ADVANCED ENERGETICS PROJECT OVERVIEW

National Research Council Review

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OUTLINE

- Goals & Objectives
- Organization & Management Structure
- Project Elements
- Budget
- Linkage to ECT Program
- Project Implementation Strategy
- Technology Strategic Planning
- Technology Product Agreements
- Systems Analysis
- Recent Accomplishment Highlights
- Project Customers
- Community Connections

ENERGETICS GOALS AND OBJECTIVES

- **Goal: A balanced project directed to provide critical technologies to meet the needs of NASA and the Nation.**
  - **Tailored to meet the NASA Enterprises' long-term needs**
  - **Strong endorsement from the Enterprise Technology Managers**
  - **Strong partnerships with other government agencies, especially the Air Force Research Labs**
- **Objective: Develop advanced power and propulsion technologies to enable lower-cost missions with increased capability, and to extend mission reach.**

ENERGETICS
ORGANIZATION & MANAGEMENT STRUCTURE

Energetics Project
GRC/Joe Nainiger

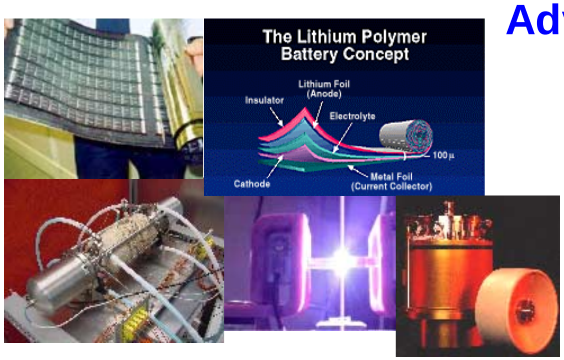
Advanced Energy Systems Element
GRC/Ray Burns

On-Board Propulsion Element
GRC/John Dunning

Technology "Product Line" Managers

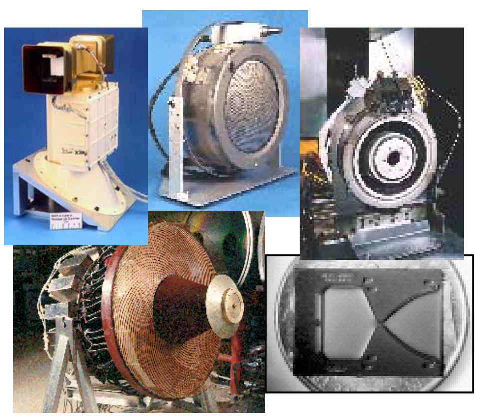
Technology Product Agreement (TPA) Managers

ENERGETICS ELEMENTS



Advanced Energy Systems (GRC/Ray Burns 216-433-5360)

- **Advanced photovoltaic solar cells and arrays,advanced radioisotope power systems, lithium battery, flywheel, and regenerative fuel cell energy storage systems, advanced cooling technology for power, power system materials and environmental interactions, and advanced power management and distribution technologies.**



On-Board Propulsion (GRC/John Dunning 216-433-5298)

- **Advanced electric propulsion systems (ion, Hall, pulse plasma thrusters, magnetoplasmadynamic thrusters, and pulsed inductive thrusters), advanced chemical propulsion systems (monoprops and biprops), and electric and chemical microthrusters.**

ENERGETICS BUDGET ($M) FY02 – FY07

Project/Element	FY02	FY03	FY04	FY05	FY06	FY07
Energetics	18.7	16.5	14.7	9.8	5.8	2.0
Advanced Energy Systems	13.9	12.0	10.1	6.7	3.9	1.4
On-Board Propulsion	4.8	4.5	4.6	3.1	1.9	0.6
Space Based NRAs	5.9	9.6	10.1	10.0	11.2	10.0
Revolutionary Spaceflight Research	0	0	0	5.0	10.0	13.9

LINKAGE TO ECT PROGRAM

NASA Mission

- To understand and protect our home planet
- To explore the universe and search for life
- To inspire the next generation of explorers

Aerospace Technology Enterprise Strategic Goal

GOAL 3: Pioneer Revolutionary Technology

Develop revolutionary technologies and technology solutions to enable fundamentally new aerospace systems capabilities and missions.

