ECT Program
NRC Review Meeting

Advanced Energetics Project

Advanced Energy Systems

June 12, 2002

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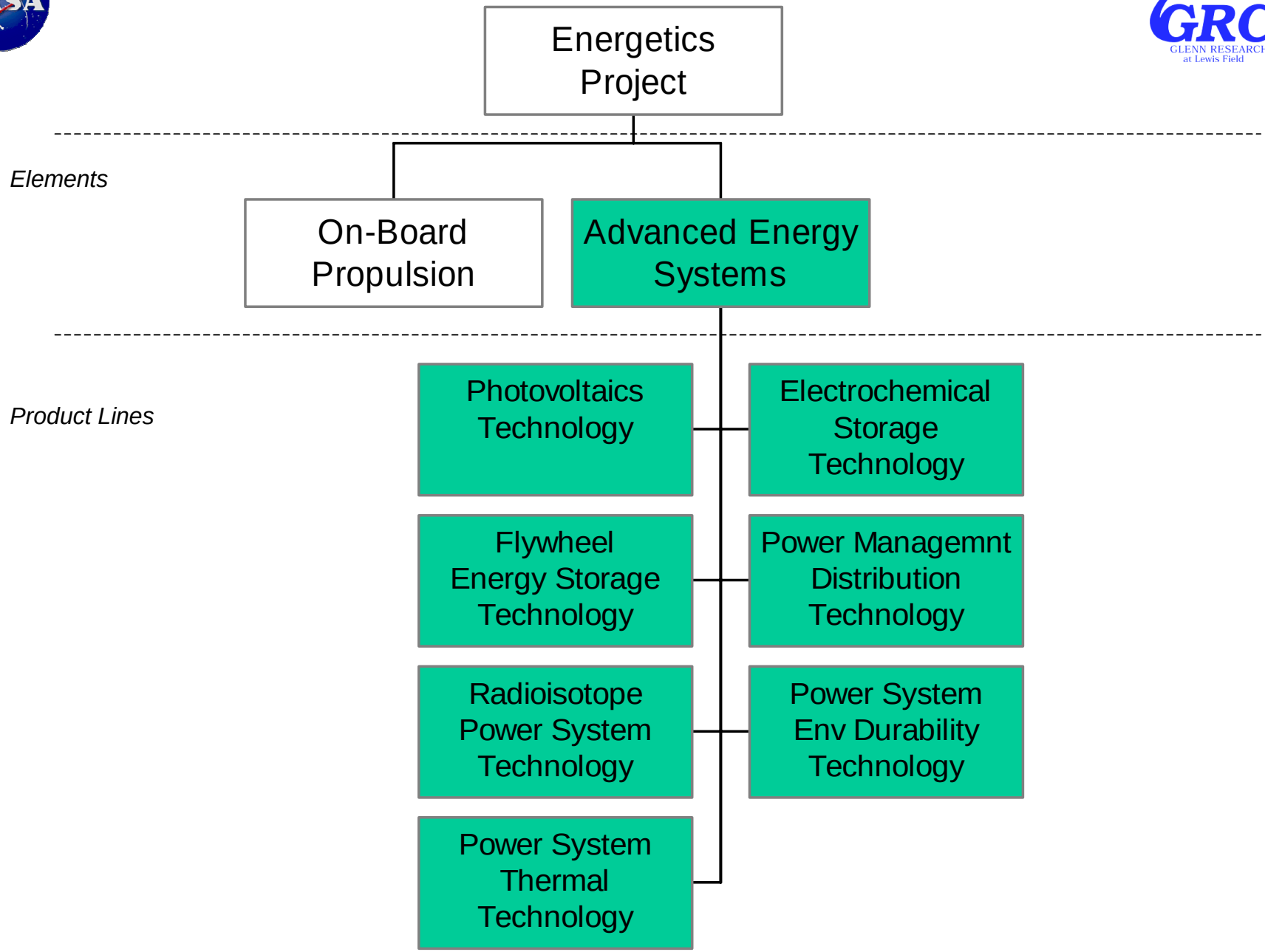
Advanced Energy Systems
Goals and Objectives

- Develop advanced power technologies to enable lower-cost missions with increased capability, and to extend mission reach.

- Develop advanced power generation, energy storage, power management & distribution, and power system durability/survivability technologies to enable a 40-60% reduction in power system mass.


Energetics Project
Elements
On-Board Propulsion
Advanced Energy Systems
Product Lines
Photovoltaics Technology
Electrochemical Storage Technology
Flywheel Energy Storage Technology
Power Managemnt Distribution Technology
Radioisotope Power System Technology
Power System Env Durability Technology
Power System Thermal Technology

Advanced Energy Systems

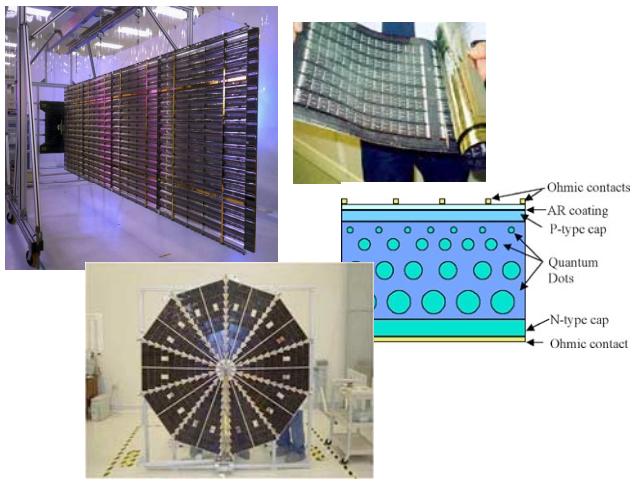
Product Lines	Product Line Managers
Advanced Photovoltaics Technology	Dr. Roshanak Hakimzadeh
Advanced Electrochemical Storage Technology	Dr. Marla Perez-Davis
Flywheel Energy Storage Technology	Mr. James Soeder
Power Management and Distribution Technology	Mr. James Soeder
Radioisotope Power System Technology	Mr. Richard Shaltens
Power System Environmental Durability, Reliability and Survivability Technology	Mr. Bruce Banks & Dr. Dale Ferguson
Power System Thermal Control Technology	Mr. Richard Shaltens

