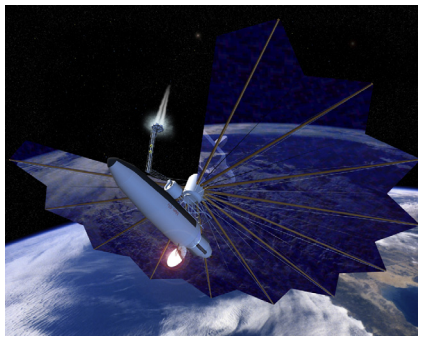
High Energy Power & Propulsion Capability Roadmap Status Update

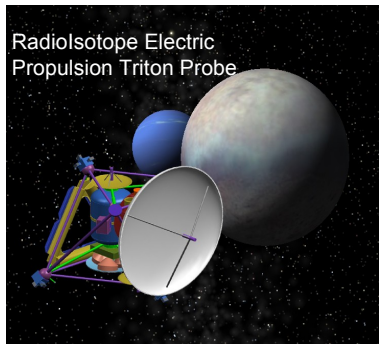
Joseph J. Nainiger, NASA Glenn Research Center
Tom Hughes, Penn State, Applied Research Lab
Jack Wheeler, DOE Headquarters

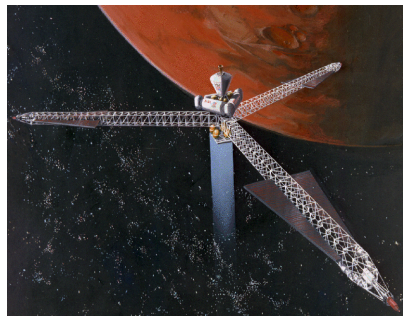
February 15, 2005

HEP & P Relevance

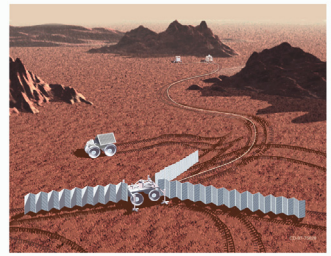


SEP/Chemical Mars Transport Stage



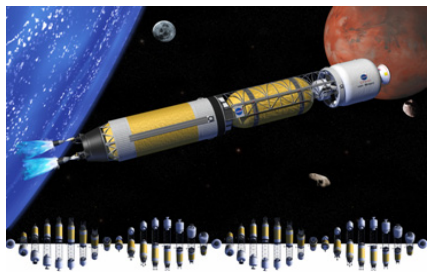


15 MWe NEP Mars Piloted Vehicle

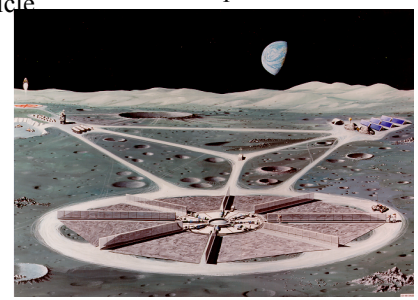


Nuclear Fission Mars Power System
Radiosotope Powered Cart

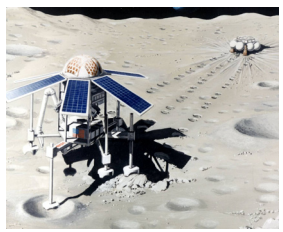
High Energy Power
& Propulsion



Nuclear Thermal Propulsion
Piloted Vehicle

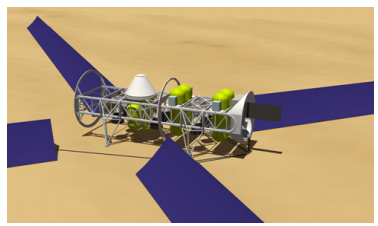


Nuclear Fission Lunar Power System



Photovoltaic Powered Robotic
Lunar Lander

Radioisotope Powered
Deep Space Probe



Photovoltaic Mars Power System

Photovoltaic Powered Mars Rover

HEP & P Scope/Domain

- **Systems Capabilities**
  - Nuclear Fission Power Systems
  - Nuclear Electric Propulsion Systems
  - Nuclear Thermal Propulsion Systems
  - Radioisotope Power Systems
  - Radioisotope Electric Propulsion Systems
  - Solar Power Systems
  - Solar Electric Propulsion Systems
  - Primary Battery/Fuel Cell Power Systems
  - Advanced Concepts (e.g., wireless power transmission)

