National Aeronautics and Space Administration

Green Engineering for Future Human Space Exploration

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Outline

- Background
- Architecture Development
- Overarching Design Philosophy
- Advanced Vehicle Technologies
- Clean Energy Development
- Summary

Green Engineering

- Green Engineering can be defined as environmentally conscious attitudes, values, and principles, combined with science, technology, and engineering practice, all directed toward improving local and global environmental quality.
- Green Engineering focuses on the design of materials, processes, systems, and devices with the objective of minimizing overall environmental impact (including energy utilization and waste production) throughout the entire life cycle of a product or process, from initial extraction of raw materials used in manufacture to ultimate disposal of materials that cannot be reused or recycled at the end of the useful life of a product.
- While Green Engineering strives to address environment impacts in the design phase of product, processes, and systems since the benefits increase as one moves upstream in a life cycle, it also embraces incremental improvements in materials, energy use, and machine efficiencies which can often be implemented more quickly than novel design approaches.

Source: Virginia Tech College of Engineering Website

Practical National Challenges

The use of green engineering for space exploration addresses all four of the Practical National Challenges:

1) Applying science and technology strategies to drive economic recovery, job creation, and economic growth;

2) Promoting innovative energy technologies to reduce dependence on energy imports and mitigate the impact of climate-change while creating green jobs and new businesses;

3) Applying biomedical science and information technology to help Americans live longer, healthier lives while reducing health care costs;

4) Assuring we have the technologies needed to protect our troops, citizens, and national interests, including those needed to verify arms control and nonproliferation agreements essential to our security.

Architecture Development Driven By A Strategy

Where We Have Been and Next Steps

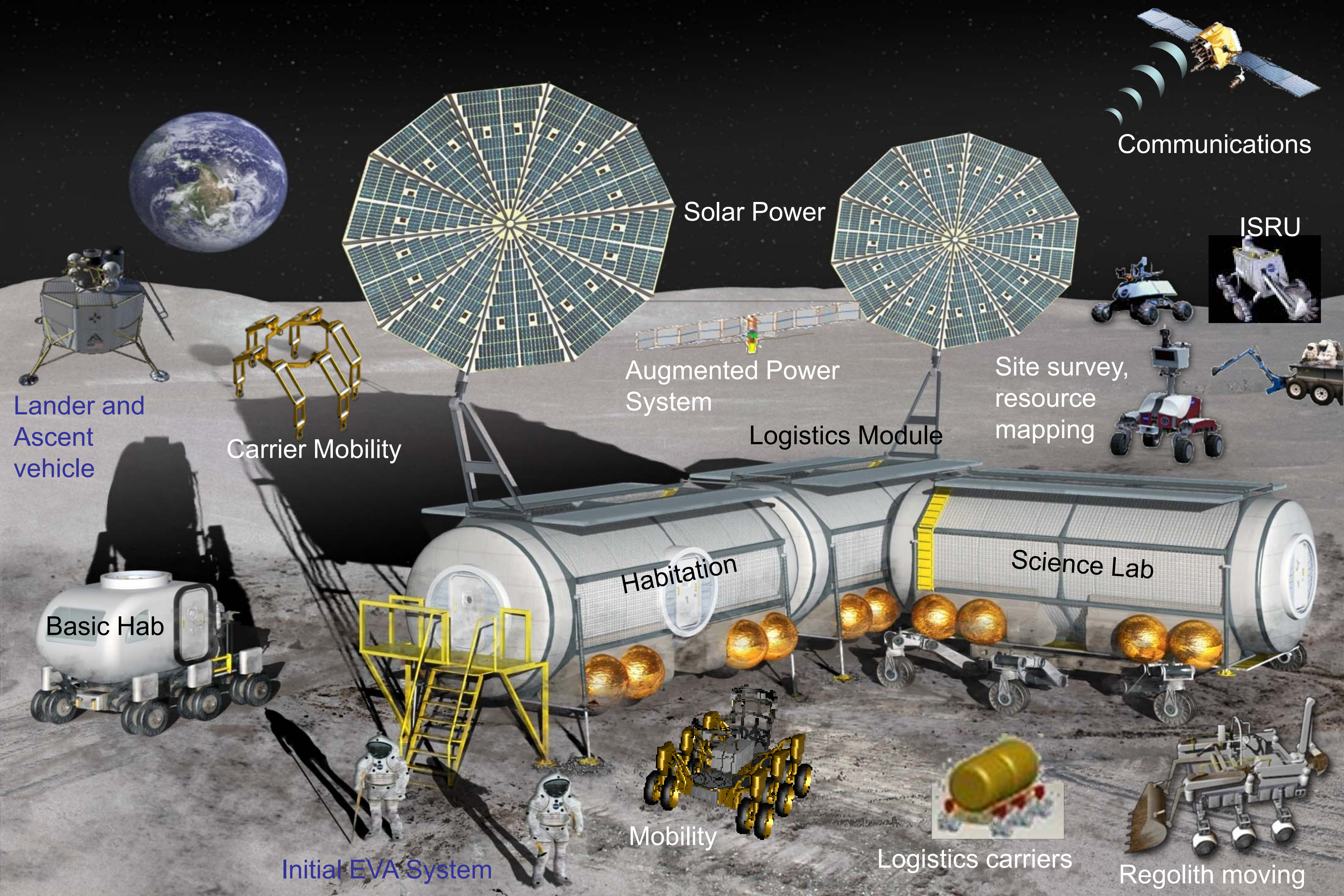
- *Global Exploration Strategy Development – Themes and Objectives*
- *Architecture Assessment (LAT1) Dec 06 – Outpost first at one of the Poles, elements critical to US*
- *Detailed Design Concepts (LAT2) Aug 07 – Operations concepts, technology needs, element requirements*
- *Lunar Capabilities Concept Review June 08 – Refinement of concepts for the transportation system*
- *Lunar surface concept additional analysis cycles and International Architecture Working Group activities*