Advanced Energy Systems
Specific Customers

	Code S	Code Y	Code M	Code R
Advanced Photovoltaics Technology	✔	✔	✔	
Advanced Electrochemical Storage Technology	✔	✔	✔	✔
Flywheel Energy Storage Technology	✔	✔	✔	✔
Power Management & Distribution Technology	✔	✔	✔	✔
Radioisotope Power System Technology	✔		✔	
Power System Environmental Durability, Reliability and Survivability Technology	✔	✔	✔	
Power System Thermal Control Technology	✔	✔	✔	

Advanced Energy Systems
Advanced Photovoltaics

Technology Products



- High efficiency multi-band gap solar cells
- Thin film solar cells on flexible substrates
- Extended temperature (high and low) solar cells
- Advanced solar blanket and array technology
- Quantum dot solar cells
- Three associated NRA contracts

Benefits

- Solar arrays with > 300 W/kg specific power.
- Solar arrays with significantly lower costs
- High voltage solar arrays for direct drive solar electric propulsion (SEP) applications
- High temperature solar cells
- Low intensity/Low temperature (LILT) solar cells

Mission Applications

<u>Earth Science</u>

Lightweight, efficient, low cost solar arrays

<u>Space Science</u>

Lightweight, efficient, low cost solar arrays for SEP and robotic Mars surface missions

High temperature solar cells for Sun-Earth Connections (SEC) missions

<u>HEDS</u>

Lightweight,efficient, low cost solar arrays for human exploration, high power SEP, transportation vehicles and planetary surface exploration

Advanced Energy Systems
Advanced Photovoltaics

GRC Task Objectives

- Demonstrate >30% lattice mismatched multi-band gap (MBG) cells on Silicon substrate
- Greater than 20% multi-band gap thin film solar cells on polyimide substrates
- Establish feasibility of quantum dot solar cells with potential of 2X increase over SOA in efficiency
- Develop/ evaluate solar array blanket component and array technologies to full advantage of advanced cell technologies
- Maintain and utilize GRC capability for accurate, objective solar cell calibration, measurements for full range of advance solar cell technologies
- Technology development for high temperature solar cells applicable to inner planetary missions and performance evaluation of existing technologies for LILT conditions

GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$2180 K	$2180 K	$2180 K
• CS Workforce	12 FTE	12 FTE	12 FTE
• GRC NRA Grants	$105 K		
• Other Grants	$949 K		
• Other Competitive Contracts	$75 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$364 K		
• CS WF Cost	$687 K		
Leverage Contributions: External to NASA	$970 K	$980 K	$730 K
Leverage Contributions: Other NASA Sources	$600 K	$260 K	$250

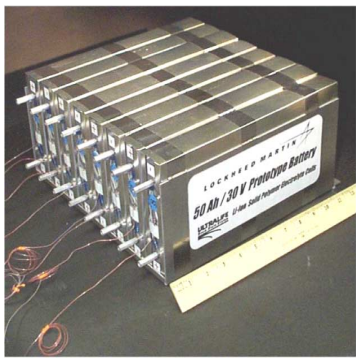
Advanced Energy Systems
Advanced Photovoltaics

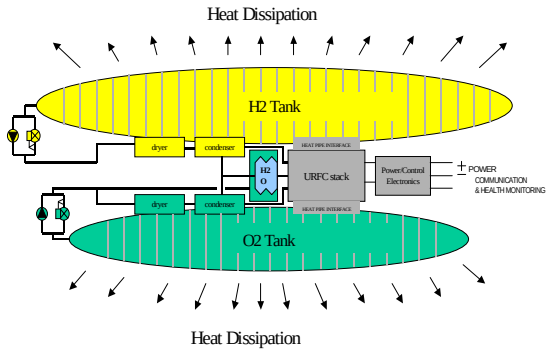
NRA Contracts	Resources		
	FY02	FY03	FY04
ENTECH:	$666 K	$339 K	
• Ultra-light, ultra-high-efficiency solar concentrator array			
Aerospace Corp:	$280 K	$477 K	$263 K
• Develop a multi-functional inflatable structure for the Power Sphere Concept			
TECSTAR (Emcore):	$472 K	$471 K	$83 K
• Develop a 40% mechanical stacked, 2 junction solar cell for concentrator arrays			

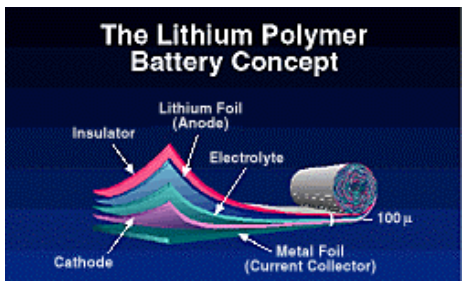
Advanced Energy Systems
Advanced Electrochemical Storage

GRC GLENN RESEARCH CENTER at Lewis Field

Technology Products







- Advanced battery technology
- NASA Aerospace Flight Battery Program
- Regenerative fuel cell systems technology