- **Subsystems/Technology Capabilities**
  - Nuclear Reactors
    - Fuels
    - Materials
    - Controls
    - Shielding
  - Power Conversion Devices
    - Materials
    - Recuperators/Regenerators
  - Heat Rejection Radiators
    - Materials
    - Structures
  - Power Management and Distribution
    - AC-DC converters
    - DC-DC converters
    - Cabling
  - Electric Propulsion Subsystem
    - Thrusters
    - Power Processing Units
    - Tankage and propellant feed systems
  - Photovoltaic arrays
    - Solar cells
    - Concentrator concepts
    - Array blankets
    - Array structures
  - Energy Storage
    - Batteries
    - Regenerative fuel cells
      - Electrolyzers
      - Fuel Cells
      - H2 – O2 tanks
    - Flywheels
  - Guidance and Navigation (In Conjunction with In-Space Transportation Team)
  - Avionics (Address unique nuclear requirements)
  - Vehicle Health Management (Address unique nuclear requirements)

HEP & P Application Areas

- Robotic-Science Spacecraft Power
- Robotic-Science Propulsion (and On-board Power)
- Lunar Surface Power
  - Stationary
  - Mobile
- Mars Surface Power
  - Stationary
  - Mobile
- Human Exploration Propulsion (and On-Board Power)
  - Piloted
  - Cargo

HEP & P Capability Roadmap Team

Co-Chairs

- **NASA: Joseph J. Nainiger, Glenn Research Center**
- **External: Tom Hughes, Penn State, Applied Research Lab**
- **DOE: John (Jack) P. Wheeler, DOE HDQs**

Team Members

- **Government**

  Elaine Kobalka, NASA Glenn Research Center
  Stan Borowski, NASA Glenn Research Center
  Jose Davis, NASA Glenn Research Center
  Jeff George, NASA Johnson Space Center
  Rao Surampudi, Jet Propulsion Laboratory
  Sherrell Greene, Oak Ridge National Laboratory
  George Schmidt, NASA Marshall Space Flight Center
  Bob Wiley, DOE HDQs
  Wayne Bordelon, NASA Marshall Space Flight Center

- **Industry**

  Samit K. Bhattacharyya, President, RENMAR Enterprises
  Gary L. Bennett, Consultant
  Dave Byers, Consultant

- **Academia**

  James Gilland, Ohio Aerospace Institute
  Henry W. Brandhorst, Jr., Director, Space Research Institute, Auburn University

Coordinators

Directorate: Overall: Betsy Park, ESMD, Technical: Raynor Taylor, ESMD, (Day-to Day, Jay Jenkins, ESMD)

APIO: Perry Bankston, Jet Propulsion Laboratory

HEP & P Capability Roadmap Process and Approach - 1

- Have divided Capability Roadmap team into 5 sub-teams
  - Fission Systems
    - Lead: Sherrell Greene, Oak Ridge National Lab
  - Radioisotope Systems
    - Lead: Bob Wiley, DOE HDQs
  - Solar Systems
    - Lead: Henry W. Brandhorst, Jr., Auburn University
  - Energy Storage
    - Lead: Rao Surampudi, Jet Propulsion Lab
  - Advanced Concepts
    - Lead: Henry W. Brandhorst, Jr., Auburn University

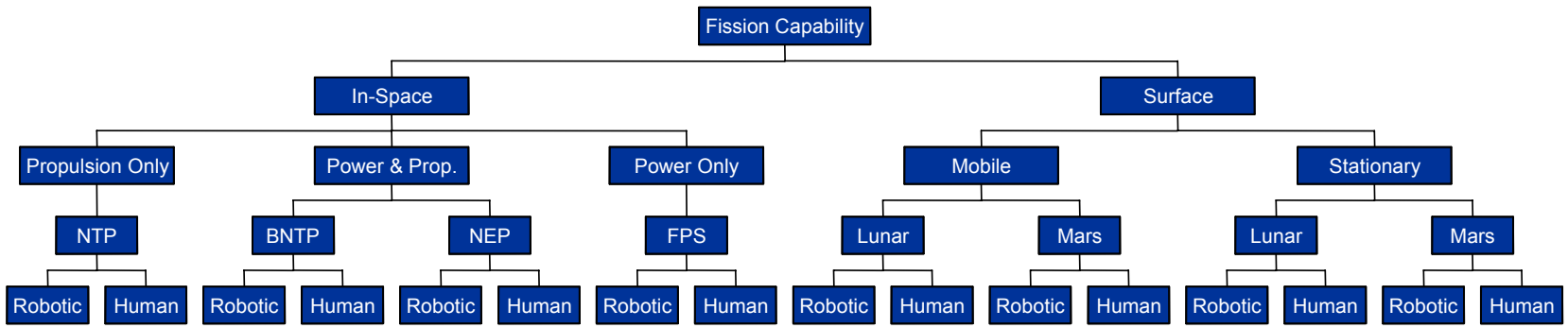
HEP & P Capability Roadmap Process and Approach - 2