Surface system concepts but no final designs

- *Global Point of Departure (gPOD) Architecture, June 2010 and NASA Lunar Surface Concept Review, June 2010*
- *Lunar transportation and surface systems SRRs*
- *Lunar surface system element SRRs*

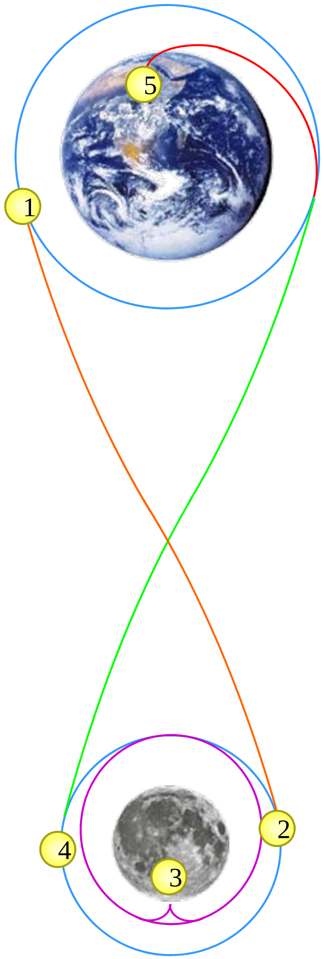
Time

Surface Architecture with Plug-in Electric Rovers and Solar Powered Homes



ESMD Architecture

Major Architecture Considerations: Gear Ratios for Various Architecture Waypoints



A Kilogram of Mass Delivered Here…	…Adds This Much Initial Architecture Mass in LEO
LEO to Lunar Orbit (#1→#2)	4.3 kg
LEO to Lunar Surface (#1→#3; e.g., Descent Stage)	7.5 kg
LEO to Lunar Orbit to Earth Surface (#1→#4→#5; e.g., Orion Crew Module)	9.0 kg
Lunar Surface to Earth Surface (#3→#5; e.g., Lunar Sample)	12.0 kg
LEO to Lunar Surface to Lunar Orbit (#1→#3→#4; e.g., Ascent Stage)	14.7 kg
LEO to Lunar Surface to Earth Surface (#1→#3→#5; e.g., Crew)	19.4 kg