- Polymer Energy Rechargeable Systems (PERS)

Benefits

Li-Ion (liquid) Goals
- Specific Energy (cell level, 100% DOD) > 100Wh/kg
- Life/DOD(Years/%): LEO 5/40; GEO 10/60

PERS Goals
- Specific Energy (cell level at 100% DOD) > 200Wh/kg
- Life/DOD (Years/%): LEO 5/50; GEO 20/75

Passive RFC:
- Highest specific energy of all energy storage options (> 400 Whr/kg)for missions with extended eclipse times

Mission Applications

Earth Science
All missions requiring energy storage

Space Science
Mars orbiters, landers, and rovers.
Missions requiring energy storage
RFC: Ultra Long Duration Balloon energy storage

HEDS
ISS Battery Upgrades
Human Exploration Missions

Aerospace Technology
ERAST energy storage for long-duration high-altitude flights

Advanced Energy Systems

Advanced Electrochemical Storage

GRC Task Objectives

- Development of lithium-ion liquid electrolyte batteries for aerospace applications through joint program with AFRL and JPL
- Advanced battery technology including advanced anode and cathode materials, glass solid-state electrolyte concepts, nano-technology advances
- Demonstrate feasibility of passive unitized regenerative fuel cell storage system, which offers significant advantage in energy density for missions with extended eclipse periods
- NASA Aerospace Flight Battery Program: Agency-wide effort aimed at ensuring the quality, safety, reliability and performance of flight battery systems for NASA applications
  - Managed by GRC, with funded tasks to each Mission Center

GRC Task Resources	FY02	FY03	FY04
• Total Budget	$2649 K	$2649K	$2649 K
• CS Workforce	4.4 FTE	4.4 FTE	4.4 FTE
• GRC NRA Grants	$99 K		
• Other Grants	$364 K		
• Other Competitive Contracts	$1525 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$417 K		
• CS WF Cost	$244 K		
Leverage Contributions: External to NASA	$2575 K	$2375 K	$1675 K
Leverage Contributions: Other NASA Sources	$300 K		

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Polymer Energy Rechargeable System

GRC GLENN RESEARCH CENTER at Lewis Field

PERS Objectives

- Development of ultra-safe, conformable advanced polymer electrolyte battery systems with >3X specific energy & 10X energy density of SOA nickel based battery systems
  - The key to the successful development of a lithium-based polymer battery is the development of a highly conductive solid polymer electrolyte (SPE). Emphasis of this phase of the development program is focused on the development evaluation and validation of a variety of diverse polymer and basic component concepts

PERS Resources

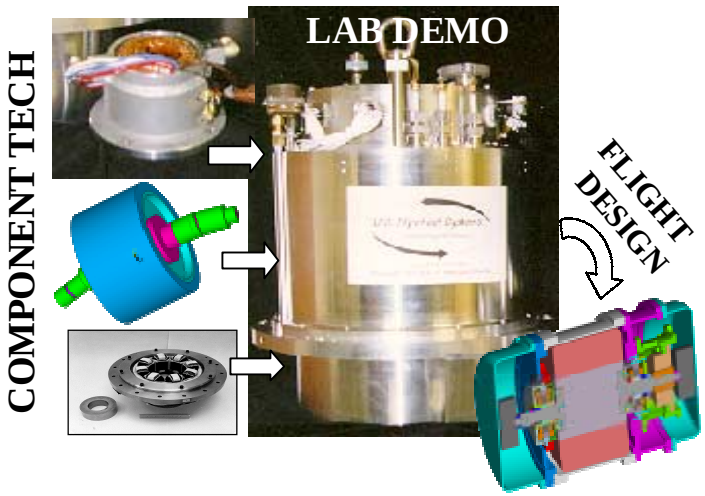
	FY02	FY03	FY04
• Total Budget	$2850 K	3000K	$3000 K
• CS Workforce	7.5 FTE		
• PERS NRA Grants	$500 K		
• Other Grants	$357 K		
• PERS NRA Contracts	$750 K		
• Other Competitive Contracts	$200 K		
• I-H Task Support Contracts and materials	$627 K		
• CS WF Cost	$416 K		

Leverage Contributions: External to NASA
Leverage Contributions: Other NASA Sources

FY02 funding is an Earmark.
Propose over-guideline for FY03 funding

Advanced Energy Systems
Flywheel Energy Storage

Technology Products



- Develop flywheel system technology for energy storage and integrated energy storage/ attitude control applications
- *Prior to FY02, flight demo on ISS was funded by HEDS*
- Three associated NRA contracts

Benefits

- Effective, usable system specific energy (SE) > 50 w-hr/kg
- Cycle life (at target SE) > 75,000 in LEO
- Energy Storage (turn around) Efficiency > 90%
- Cost > 25% reduction compared to existing battery systems

* At an integrated system level including all required functions for energy storage, power transfer to and from the spacecraft bus and attitude control actuation

Mission Applications

Missions requiring rechargeable energy storage with long cycle life and/or integrated attitude control such as LEO spacecraft

Earth Science - Earth Observing System

Space Science – Structure and Evolution of the Universe

HEDS - ISS

Aerospace Technology – 3rd Generation RLVs

Advanced Energy Systems
Flywheel Energy Storage

GRC Task Objectives

- Develop a smaller (300-1500 Whr) lower-cost flywheel prototype that is targeted to serve a wide class of Earth Science and Space Science missions
  - Component technologies such as motor/ generators, bearing systems and motor controls
  - Integrated system design including momentum and energy transfer on an air table facility at GRC
- Conduct advanced composite rotor design and development to increase the performance and life capabilities of flywheel rotors