<u>Enabling Concepts and Technologies Program</u>

- Explore revolutionary aerospace system concepts to enable the grand challenges and strategic visions of the NASA Enterprises, and to expand the possibilities for future NASA missions.
- Develop advanced technology for sensing and spacecraft systems to enable bold new missions of exploration, and to provide increased scientific return at lower cost.
- **Develop adv Energetics technology to provide low-cost power & propulsion for enhanced mission capabilities, & to enable missions beyond current horizons.**

PROJECT IMPLEMENTATION STRATEGY

- **Technology development tasks grouped by "Product Lines"**

- **Product Lines contain individually-funded technology tasks documented by a "Technology Product Agreement (TPA)"**

- **TPAs and corresponding funding within each Product Line is *__revised__*, *__stopped__* *or* *__started__* based on annual review:**

  - **Product Line technology plans/visions status:**
    - **Assessment of the SOA and where the overall "community" is going**
    - **Vision/understanding of NASA mission needs and benefits to missions of specific new technologies via Systems Analysis**
    - **Understanding of which NASA mission needs are unique and will not be met by the private sector market incentives**
    - **Assessment of which technology areas should be addressed by Energetics**

  - **Individual TPA status/progress**
    - **Accomplishments to date**
    - **Continuing system level assessment by GRC Systems Assessment Team (SAT) of the mission applicability and potential benefits**
    - **Priorities within context of the Product Line plans/ visions**

ENERGETICS TECHNOLOGY STRATEGIC PLANNING

Understanding of the SOA in all areas of power technology

Understanding/ vision of where technology developments are going vs time

Acknowledge/ recognize that NASA is likely not driving this in all cases

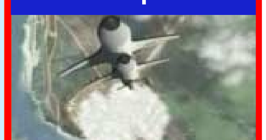
Understanding of GRC capabilities (particularly unique capabilities)

Understanding of which technologies needed by NASA missions will not be available unless funded by NASA

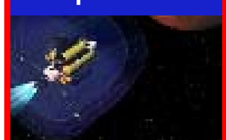
Understanding of NASA mission needs
(“pull” requirements)

Understanding/ vision of what mission capabilities would be enabled by power technology
(“push” requirements)

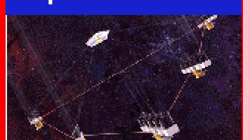
Aerospace



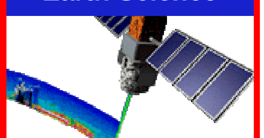
Exploration



Space Science



Earth Science



Energetics Specific Technology Plan

Current funded efforts:

Technology Product Agreement

- Product Description
- Technology Goals
- Schedule
- Resources
- Signatures

Vision of future efforts:

Goals:

2015

>20% Eff
>400 W/kg

Challenges:

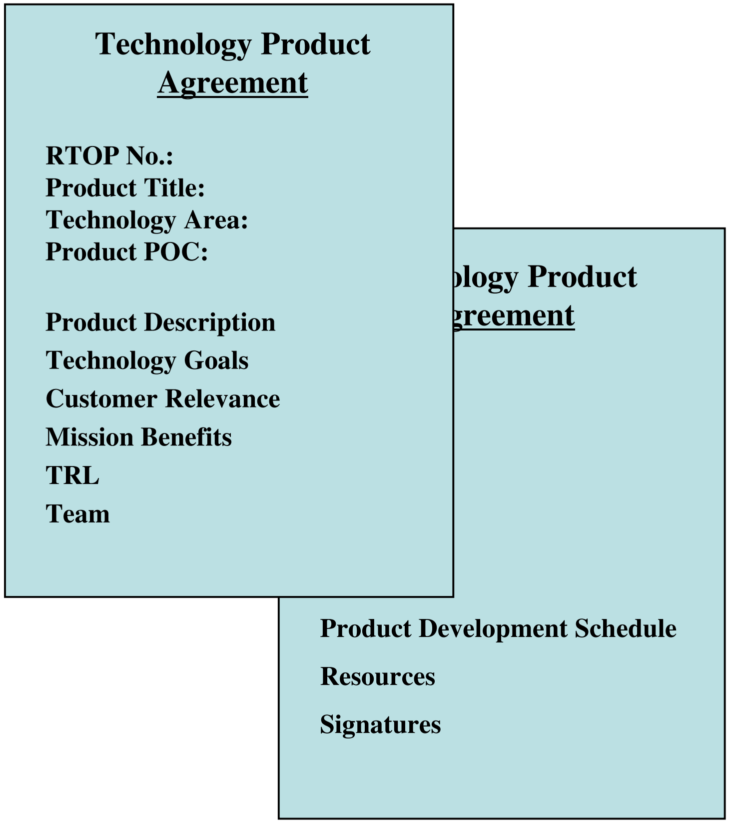
Technology Strategic Planning provides the basis to address:

- ***Why NASA must fund?***
- ***Why Energetics funding?***
- ***Mission applications and benefits***
- ***Relationship to OGA, industry funded efforts***

TECHNOLOGY PRODUCT AGREEMENTS

Technology Product Agreements (TPAs) consist of:

- **Product description/ task objectives**
- **Technology goals**
- **Customer relevance:**
  - **Target mission applications**
  - **Potential mission benefits**
- **Team:**
  - **In-house tasks**
  - **Contracted tasks**
  - **University grants**
  - **Collaboration with other agencies**
  - **Leverage**
- **Schedule/ milestones**
- **Overall resources**



THE KEY ROLE OF SYSTEMS ANALYSIS

- **Systems analysis provides the basis for sound technology program planning:**
  - indicates the range of applicability of various technologies.
  - indicates the most beneficial technology for a given mission or application.
  - provides rationale to advocate and/or defend technology development.
- **A well-planned, defendable technology development program needs accurate, consistent, unbiased "honest broker" assessments that…**
  - tempers the enthusiasm of advocates.
  - fairly quantifies the technology benefits.
  - identifies specific missions and applications.
  - utilizes the latest technology performance data & sizing models.
- **Systems analysis also provides the insight to guide systems operation and enable scenario evaluation and troubleshooting during mission operations.**

TRADE STUDIES
Propulsion, Power & Trajectories

Expertise In All Three Exist at GRC

Propulsion
- Various Propulsion Techniques
- Various Stages of Development
- Various Power Levels
- Various Specific Impulses

Power Source
- Solar
- Radioisotope
- Fission

Trajectory Design
- Low Thrust Trajectories
  - Long Thrust Periods

Each Mission Application is Unique

GRC Performs Complete Systems Analysis

Power & Propulsion System Sizing Tightly Coupled with Trajectory Design

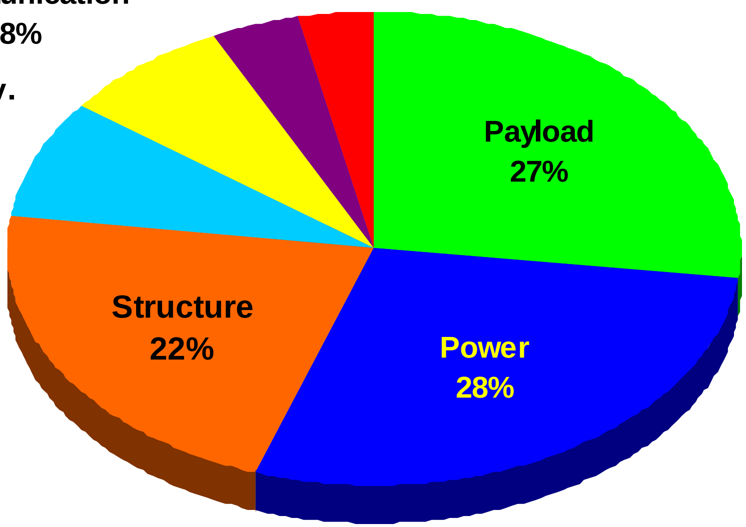
Refinement with Mission Center

(e.g. JPL Team X, GSFC IMDC, APL)

GRC SYSTEMS ANALYSIS CAPABILITY

- **GRC systems analysts have power and propulsion system performance and sizing models of various levels of fidelity for a wide range of technologies.**
  - **Nuclear & radioisotope systems**
  - **Photovoltaic solar arrays**
  - **Chemical battery and flywheel energy storage**
  - **Regenerative fuel cells**
  - **Power management and distribution**
  - **Electric propulsion**
- **GRC systems analysts play a mission critical role in supporting the operations of the International Space Station with a detailed analytical models of its electric power system (EPS).**
  - **Verification that EPS can support planned assembly operations.**
  - **Support to the ISS Mission Evaluation Room and Flight Controllers for on-orbit operations scenario evaluation and troubleshooting.**