1. LEO
2. Lunar Destination Orbit
3. Lunar Surface
4. Lunar Rendezvous Orbit
5. Earth Surface

Earth surface to LEO – 20.4 kg
Earth surface to lunar surface - ~153 kg

Overarching Architecture Design Philosophy

- **Because of the cost of sending systems to the lunar surface, a primary tenet of the architecture design philosophy is to reduce the consumption of resources, which is accomplished by implementing the following:**
  - **Reduce** – design systems and optimize operations to minimize resources used for exploration
  - **Reuse** – use for the original purpose multiple times
  - **Repurpose** – use for a different purpose without significant modification
  - **Recycle** – use for a different purpose with significant modification

- **In addition to resource conservation, some of the objectives of the Human Space Exploration Architecture are the following:**
  - Provide technologies and systems that improve life on Earth and the environment
  - Minimize the impact to the space environment
  - Minimize the impact to the Earth’s environment

Exploration Architecture - Reduce

Some examples of architectural design reductions

- **Systems Level**
  - Reduce element masses through lightweight materials, design optimization and efficient operations
  - Utilize closed-loop life support systems
  - Decrease power consumption
  - Minimize packaging overhead and attachment hardware

- **Component Level**
  - Reduce component mass through lightweight materials and design optimization
  - Decrease power consumption (computers, boards, motors, etc.)

- **Operations Level**
  - Simplify cargo off-loading
  - Incorporate efficient EVA planning
  - Maximize the use of ISRU

Exploration Architecture - Reuse

Some examples of architectural reuses

- **Systems Level**
  - Use of lander airlock by surface elements
  - Multi-function use of in-space transportation habitation elements
  - Relocation of surface elements to multiple exploration sites

- **Component Level**
  - Avionics
  - Batteries
  - Fuel Cells
  - Solar Arrays
  - Rover wheels
  - Lander fuel tanks used for surface fuel storage
  - Environmental Control & Life Support Systems

Exploration Architecture - Repurpose

Some examples of architectural component-level repurposing

- **Leverage avionics commonality**
  - Lander sensors used on rovers
  - Multi-use computers
  - Common electronic boards
  - Extensible software
- **Extract lander consumables for surface systems (e.g., water)**
- **Convert lander fuel tanks into surface fuel cell tanks**
- **Utilize trash and packaging materials for radiation shielding**
- **Use lander cabling for surface systems**
- **Modify lander structural components for use on the surface**
  - Covert decking into regolith manipulation implements
  - Use decking for high traffic area dust mitigation
  - Modify legs to support communication towers

Exploration Architecture - Recycle

Some examples of architectural recycling (including the use of ISRU techniques to further leverage recycled materials)

- **Process lander structural and surface system components into raw materials**
- **Purify waste water**
- **Extract and recover gases (nitrogen, oxygen, etc.)**
- **Convert waste solids for use in greenhouse applications**

Exploration Architecture - Technologies

- **Advanced Vehicle Technologies**
  - Batteries
  - Electric Motors
  - Wheels
  - Energy Regeneration Braking
  - Greaseless Bearings
  - Lightweight Materials

- **Clean Energy Development**
  - Fuel Cells
  - Solar Cells
  - Power Management
  - Transportation
    - Green Propellant
    - Propellant Storage and Transfer (e.g., Hydrogen)

Advanced Vehicle Technologies : Batteries

Challenges

- **Exploration elements require more advanced battery capabilities then currently exist**
  - **Safety: overcharge handling, operate in extreme environments, “thermal runaway”, other abusive conditions (shock, vibration, etc.)**
  - **Performance: ~600 watt-hours/kg, very low/very high temperature operations, low vol.**
  - **Durability: thousands of charge/discharge cycles, deep discharge issues, achieve 10+ years life**

Examples of Space Exploration Applications

Terrestrial Benefits

- **Cost-effective electric vehicles and equipment**
- **Reduced hydrocarbon usage**
- **Conserves resources and reduces environmental impact**

Examples of Terrestrial Applications

Advanced Vehicle Technologies: Electric Motors

Challenges

- Exploration elements require more advanced electric motors then currently exist
  - Safety: Operations in extreme environments, other abusive conditions (shock, vibration, etc.)
  - Performance: Very low/very high temperature operations, light weight, low volume
  - Durability: achieve 10+ years life

Examples of Space Exploration Applications

Lunar Electric Rover

ATHLETE Payload Handling System

Robotics

Terrestrial Benefits

- More capable electric motors
  - Lower power
  - Higher torque
  - Lower weight
- Great dexterity for robotic manipulators
- Low maintenance and long life reduces operating costs