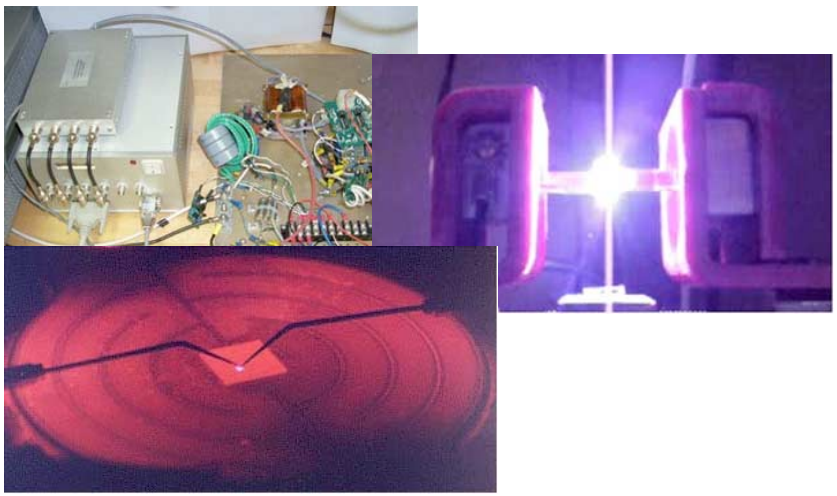
GRC Task Resources	FY02	FY03	FY04
• Total Budget	$1475 K	$1475 K	$1475 K
• CS Workforce	8.5 FTE	8.5 FTE	8.5 FTE
• GRC NRA Grants	$275 K		
• Other Grants	$136 K		
• Other Competitive Contracts	$278 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$237 K		
• CS WF Cost	$549 K		
Leverage Contributions: External to NASA	$300 K	$200 K	$200 K
Leverage Contributions: Other NASA Sources	$350 K	$350 K	

Advanced Energy Systems
Flywheel Energy Storage

NRA Contracts	Resources		
	FY02	FY03	FY04
Lockheed Martin: Demonstration of Coordinated Momentum and Energy Transfer (COMET) for flywheel systems	$677 K	$721 K	$168 K
Texas A&M: • Low power loss, fail safe magnetic suspension for energy storage/ attitude control flywheel systems	$319 K	$232 K	$13 K
University of Texas – CEM: • Integrated composite arbor and flywheel rim technology development	$64 K	$220 K	$220 K

Advanced Energy Systems
Power Management & Distribution

Technology Products



- Intelligent power management and distribution components and systems using distributed digital controllers
- Advanced electrical component technology
  - Development of high density, high temperature and high voltage electrical power components
- One associated NRA contract

Benefits

- > 3X increase in PMAD specific power
- 50% reduction in PMAD losses
- Increase in reliability
- Reduced cooling requirements and thus reduced complexity, size, and mass of thermal transport system and radiators

Mission Applications

Earth Science

- Allow new satellites to be developed using a common module family which decreases DDT&E and Integration costs

Space Science

- Increasing the power density of the Electric Propulsion PPUs. Missions using electric propulsion will benefit.

HEDS

- Advanced, lightweight, high efficiency power converter replacements for the ISS DDCU and BCDU

Aerospace Technology - Launch vehicles

Advanced Energy Systems
Power Management & Distribution

GRC Task Objectives

- Modular PMAD systems with autonomous operation.
- High voltage systems with incipient fault detection.
- Advanced high temperature, high power density passive components (capacitors and magnetics)
- High voltage, high temperature SiC switches and diodes.

GRC Task Resources	FY02	FY03	FY04
• Total Budget	$1353 K	$1353 K	$1353 K
• CS Workforce	5.8 FTE	5.8 FTE	5.8 FTE
• GRC NRA Grants	$233 K		
• Other Grants	$330 K		
• Other Competitive Contracts	$170 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$305 K		
• CS WF Cost	$315 K		
Leverage Contributions: External to NASA			
Leverage Contributions: Other NASA Sources	$655 K	$25 K	

Advanced Energy Systems
Power Management & Distribution

NRA Contracts

Resources

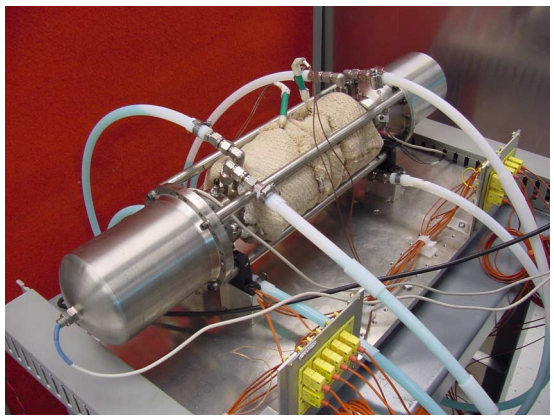
	FY02	FY03	FY04
University of Minnesota:	$261 K	$33 K	

- Develop an ultra-compact soft-switching DC-DC power converter

Advanced Energy Systems

Advanced Radioisotope Power System Technology

Technology Products



- Develop a high efficiency, low mass Stirling convertor
  - multi-dimensional Stirling CFD code
  - system dynamic model including dynamic model of engine/alternator/controller
  - advanced alternator
  - advanced controller
  - high temperature material alternatives
- Higher TRL efforts for Stirling have been funded by Space Science (Outer Planets and Mars Programs)
- Two associated NRA contracts

Benefits

- System Efficiency = 25-35%. SOA Radioisotope Thermoelectric Generators (RTG) = 6.5%
- General Purpose Heat Source Blocks for Nominal 100We System = 2. SOA RTGs = 8
- Beginning of Mission Specific Power = 6.0 to 9.6 W/kg (SOA RTGs = 4.5 W/kg)