RELATIVE IMPORTANCE OF POWER

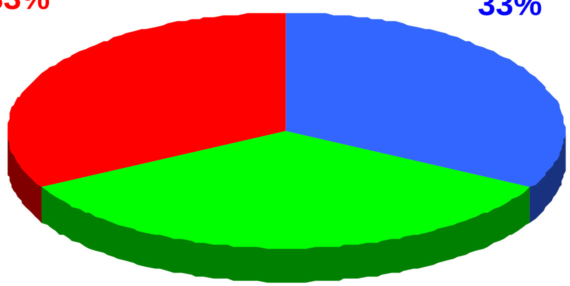


The Power System is typically 20% to 30% of Spacecraft Dry Mass.

- **Pie Chart shows the average mass breakdown by system for 24 spacecraft.**
- **Data from "Space Mission Analysis and Design", Wertz & Larson, 3rd Ed., Appendix A.**

- **Power is a relatively heavy *mission critical* system required by every other system (except Structures).**
- **Relative to spacecraft dry mass, the return on investment from advanced power system technology can be greater than any other spacecraft system for a wide variety of missions!**

Typical Power Subsystem Mass Breakdown by Function



Power Generation -	**required for every mission; advanced technology can be <u>mission enabling</u>.**
Energy Storage -	**when required, improvements in this subsystem typically result in the largest systems-level mass reductions.**
PMAD -	**improvements benefit ALL missions, especially large high power missions with significant power conversion requirements.**

Investments in advanced technology for each power subsystem will benefit the widest variety of missions!

EXAMPLE BENEFITS of
Power and Electric Propulsion for Earth Science

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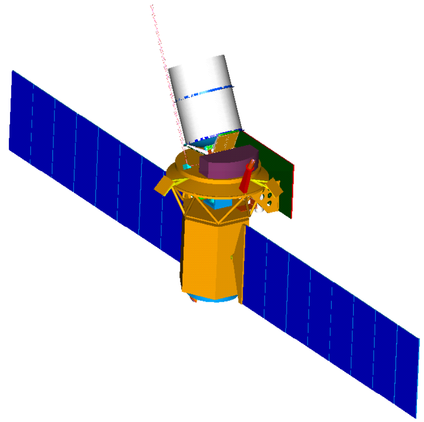
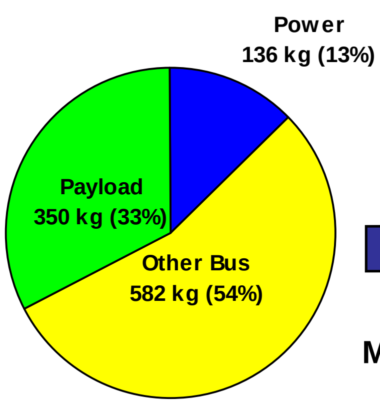
LIDAR Mission & Spacecraft Highlights
- Measure atmospheric wind profiles from 0 to 20 km altitude using a high power laser instrument (LIDAR).
- 5 year life goal, 3 year minimum life
- 450 km, 97° inclination sun sync orbit
- Fixed arrays (instrument pointing req.)
- No propulsion system required
- 875 W payload, 155 W bus
- 1065 kg baseline spacecraft mass



Benefits
- ✓ 24% more payload
- ✓ Active altitude control
- ✓ Extended mission life

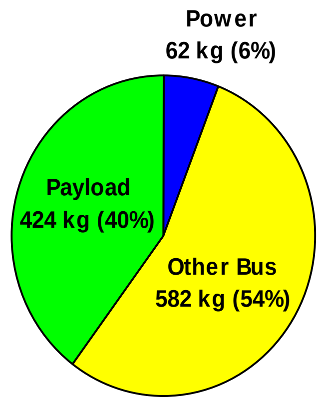
Baseline
Battery: 64 AH NiH_2 IPV (27 Wh/kg)
Array: 16 m^2 GaAs (15%) (30 W/kg)



