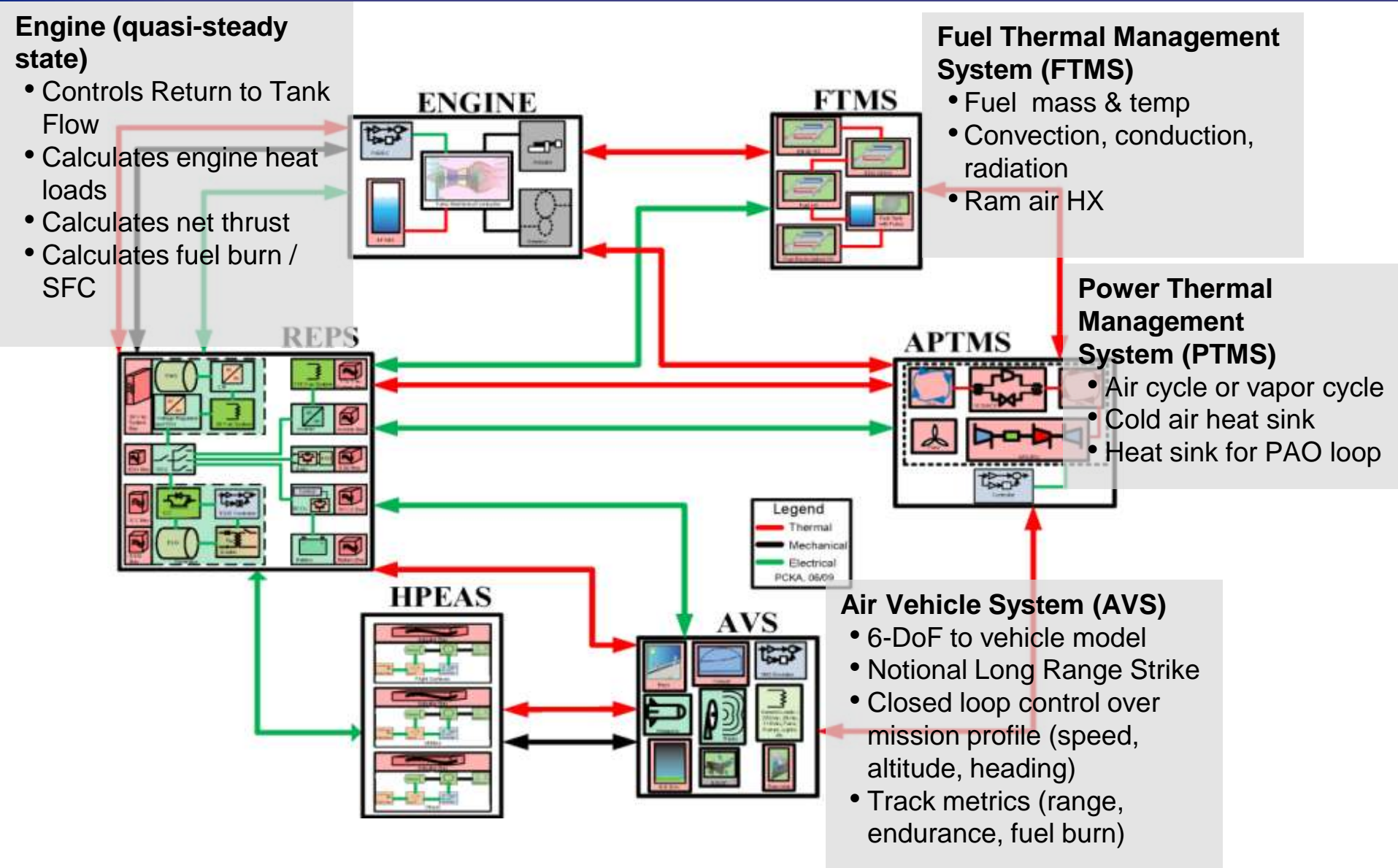


- Power and thermal M&S toolset development
- Power and thermal component and subsystem modeling
- Vehicle system-level modeling “Tip-to-Tail”
 - Power and thermal technology trades
 - Mission impact/benefits assessments for “energy optimized” vehicle architectures





Power and Thermal Analysis and M&S





Summary



- **Energy, power, and thermal are inter-related technologies and design considerations**
- **We investigate fuels, power and thermal devices and components, and system level M&S**
- **System optimization at the platform level saves energy and addresses thermal limitations**
- **International collaborations on energy, power, and thermal science and technologies are welcomed and desired**



Questions?



Warfighters: Today's and Tomorrow's