Mission Applications

<u>Space Science</u>

- Near-term Stirling technology has been identified for potential use on Mars landers/ rovers
- Advanced Stirling applicable to Europa Lander, Neptune Orbiter, Saturn Ring Observer, and Titan Explorer
- A combined Stirling convertor/cooler may enable a Venus surface mission

<u>HEDS</u>

- Radioisotope and Nuclear Stirling has been incorporated in Human Exploration Mission Architectures

Advanced Energy Systems

Advanced Radioisotope Power System Technology

GRC Task Objectives

- Develop a high efficiency, low mass Stirling convertor for use with a radioisotope, reactor, or solar concentrator heat source
- Improve the Stirling power system to 25% efficiency and 6-8 W/kg and then to 35% and 8-10 W/kg
  - Near-term Stirling capability is 23% efficiency and 4-6 W/kg
- Technology developments to achieve Stirling system improvements:
  - multi-dimensional Stirling CFD code
  - system dynamic model
  - advanced alternator
  - advanced controller
  - high-temperature material alternatives

GRC Task Resources

	FY02	FY03	FY04
• Total Budget	$552 K	$552 K	$552 K
• CS Workforce	2.2 FTE	2.2 FTE	2.2 FTE
• GRC NRA Grants	$102 K		
• Other Grants	$142 K		
• Other Competitive Contracts	$70 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$123 K		
• CS WF Cost	$115 K		
Leverage Contributions: External to NASA	$15 K	$15 K	
Leverage Contributions: Other NASA Sources	$1200 K	$3000 K	$3000 K

Advanced Energy Systems

Advanced Radioisotope Power System Technology

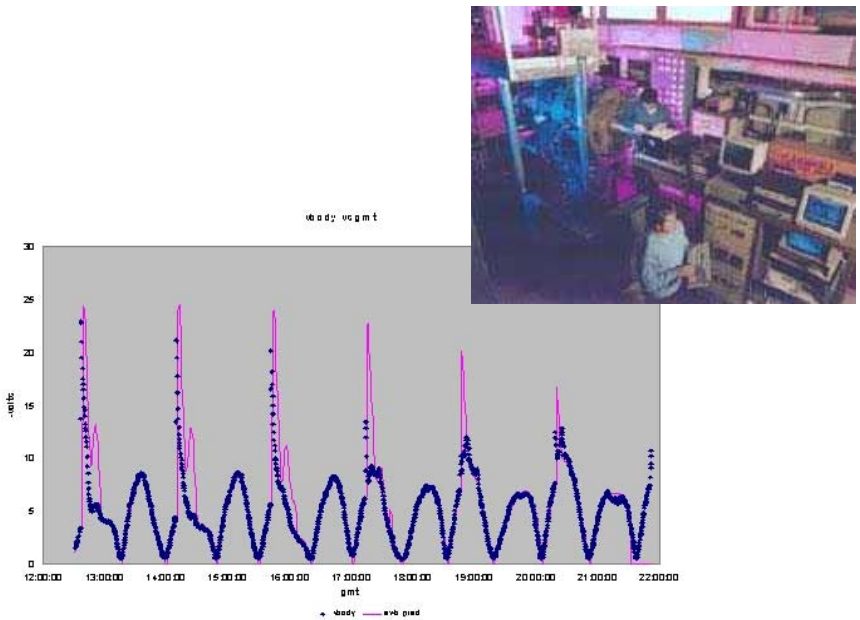
NRA Contracts

Resources

	FY02	FY03	FY04
University of New Mexico:	$311 K	$341 K	$24 K
• Design/ optimize advanced segmented thermoelectric modules			
TRW:	$370 K	$303 K	
• Design/ fabricate Stirling thermo-acoustic driver and test of a power unit			

Advanced Energy Systems
Power System Environmental Durability, Reliability and Survivability

Technology Products



- Power System Environmental Modeling, Test & Analysis
- Power Systems Surfaces/ Materials Technology

- One associated NRA contract

Benefits

- Analysis and testing to:
  - Improve reliability of power system
  - Improve design margins
  - Allow use of new materials, structures, components and architectures to enhance efficiency, lower weight and increase life
- Technology to enable long-term durability of power system surfaces in LEO atomic Oxygen (AO) environment
- EMI and radiation shielding with 3X increase in shielding capability

Mission Applications

<u>Earth Science</u>
All missions

<u>Space Science</u>
Mars orbiters, landers, and rovers
Deep space missions

<u>HEDS</u>
ISS
Human Exploration Missions

Advanced Energy Systems
Power System Environmental Durability, Reliability and Survivability

GRC Task Objectives

- Power system environmental design codes to enable operation in the space environment with higher efficiency, lower weight and improved lifetime
- Laboratory plasma chamber testing of components, materials to develop databases and design guidelines and extend / validate environmental analytical models
- Development of prediction concepts for LEO durable atomic oxygen protective coatings and surfaces
- Development of intercalated graphite EMI and radiation shielding concepts
- Durable high performance thermal control surfaces and coatings

GRC Task Resources	FY02	FY03	FY04
• Total Budget	$1450 K	$1400 K	$1400 K
• CS Workforce	12.0 FTE	12.0FTE	12.0 FTE
• GRC NRA Grants			
• Other Grants	$480 K	Projected to be similar to FY02	
• Other Competitive Contracts			
• I-H Task Support Contracts and materials	$304 K		
• CS WF Cost	$666 K		
Leverage Contributions: External to NASA	$450 K	$500 K	$550 K
Leverage Contributions: Other NASA Sources			