350 kg Initial Payload Mass

Multi-junction Array
Li Battery

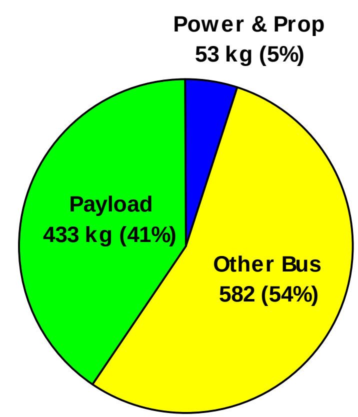
Advanced Power
Battery: 59 AH Li (80 Wh/kg)
Array: 10 m^2 3j GaAs (24%) (90 W/kg)



Additional 74 kg Payload Mass (21% Increase)

Multi-junction Array
Li Battery
Hall Thrusters

Advanced Power & Propulsion
Battery: 44 AH Li (80 Wh/kg)
Array: 5.6 m^2 3j GaAs (24%)(90 W/kg)
Prop: Solar Electric Hall Thruster



Additional 83 kg Payload Mass Over baseline (24% Increase)
61% Reduction in Power System Mass

EXAMPLE BENEFITS of
Power and Electric Propulsion for Space Science

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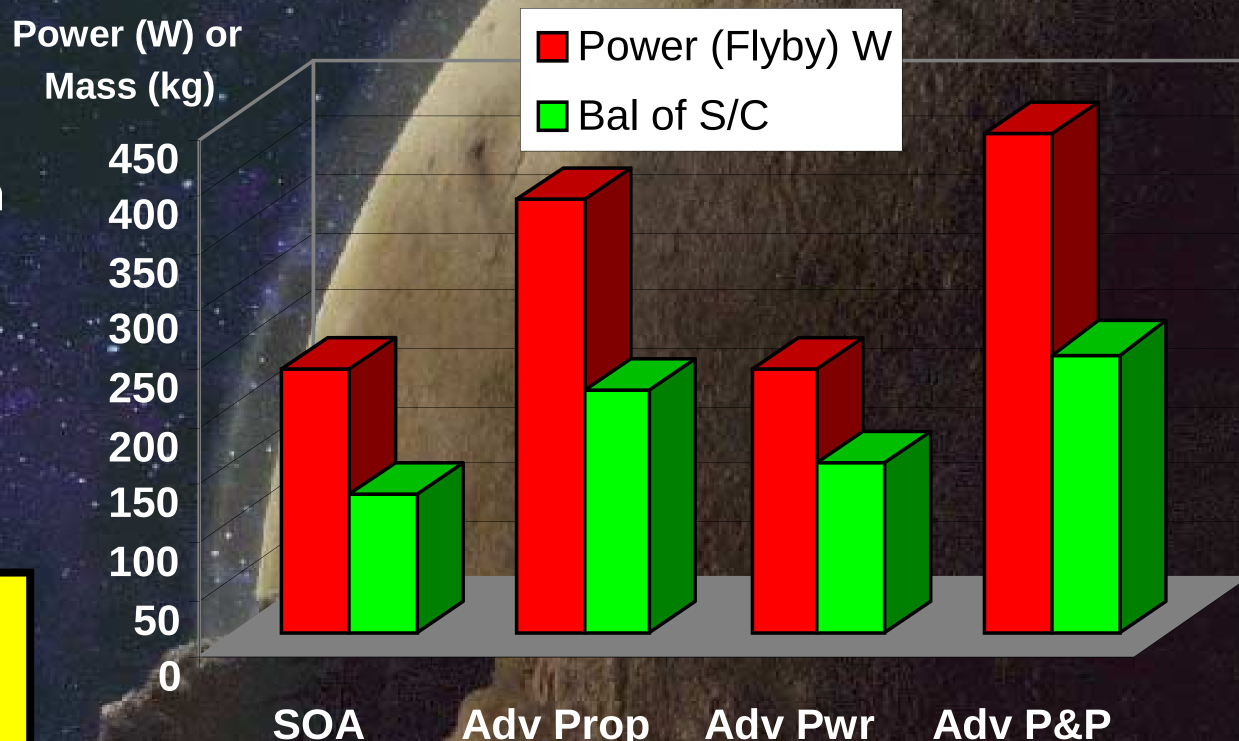
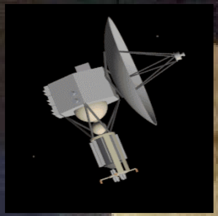
Pluto Flyby with Stirling Radioisotope Power & Ion Electric Propulsion