Examples of Terrestrial Applications

Robotics Assembly & Industrial Applications

Biomedical devices

Automotive Applications

Locomotive applications

Advanced Vehicle Technologies : Greaseless Bearings

Challenges

- Exploration elements require more advanced greaseless bearings then currently exist
  - Need to operate in harsh lunar and Martian environments
    - Extremely abrasive dust
    - Very low and high temperatures
  - Durability: achieve a 10+ years life

Examples of Space Exploration Applications

Terrestrial Benefits

- Low maintenance and long life for equipment and vehicles operating in dusty environments
- Improved efficiency for manufacturing operations

Examples of Terrestrial Applications

Advanced Vehicle Technologies
Wheels

Challenges

- **Exploration elements require more advanced wheels then currently exist**
  - **Need to operate in harsh lunar and Martian environments**
    - **Extremely abrasive dust**
    - **Very low and high temperatures**
  - **Durability: achieve 10+ years life**

Examples of Space Exploration Applications

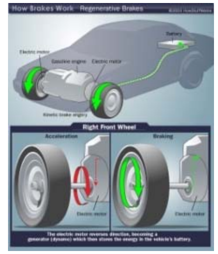
Terrestrial Benefits

- **Long life and low maintenance tires for automotive applications**
- **Reduces the number of tires being put in landfills**
- **Reduces use of hydrocarbons**

Examples of Terrestrial Applications

Advanced Vehicle Technologies
Energy Regeneration Braking

Challenges



- **Exploration elements require more advanced energy regeneration braking systems then currently exist**
  - **Need to operate in harsh lunar and Martian environments**
    - **Extremely abrasive dust**
    - **Very low and high temperatures**
  - **Higher efficiencies (>50% braking energy)**
  - **Durability: achieve 10+ years life**

Examples of Space Exploration Applications

Terrestrial Benefits

- **Cost-effective electric vehicles and equipment**
- **Reduced hydrocarbon usage**
- **Conserves resources and reduces environmental impact**

Examples of Terrestrial Applications

Advanced Vehicle Technologies
Lightweight Materials

Challenges

- Exploration elements greatly benefit from lightweight materials
  - Need provide higher strength to weight than current materials
  - Radiation tolerant
  - Extremely abrasive dust
  - Vacuum / low pressures
  - Very low and high temperatures
  - Durability: achieve 10+ years life

Examples of Space Exploration Applications

Terrestrial Benefits

- High strength-to-weight structures benefit many applications
- Higher fuel efficiency in transportation vehicles
- Design flexibility without compromising on performance or safety
- More efficient packaging

Examples of Terrestrial Applications

Clean Energy Development
Fuel Cells

Challenges

Advanced Fuel Cells

- **Exploration elements require more advanced fuel cells then currently exist**
  - **Durability and reliability - achieve 10+ years life with thousands of charge & discharge cycles**
  - **Cost**
  - **System size (low volume)**
  - **Thermal and water management**
  - **Vacuum / low pressures**
  - **Very low and high temperatures**

Examples of Space Exploration Applications

Lunar Electric Rover

ATHLETE Payload Handling System

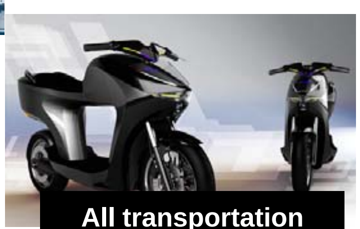
Terrestrial Benefits

- **Zero-emission power sources**
- **Lightweight/long-lasting battery alternative**
- **Efficient and reliable distributed energy storage**
- **Increased electrical power generation efficiency**