Advanced Energy Systems
Power System Environmental Durability, Reliability and Survivability

NRA Contracts

SAIC:

- Develop and test high voltage array and simplified PPU, develop spacecraft electrical and thermal designs for “Direct Drive Hall Effect Thruster System”

Resources

FY02	FY03	FY04
$315 K	$597 K	$193 K

Advanced Energy Systems

Power System Thermal Control Technology

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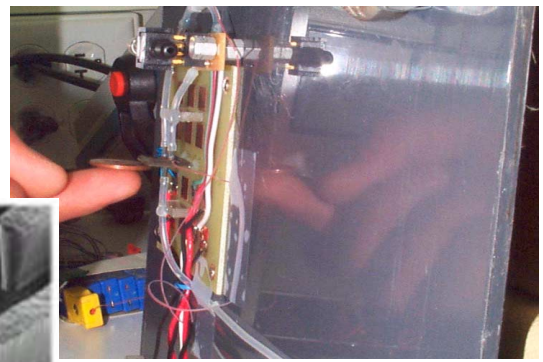
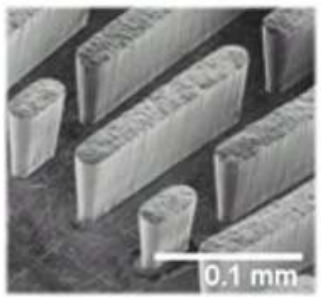
Technology Products



Silicon Micro Loop Heat Pipe
(Breadboard Test Bed)



Metal microstructures (Polar Thermal Technologies, Inc.)

- MEMS Stirling cooler for direct, active, precise cooling for power electronics and avionics
- Micro loop heat pipe in Silicon for passive cooling of electronics

Benefits

- MEMS Stirling cooler would provide order-of-magnitude increase in efficiency compared to thermoelectric coolers where active cooling is required
- Allow higher power density (330W/cm2) power electronics at lower temperatures (125 deg C) for lower mass and increased reliability

Mission Applications

<u>Earth Science</u>
All missions

<u>Space Science</u>
All missions

<u>HEDS</u>
All missions

Advanced Energy Systems

Power System Thermal Control Technology

GLENN RESEARCH CENTER at Lewis Field

GRC Task Objectives

- Develop MEMS Stirling cooler to provide active cooling and precise temperature control to electronics, sensors, optical components, biomedical/biotech devices, and other potential applications in support of NASA missions and commercial markets
- Develop an advanced micro-loop heat pipe in silicon to remove heat from high power density electronics
  - Micro-scale would allow direct contact to typical electronic power processor chip and allow maintenance of junction temperatures below 125 deg C

GRC Task Resources	FY02	FY03	FY04
• Total Budget	$572 K	$572 K	$572 K
• CS Workforce	1.3 FTE	1.3 FTE	1.3 FTE
• GRC NRA Grants	$172 K		
• Other Grants	$260 K		
• Other Competitive Contracts	$45 K	Projected to be similar to FY02	
• I-H Task Support Contracts and materials	$21 K		
• CS WF Cost	$74 K		
Leverage Contributions: External to NASA			
Leverage Contributions: Other NASA Sources	$560 K	$325 K	$400 K

Advanced Energy Systems
Recent Accomplishments

Photovoltaic Technology:

- Successfully grew 17% efficient GaAs cell on graded Si to Ge substrate as a step toward demonstrating the feasibility of multi-band-gap (MBG) cells on a silicon substrate for more robust, less expensive and significantly lighter high efficiency MBG solar cells
- Established the feasibility of single gas CVD process to enable higher efficiency thin film solar cells on low temperature flexible substrates
- Entech, under NRA contract, fabricated hardware and completed testing indicating the feasibility of 300 W/m^2, 170 W/kg stretched lens concentrator solar array

Electrochemical Storage Technology:

- In partnership with AFRL and JPL, as part of the AFRL/ NASA liquid electrolyte Lithium battery consortium, developed technology that enabled selection of Li-ion batteries for the 2001 Mars Lander and 2003 Mars Rover
- PERS initiated NRA contracts/grants and GRC, JPL, AFRL tasks to identify, evaluate novel polymer electrolytes

Advanced Energy Systems
Recent Accomplishments

Aerospace Flywheel Technology:

- High Speed Shaft (HSS) Unit tested to 57,500 RPM on magnetic bearings at GRC
  - Demonstrates the efficient/ routine operation of the magnetic bearings and motor control
- High Energy Flywheel Facility (HEFF) with air table brought on line
  - Capability needed for testing of integrated power and attitude control

PMAD Technology:

- Developed *first-ever* digitally controlled full-bridge dc-dc converter using non-linear Proportional Integral Derivative (PID) control.
  - 200% better transient performance.
  - Stability greatly improved

Radioisotope Power System Technology:

- GRC technology efforts have been a key factor in the selection of the Stirling Radioisotope Generator (SRG) as a high-efficiency candidate for the next-generation radioisotope power source for NASA Space Science missions

Advanced Energy Systems
Recent Accomplishments

Power System Environmental Durability, Reliability, Survivability Technology:

- Provided significant support, expertise to several flight applications to avoid potential or experienced solar array arcing (SS/ Loral, Terra, DS-1)
- Environment WorkBench, NASCAP, SAVANT computer codes, spacecraft charging guidelines
- Over 40 space flights using technology developed

Power System Thermal Technology:

- MEMS Stirling Cooler invented (patented) and proof of feasibility hardware design and fabrication initiated

Advanced Energy Systems
Community Connections

- Significant regular coordination/ collaboration with organizations external to GRC