- *No launch window constraints, direct, fast trajectories*
- *Stirling Converter Reduces required number of Pu GPHS bricks*

Doubles Payload Power & Mass at Flyby

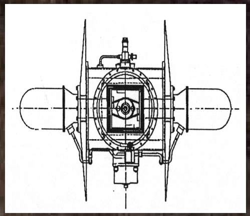
All Cases:
Atlas IIIb//Star48V
2009 Launch
2020 flyby





Direct RTG

Electric Prop- 8cm Ion thrusters



Radioisotope with Stirling Converters

Electric Propulsion and Stirling Radioisotope Converters

RECENT ACCOMPLISHMENT HIGHLIGHTS

Advanced Energy Systems

- Stirling Radioisotope Generator (SRG) selected as a high-efficiency next-generation candidate radioisotope power source for Space Science missions.
- Partnering with JPL & AFRL, developed technology that enabled selection of Li-ion batteries for the 2001 Mars Lander & 2003 Mars Rover missions.
- Developed ***first-ever*** digitally controlled full-bridge DC-DC converter using non-linear Proportional Integral Derivative (PID) control.
- High Speed Flywheel Shaft tested to 57,500 rpm on magnetic bearings at GRC.
- ENTECH, under NRA contract, fabricated hardware & completed testing indicating feasibility of 300 W/m^2, 170 W/kg stretched lens concentrator solar array.

On-Board Propulsion

- Successfully completed the DS-1 ion engine mission & demo'd 1^{st} Generation PPT on EO-1.
- Received patent for "Design & Manufacturing Processes of Long-Life Hollow Cathode Assemblies".
- Operated GRC-designed Hall thruster at 50% beyond design point of 50 kW.
- Quantified Hall thruster erosion/ sputtering mechanisms.
- Verified design of 50 cm grids for a 9000 sec specific impulse (Isp) engine.
- Successfully tested pyrolytic graphite grids on an 8 cm ion engine.
- Successfully operated 2^{nd} generation PPT and driver electronics.
- Operated MPD thruster and verified modeling analysis.

SPECIFIC PROJECT CUSTOMERS

	Space Science (Code S)	Earth Science (Code Y)	HEDS (Code M)	Aerospace Technology (Code R)
On-Board Propulsion	✔	✔	✔	✔
Advanced Energy Systems	✔	✔	✔	✔

POTENTIAL PARTNERSHIPS
For Transition Of Technology Products

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Space Science (Code S)

- **Advanced High Efficiency Solar Cells**
- **Extended Temperature Photovoltaics**
- **Advanced Solar Blanket and Array Technology**
- **Advanced Battery Technology**
- **Polymer Energy Rechargeable System**
- **Advanced Technology Development for Stirling Convertors**
- **Ion Electric Propulsion**
- **Hall Electric Propulsion**
- **Pulsed Inductive Thruster (PIT)**
- **Magnetoplasmadynamic (MPD) Thruster**

Aerospace Technology (Code R)

- **Flywheel Energy Storage Systems**
- **Advanced Battery Technology**
- **Polymer Energy Rechargeable System**

Earth Science (Code Y)

- **Advanced High Efficiency Solar Cells**
- **Advanced Solar Blanket and Array Technology**
- **Advanced Battery Technology**
- **Polymer Energy Rechargeable System**
- **Flywheel Energy Storage Systems**
- **Pulsed Plasma Thrusters**

HEDS (Code M)

- **Advanced Thin Film Solar Cells**
- **Adv Solar Blanket & Array Technology**
- **Regenerative Fuel Cell Systems**
- **Advanced Electrical Components**
- **Intelligent Power Management & Distribution Systems**
- **Hall Electric Propulsion**
- **Pulsed Inductive Thruster (PIT)**
- **Magnetoplasmadynamic (MPD) Thruster**

ENERGETICS "COMMUNITY CONNECTIONS"