Examples of Terrestrial Applications

Alternative Energy & Home Energy Storage

Personal electronic devices



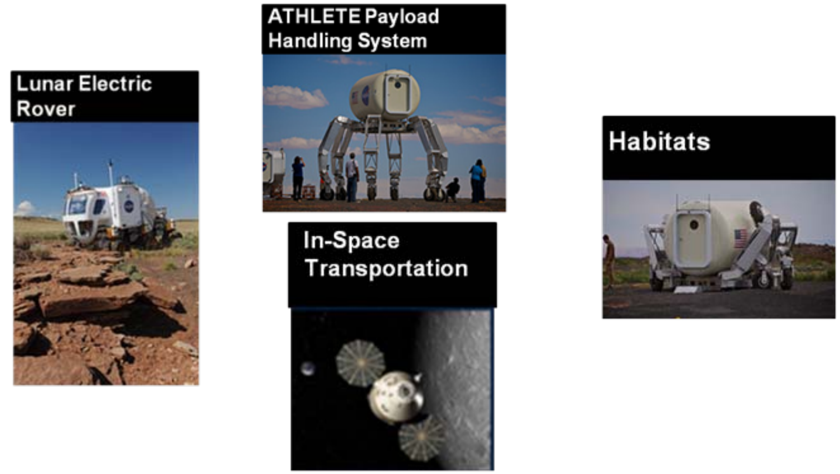
All transportation vehicles

Clean Energy Development
Solar Cells

Challenges

- Exploration elements require more advanced solar cells then currently exist
  - Increased cell efficiency and longevity
  - Operate in harsh in-space and surface environments
    - Dust tolerant
    - Very low and high temperatures
    - Radiation tolerant
  - Durability: achieve 10+ years life

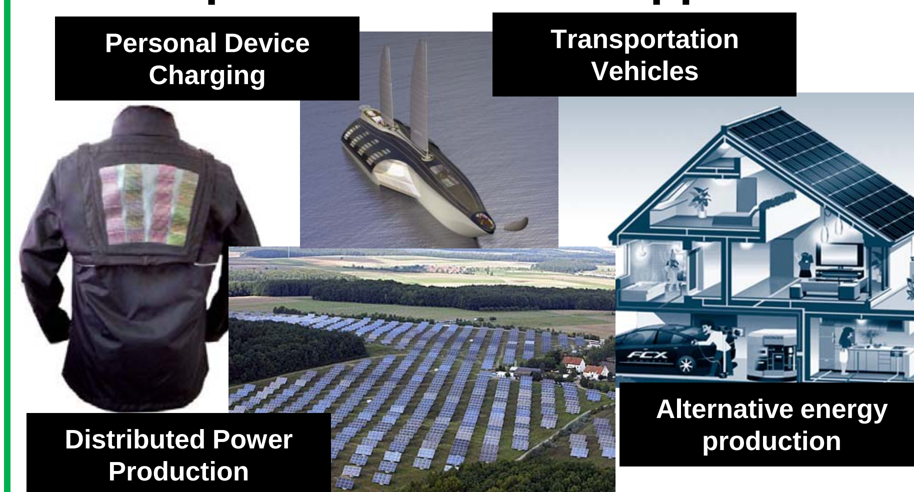
Examples of Space Exploration Applications



Terrestrial Benefits

- Zero-emission power generation
  - Renewable
  - Quiet
  - Highly reliable
  - Low maintenance
- Distributed power generation reduces the need for additional power plants and increases efficiency (reduced transmission losses)

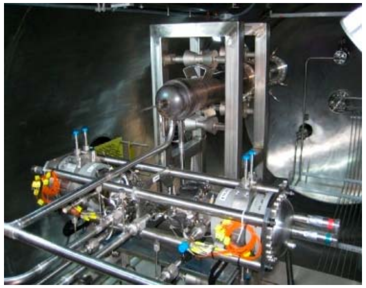
Examples of Terrestrial Applications



Clean Energy Development - Stirling Power Conversion

Challenges

- Stirling heat engines provide efficient and affordable power generation from concentrated solar energy, nuclear fission, and radioisotope power sources.

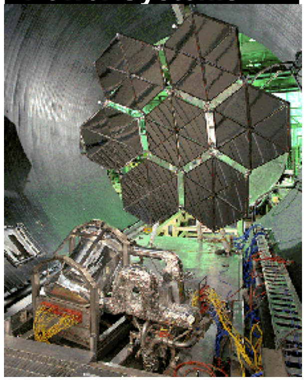


2 KW Stirling power conversion system integrated with liquid metal coolant loop

Examples of Space Exploration Applications

Fission Surface Power Systems

Solar Dynamic Power Systems



Terrestrial Benefits

- Solar concentrator power systems
- Power generation from waste heat
- Thermal energy reservoirs for energy storage