- Each sub-team has been given the same set of initial requirements from which more detailed requirements will be determined
  - Lunar Roadmap Framework: Short Stay
  - Lunar Roadmap Framework: Long Stay
  - Lunar DRM TP2001
  - Lunar Robotic Science DRM
  - Mars Roadmap Framework
  - Mars FY03 NEP Architecture
  - Mars NASA SP2
  - Mars NASA SP-6107
  - Mars TP 2002
  - Mars Robotic Science DRM
  - Outer Solar System Science DRM

HEP & P Capability Roadmap Process and Approach

- Each sub- team is in the process of establishing the State-of-the-Art (SOA) or State-of-the-Practice (SOP) for their particular area (At the systems, subsystems, and technology level)
- Derived assumptions/requirements will be scrubbed as a total team
- Each sub-team, based upon derived assumptions/requirements, will lay out path for each capability/system and supporting technology development required to meet the NASA need (both in time as well as performance)
- This path will indicate major decision points and milestones
- Team is interacting/iterating with several other capability roadmap teams
- Team is interacting/iterating extensively with SRC-13

Fission Power and Propulsion Roadmap Will Focus On A Subset Of Possible System Architectures



Strategic Issues posed by CR-2 for SRC-13 Consideration

- Should continue to re-establish infrastructure (both NASA and DOE) for space nuclear systems – some strategic issues include
  - Long lead time for both fission and RPS systems technology development
  - Some current facilities critical for future nuclear development are being threatened with shut-down due to budget priorities
- Past and current studies have indicated enhancing/enabling benefits of nuclear systems for a variety of science/human exploration architectures
- Key criteria needed to establish the "business case" for applications of nuclear systems
- As current science/exploration requirements are defined, further systems studies would be performed comparing nuclear systems with other non-nuclear system options
- Scenarios (including prioritization) for strategic deployment of nuclear systems based upon evolving lunar and Mars strategic architectures
- Examine nuclear systems evolutionary paths (demonstrations, prototype missions) leading to enabling applications
- Examine opportunities and issues for international participation; foreign facilities

Backup

HEP & P Capability Roadmap Milestones to Date

• Team Formation	Oct04
• Initiate Weekly Team Telecons	Nov04
• APIO Workshop to Collect Ext. Input	Nov04
• 1st Team Meeting	Dec04
• Fission Sub-Team Meeting	Jan04
• Solar Sub-Team Meeting	Jan04
• Energy Storage Sub-Team Meeting	Jan04
• 2nd Team Meeting	Feb04

Key Dates Upcoming

- Roll-up of sub-team Capability Roadmaps, late February
- 1st Draft of Capability Roadmap To Academy (Presentation Product Due) March 31

HEP & P Sub-Teams and Members

- **High Energy Storage**
  - Surampudi (L)
    - Davis
    - Brandhorst
    - Bennett
    - Schmidt
- **Solar**
  - Brandhorst (L)
    - Davis
    - Surampudi
    - Byers
    - Gilland
    - George
    - Schmidt
- **Advanced Concepts**
  - Brandhorst (L)
    - Byers
    - Gilland
- **Nuclear – Wheeler (L)**
  - **Nuclear Fission**
    - Greene (L)
      - Wheeler
      - Borowski
      - George
      - Schmidt
      - Bennett
      - Byers
      - Gilland
      - Hughes
      - Batacharyyia
      - Bordelon
  - **RPS**
    - Wiley (L)
      - Surampudi
      - Schmidt
      - Bennett
      - Byers
      - Gilland
      - Hughes
      - Davis

HEP & P Application Areas

- Robotic-Science Spacecraft Power
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  - Mobile
- Human Exploration Propulsion (and On-Board Power)
  - Piloted
  - Cargo