- **Significant regular coordination, collaboration and partnerships with organizations external to GRC:**
  - **Other Government Organizations**
    - **Air Force Research Lab (Wright Patterson Lab, Phillips Lab, Edwards), Lawrence Berkeley Nat. Lab, Naval Air Warfare Center, Los Alamos Nat. Lab, Army Research Lab, DARPA, DOE HDQs, MDA, etc.**
  - **Other NASA Centers**
    - **JPL, JSC, GSFC, MSFC**
  - **Industry**
    - **Relationships with over 30 Companies**
    - **Contracts, SBIRs, Space Act Agreements, etc.**

ENERGETICS "COMMUNITY CONNECTIONS"

- **Significant Involvement with Universities**
  - **Over 65 Grants with Universities and Non-Profit Organizations**
    - **University Power Technology NRA initiated by GRC**
    - **Polymer Energy Rechargeable Systems (PERS) NRA University Grants**
    - **Grants associated with GRC TPAs**

- **Significant Leveraging Activities**
  - **Examples:**
    - **AFRL and JPL on Li-Ion and PERS/Li-poly Battery Technology**
    - **AFRL, DOT, DARPA, DOE, Army, NRO on Flywheel Technology**
    - **Over 20 Space Act Agreements**

- **Significant Participation in Annual Technical Conferences**
  - **e.g. IECEC, AIAA Aerospace Sciences, STAIF, IEEE PVSC, Space Power Workshop, SPRAT (GRC Organized), Joint Propulsion Conference**

- **Significant Memberships on Technical Committees**
  - **e.g. Space Technology Alliance, Interagency Advance Power Group**

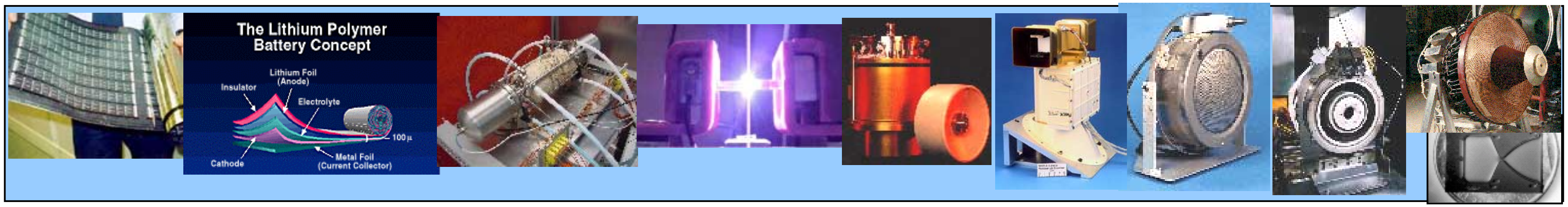
ENERGETICS PROJECT ELEMENTS BRIEFINGS

GLENN RESEARCH CENTER
at Lewis Field

This "Advanced Energetics Project Overview" presentation will be followed by briefings of the Energetics Project Elements:

- **Advanced Energy Systems**
- **On-Board Propulsion**

ENERGETICS PROJECT SUMMARY

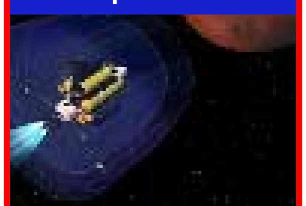


The ECT Energetics Project…

- A balanced project directed to provide critical technologies to meet the needs of NASA and the Nation.
- Developing advanced power and propulsion technologies to enable lower-cost missions with increased capability, and extended mission reach.
- Project implementation via Product Lines and Technology Product Agreements reviewed on an annual basis, guided by extensive Systems Analysis and Strategic Planning.
- Significant involvement from government, commercial and academic communities

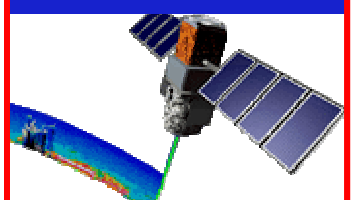
Energetics Project	Joe Nainiger (GRC)	216-977-7103
Advanced Energy Systems	Ray Burns (GRC)	216-433-5360
On-Board Propulsion	John Dunning (GRC)	216-433-5298

Exploration



Space Science

Earth Science



Aerospace