Examples of Terrestrial Applications

Solar Concentrator Arrays

Power Generation from Waste Heat

Clean Energy Development
Power Management

Challenges

- Exploration elements require more efficient power management systems then currently exist
  - Intelligent monitoring and control of dissimilar systems – turning off systems when not needed
  - Need to operate in harsh lunar and Martian environments
    - Radiation tolerant
    - Very low and high temperatures
  - Durability: achieve 10+ years life

Examples of Space Exploration Applications

Terrestrial Benefits

- Zero-emission power sources
- Lightweight/long-lasting battery alternative
- Efficient and reliable distributed energy storage
- Increased electrical power generation efficiency

Examples of Terrestrial Applications

Transportation Vehicles

Smart Grid Applications

Home and Office Power Distribution

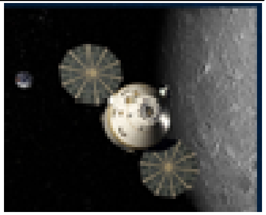
Clean Energy Development
Transportation – Green Propulsion

Challenges

- Exploration elements require more environmentally friendly systems and approaches then currently exist
    - Need to reduce pollution from aircraft and launch vehicles
    - Reduce ground operational constraints
    - Maximize performance of mono-propellants

Examples of Space Exploration Applications

Non-Toxic Mono-propellant RCS



Non-Toxic Lander Main Engines

Terrestrial Benefits

- Reduces/eliminates pollutants released into the atmosphere
- Increases safety during ground handling

Examples of Terrestrial Applications

Non-polluting Aircraft

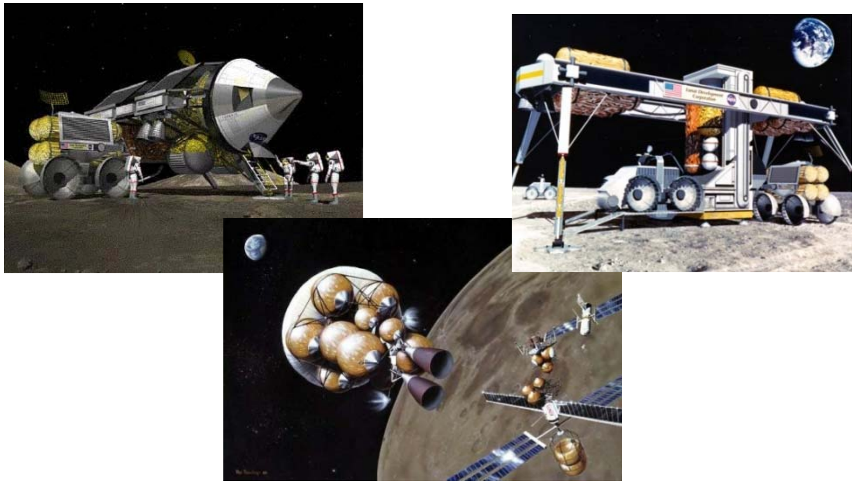
Non-polluting Earth-To-Orbit Access

Clean Energy Development
Transportation – Propellant Storage and Transfer

Challenges

- **Exploration elements require more advanced propellant storage and propellant transfer then currently exist**
  - **Minimizing boil-off and operating in harsh in-space and surface environments (very low and high temperatures & high radiation)**
  - **Material compatibility and robustness (hydrogen embrittlement)**
  - **Leak detection & quick disconnects**
  - **Durability: achieve 10+ years life**

Examples of Space Exploration Applications



Terrestrial Benefits

- **Enables safe, cost-effective distribution systems**
- **Increases reliability and provides more effective system monitoring**

Examples of Terrestrial Applications

Effective Distribution Systems

Industrial and Home Energy Storage Systems

Transportation Vehicles

Summary

- Green Engineering Practices aren't just useful in the human exploration architecture, they are fundamental to our ability to extend human presence past LEO. NASA can not live in space without making the architecture depend on green technologies.
- The innovative energy technologies needed for human exploration of space have direct applications to Earth's needs to reduce dependency on energy imports and mitigate the impact of climate-change
  - Advanced Vehicle Technologies
  - Clean Energy Development
- Advances will enable the creation of green jobs and new businesses
  - 80+% of money given to NASA is given to American companies – essentially reinvested into our economy
  - Investment in innovative energy technologies benefits both Earth and Human Space Exploration needs