  Examples:

  - Technical exchange/ program coordination reviews with AFRL
    - Semi-annual formal review plus ad hoc splinter meeting in specific technical areas
    - Current areas of collaboration include Li batteries, PERS, flywheel systems, PMAD, photovoltaics
  - Interagency Advanced Power Group
    - Coordination and regular review of power technology program plans/ status
    - Sponsoring members are NASA GRC & GSFC, Air Force, Navy-ONR, Army
  - Annual Flywheel Technology Workshop organized by NASA-GRC and AFRL
    - Technical exchange to review plans/ status, includes all program participants and other interested parties

Advanced Energy Systems
Community Connections

- Significant regular coordination/ collaboration with organizations external to GRC (continued)

  Examples:

  - PERS annual workshop organized by NASA-GRC
    - Technical exchange to review plans/ status, includes all program participants and other interested government agency representatives
  - NASA Aerospace Flight Battery Program is planned/ coordinated through a GRC chaired steering group consisting of MSFC, JSC, JPL, GSFC, KSC and AFRL, Navy-NRL, CIA and Aerospace Corp
    - Annual NASA Battery Workshop held to review plans/ status is attended by all participants and other industry interested parties
    - Specific tasks are managed at GRC, MSFC, JSC, JPL and GSFC
  - Annual review of PMAD development plans with participating contractor organizations (Boeing, Lockheed Martin, TRW)
  - Membership in:
    - Power Electronics Research Group (University of Illinois)
    - Center for Power Electronic Systems (VPI)
    - Wisconsin Electric Machine Power Electronics Consortium

Advanced Energy Systems
Community Connections

- Significant involvement with Industry;

  Examples:

  - Boeing
  - Lockheed Martin
  - TRW
  - Entech
  - Yardley
  - Sunpower Inc
  - Max Power Inc
  - Lithium Power
  - LithChem
  - SAIC
  - Physical Sciences Inc
  - Core Technologies
  - Stirling Technology Co
  - TECSTAR (Emcore)

- Significant participation in annual conferences relevant to power technology development, including:
  - Intersociety Energy Conversion Engineering Conference
  - SAE Power Systems Conference
  - AIAA Aerospace Sciences Conference
  - Space Technology & Applications International Forum (STAIF)
  - Space Power Workshop organized by Aerospace Corp
  - IEEE Photovoltaics Specialists Conference
  - Space Photovoltaics Research & Technology Conference (SPRAT) organized by NASA-GRC

Advanced Energy Systems
University Involvement

- Significant involvement with Universities, with over 55 currently funded University Grants/ Cooperative Agreements
  - University Power Technology NRA initiated by NASA-GRC
    - Currently eleven funded Grants selected in FY01
    - Each has been associated with an on-going TPA and is being coordinated by the corresponding TPA manager
  - PERS NRA
    - Currently five University Grants selected through the FY00 PERS NRA are funded to develop Li polymer electrolyte technologies
  - Four University Cooperative Agreements are currently funded as a result of the Space Based NRA
  - And, over 35 University Grants were initiated and are currently funded as part of the on-going TPAs

Advanced Energy Systems
University Grants

Advanced Photovoltaics Technology

Grants	Research Topic
Cleveland State University	Thin film precursor processing (e.g., CVD method)
Florida Solar Energy Center	High efficiency $CuInSu_2$ solar cells
Ohio Aerospace Institute	Advanced materials: energy conversion & storage
Ohio Aerospace Institute	Thin film technology
Ohio Aerospace Institute	PV engineering for solar cell research & testing
Ohio State University	Growth of multi-bandgap cells on silicon substrates
Penn State University	Production of solar cells for quantum dot research
Rochester Institute of Technology	Metal contact formation; high bandgap analysis
Rochester Institute of Technology	Thin film PV technology
Rochester Institute of Technology	Quantum dot characterization & development
University of Michigan	High bandgap cell analysis
Wheeling Jesuit University	Synthesis - In, Ga, & Cu Dithiocarbonate complexes
Wayne State University	Characterize multi-junction cells

NRA Selected Grants	Research Topic
University of South Florida	Thin film, dual junction cells on polymer

Advanced Energy Systems
University Grants

Power Systems Environmental Durability, Reliability, & Survivability

Grants	Research Topic
Cleveland State University	Physical properties (e.g., AO, EMI, coatings)
Manchester College	Intercalation of graphite fibers
Ohio Aerospace Institute	Solar array plasma arc & arc-tracking testing
Ohio Aerospace Institute	Investigate environment of space interactions
University of Nebraska	Investigate Atomic Oxygen interactions

Power System Thermal Control Technology

Grants	Research Topic
Johns Hopkins University APL	Design/test of actuation/diaphragm & control electronics
University of Cincinnati	Fab/test micro-loop heat pipe in silicon

NRA Selected Grants	Research Topic
University of Florida	G-independent, high flux phase change heat exchanger
University of Florida	Novel heat pump weight optimization

Advanced Energy Systems
University Grants

Advanced Electrochemical Storage Technology

Grants	Research Topic
Carnegie Mellon University	Develop approaches for synthesizing nanocomposites
Case Western Reserve University	Microbattery fabrication: ink-jet methodologies
Iowa State University	Develop Li fast-ion conducting chalcogenide glasses
Rutgers University	Microscopy studies: polymer-electrolyte interface
Tufts University	Develop Li ion battery w/conducting polymer anode

NRA Selected Grants	Research Topic
University of Colorado	New materials for proton-conducting membranes

Polymer Energy Rechargeable Systems (PERS)