Nuclear Thermal Propulsion Systems Breakdown Structure

- Nuclear Fission Reactors
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion (For Bi-Modal options)
- Fuel Tanks (Addressing materials considerations unique to nuclear radiation environment)
- Pumps (Addressing technology issues related to long run times and nuclear radiation environment)
- Nozzles (Addressing technology issues related to long run times and nuclear radiation environment)
- Guidance and Navigation (From In-Space Transportation team)
- Avionics (Addressing unique nuclear requirements)
- Vehicle Health Management (Addressing unique nuclear requirements)

Nuclear Electric Propulsion Systems Breakdown Structure

- Nuclear Fission Reactor
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection Systems
  - Materials
  - Structure
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling
- Electric Propulsion Subsystem
  - Thrusters
  - Power Processing Units
  - Tankage and propellant feed system
- Guidance and Navigation (In Conjunction with In-Space Transportation Team)
- Avionics (Address unique nuclear requirements)
- Vehicle Health Management (Address unique nuclear requirements)

Photovoltaic Power Systems Breakdown Structure

- Photovoltaic arrays
  - Solar cells
  - Concentrator concepts
  - Array blankets
  - Array structures
- Energy Storage
  - Batteries
  - Regenerative fuel cells
    - Electrolyzers
    - Fuel Cells
    - H2 – O2 tanks
  - Flywheel
- Power Management and Distribution
  - DC-DC converters
  - Cabling
  - Charge/Discharge control
  - Shunt regulator

Nuclear Fission Power Systems Breakdown Structure

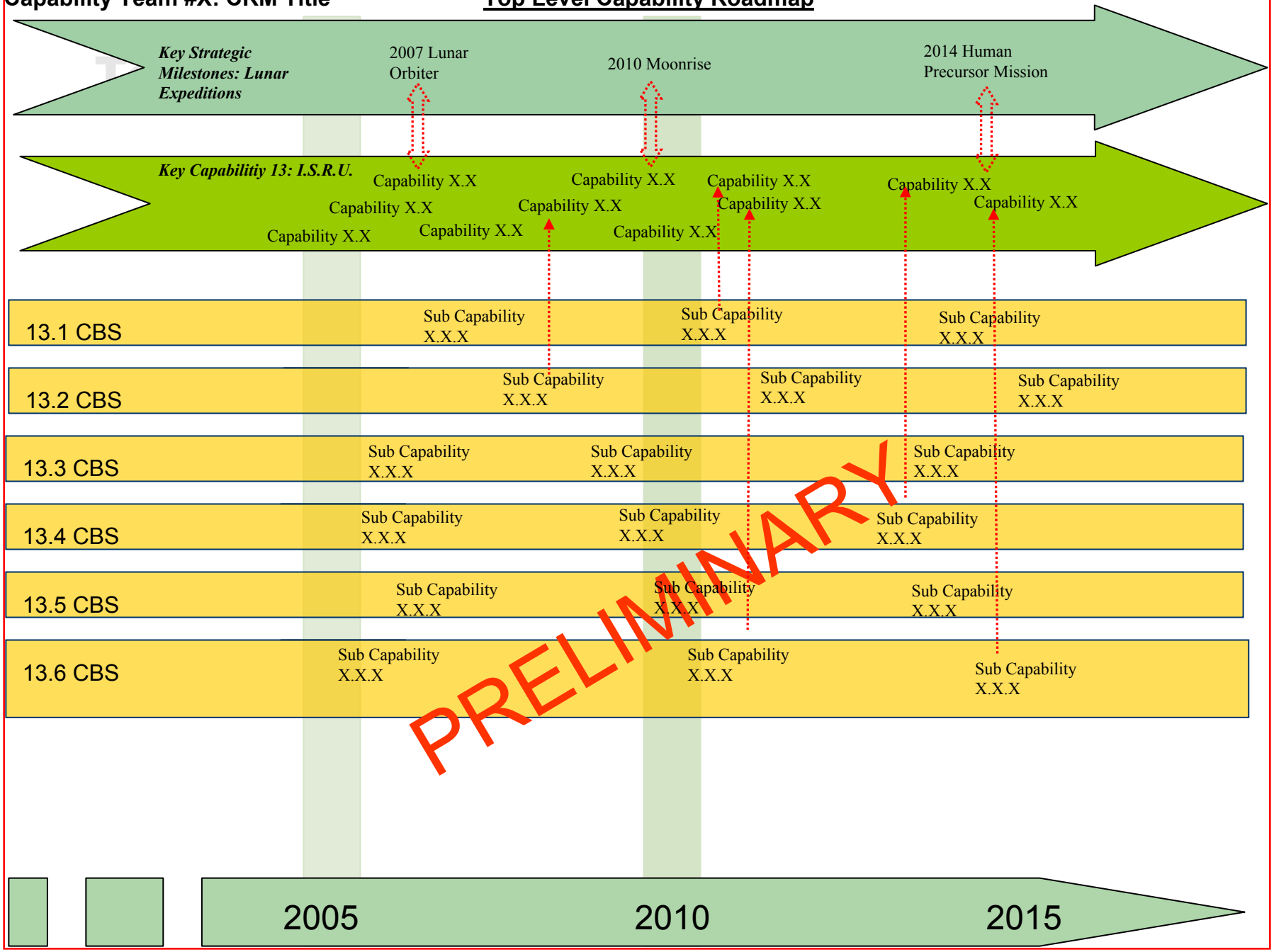
- Nuclear Fission Reactor
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection Systems
  - Materials
  - Structure
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling

Radioisotope Electric Propulsion Systems Breakdown Structure

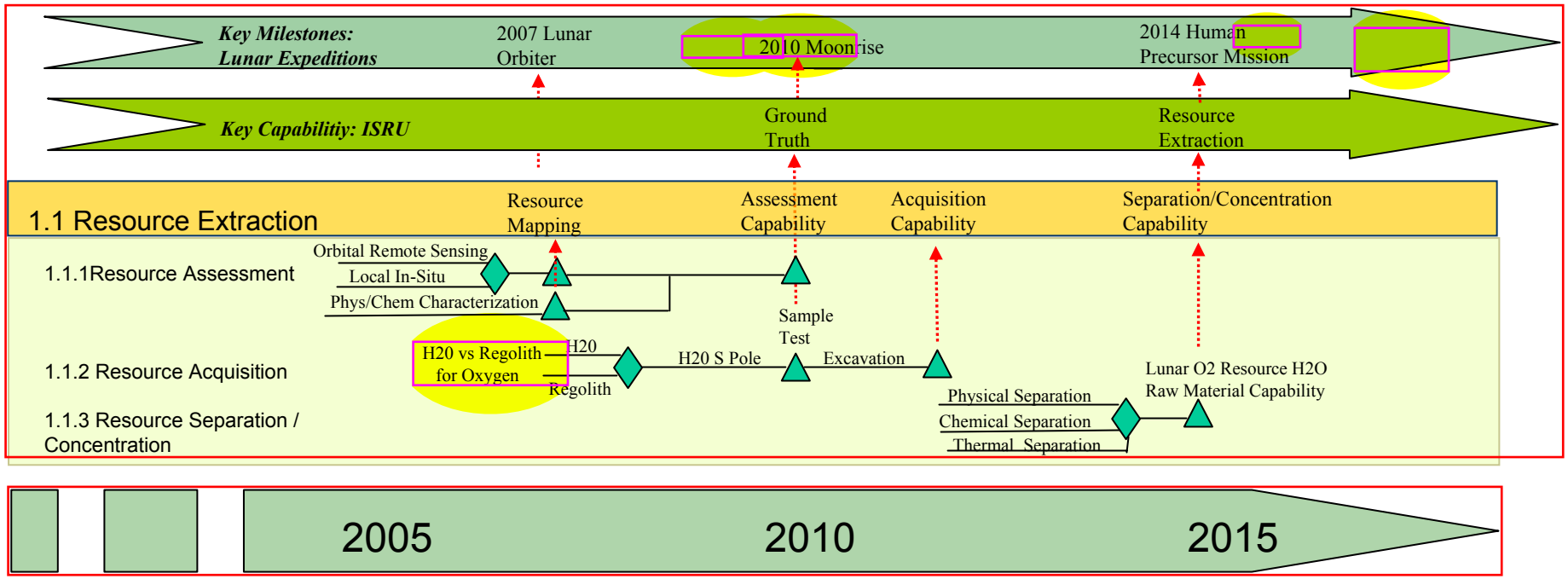
- GPHS Modules
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection System/Housing
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling
- Electric Propulsion Subsystem
  - Thrusters
  - Power Processing Units
  - Tankage and propellant feed system
- Guidance and Navigation (In conjunction with In-Space Transportation Team)
- Avionics (Address unique nuclear requirements)
- Vehicle Health Management (Address unique nuclear requirements)

Capability Team #X: CRM Title

Top Level Capability Roadmap



Sub-Capability 1.1, CBS Title Roadmap

Advanced Planning & Integration Office

DRAFT EXAMPLE CAPABILITY DECISION ROADMAP