Grants	Research Topic
Ohio Aerospace Institute	Molecularly engineered polymeric materials
University of Akron	Synthesize polyethyleneoxide-based homopolyrotaxane
University of Akron	Polymer solid electrolytes: grafting copolymers

NRA Selected Grants	Research Topic
Indiana University	Nanostructured single ion solid polymer electrolytes
Northwestern University	Develop highly conductive polyelectrolytes
Texas A&M University - TEES	Characterize composite anodes, electrolytes, & cathodes
University of Minnesota	High temp conductivity: polymer/polyelectrolyte-salts
University of Utah	Simulation: nanocomposite solid polymer electrolytes

Advanced Energy Systems
University Grants

Flywheel Energy Storage Technology

Grants	Research Topic
Cleveland State University	X-ray tomography and ultrasonic spectroscopy
University of Akron	Life prediction of polymer matrix composites
University of Toledo	Investigate bearing & motor control methods in testbed

NRA Selected Grants	Research Topic
Auburn University	Damping of composites: rotor dynamics/control effects
Pennsylvania State University	High speed motor/generator & drive electronics
Texas A&M University - TEES	Low power loss, fail safe magnetic suspensions
University of Texas at Austin	Integrated composite arbor and rim technology
University of Toledo	Damping: mechanical bearings & magnetic rotors

Advanced Energy Systems
University Grants

Radioisotope Power System Technology

Grants	Research Topic
Cleveland State University	Develop multi-dimensional Stirling CFD code

NRA Selected Grants	Research Topic
Johns Hopkins University APL	Low temperature differential stirling engine
University of New Mexico	High efficiency segmented thermoelectrics

Power Management & DistributionTechnology

Grants	Research Topic
Cleveland State University	Advanced digital control for DC-DC converters
Pennsylvania State University	Develop high temperature dielectric materials
University of Minnesota	Develop digital switchgear and control algorithms
University of Toledo	Research in controls: power system technology apps

NRA Selected Grants	Research Topic
Auburn University	Investigate radiation: SiC diodes, metal oxide transistors
Howard University	Develop arc fault detection algorithms
University of Minnesota	Design high efficiency, compact power supply
University of Texas at Austin	High performance AlGaN & GaN electronic devices

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Leverage Summary

- Collaboration with AFRL and JPL for Li-Ion battery development and PERS/ Li polymer battery technology development
  - GRC, AFRL and JPL co-fund industry development contracts as well as conduct in-house research efforts for AF/NASA Li-Ion battery Development Program
  - GRC funds AFRL and JPL research tasks for PERS
- Collaboration for flywheel storage systems and rotor development
  - Co-funding with AFRL of AF contracts integrated flywheel storage/ attitude control systems development
  - Collaboration and co-funding with AFRL, DOT, DARPA, DOE, Army, NRO involving rotor development
- Co-funding for battery testing/ validation efforts in the NASA Aerospace Flight Battery Program
  - Additional funding provided by JSC, MSFC and CIA

Advanced Energy Systems
Leverage Summary

- Current Space Act Agreements include efforts with:
  - Industry organizations (3) in area of photovoltaics development
  - DARPA in area of regenerative fuel cell (RFC) systems development
  - AFRL in area of flywheel systems development
  - Over 10 small tasks funded by industry organizations in area of Electro-Physics, space environmental durability/ survivability
  - APL for power system related testing in support of MESSENGER mission
  - MDA SBIR technical management
- Funding from other NASA sources includes:
  - Direct funding from Code S for Stirling radioisotope power system development
  - Direct funding from Code M for power technology planning in support of potential future HEDS exploration missions
  - Indirect funding from NASA:
    - Graduate Student Research Program (GSRP) support to University researchers working at GRC
    - EPSCoR (Exp Program to Stimulate Competitive Research) to Oklahoma CVD Alliance in area of Thin Film Solar Cell development

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FY02 Funded Tasks

Advanced Photovoltaics Technology

- Advanced High Efficiency Solar Cell Technology
- Advanced Thin Film Solar Cell Technology
- Extended Temperature Solar Cells
- Advanced Solar Blanket and Array Technology
- Quantum Dot Solar Cells
- Solar Cell Measurements and Calibration

Advanced Electrochemical Storage Technology

- Advanced Battery Technology
- NASA Aerospace Flight Battery Systems Program
- Passive Regenerative Fuel Cell Technology
- Polymer Energy Rechargeable System (PERS)

Flywheel Energy Storage Technology

- Aerospace Flywheel Systems Technology
- Aerospace Flywheel Rotor Technology

Advanced Energy Systems
FY02 Funded Tasks
(continued)

Power Management and Distribution Technology
- Intelligent Power Management & Distribution Systems
- Advanced Electrical Components Technology

Radioisotope Power System Technology
- Advanced Technology for Stirling Convertors

Power System Environmental Durability, Reliability and Survivability Technology
- Power System Environmental Modeling, Test and Analysis
- Power System Surfaces/ Materials Technology

Power System Thermal Control Technology
- Micro-Loop Heat Pipe in Silicon
- MEMS Stirling Cooler

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FY02 Funding Distribution

			FY02	FY02
			$K	FTE
Advanced Energy Systems				
	GRC NRA Grants		985	
	Other Grants		2611	
	Contracts		2203	
	I-H Task Support Contracts		1804	
	CS WF		2868	56.4
PERS				
	PERS NRA Grants		500	
	Other Grants		357	
	PERS NRA Contracts		750	
	Other Contracts		200	
	I-H Task Support Contracts		627	
	CS WF		416	7.5
Space Based NRA				
	NRA Grants		1307	
	NRA Contracts		2844	
	CS WF		195	4.5

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FY02 Funding Distribution