



Advanced Space Exploration

Top 10 Technologies for Reusable Cislunar Transportation

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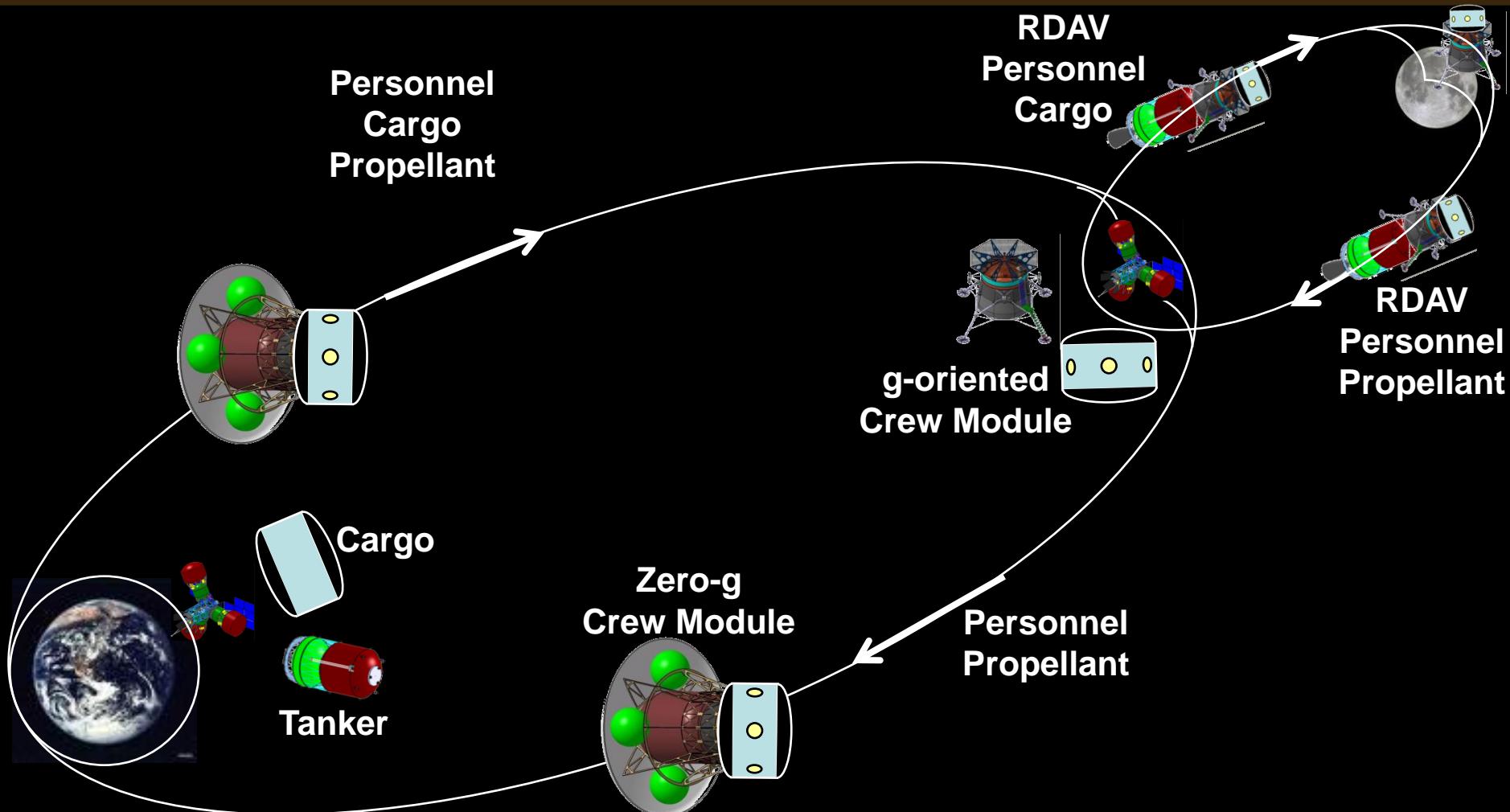
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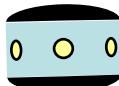
Top 10 Technologies for Reusable Cislunar Transportation

- A Reusable Cislunar Transportation Architecture
- Top 10 Technologies
- Technology and Cislunar Transportation Timeline
- NASA Budget Funding
- Technology Impact

A Depot-Enabled Reusable Cislunar Architecture



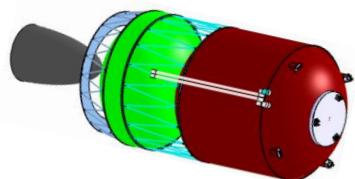
Systems Comprising a Depot-Enabled Reusable Cislunar Architecture



Personnel Modules
0-g and g-oriented

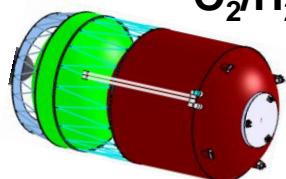


**ETO
Propellant Carrier**

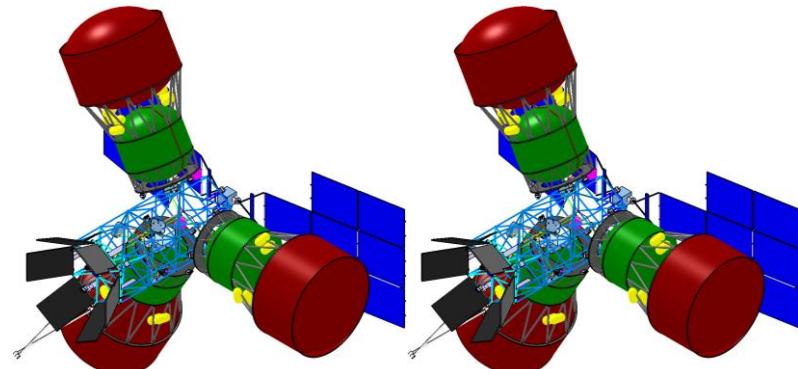


Reusable Circumlunar Transfer Vehicle
EML1 to Perilune delivery

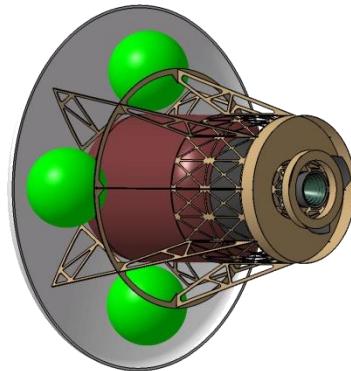
O_2/H_2



Propellant Tanker



Modular Propellant Depots



Reusable Aerocapture Transfer Vehicle
GTO and/or GEO delivery

O_2/H_2



**Reusable Descent
Ascent Vehicle**
Perilune to Surface

O_2/H_2

Top 10 Technologies for Reusable Cislunar Transportation

Top 10 Technologies for Reusable Cislunar Transportation

10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

- 9. Low-g and zero-g O₂/H₂ liquefaction.**
- 10. Variable mixture ratio O₂/H₂ Space rocket engine.**

Top 10 Technologies for Reusable Cislunar Transportation

8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

5. Long-life reusable O₂/H₂ Space rocket engine.
6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

4. Aero-assisted entry, descent, and landing (AEDL).
5. Long-life reusable O₂/H₂ Space rocket engine.
6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

3. Long-term zero-g cryogenic storage.
4. Aero-assisted entry, descent, and landing (AEDL).
5. Long-life reusable O₂/H₂ Space rocket engine.
6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

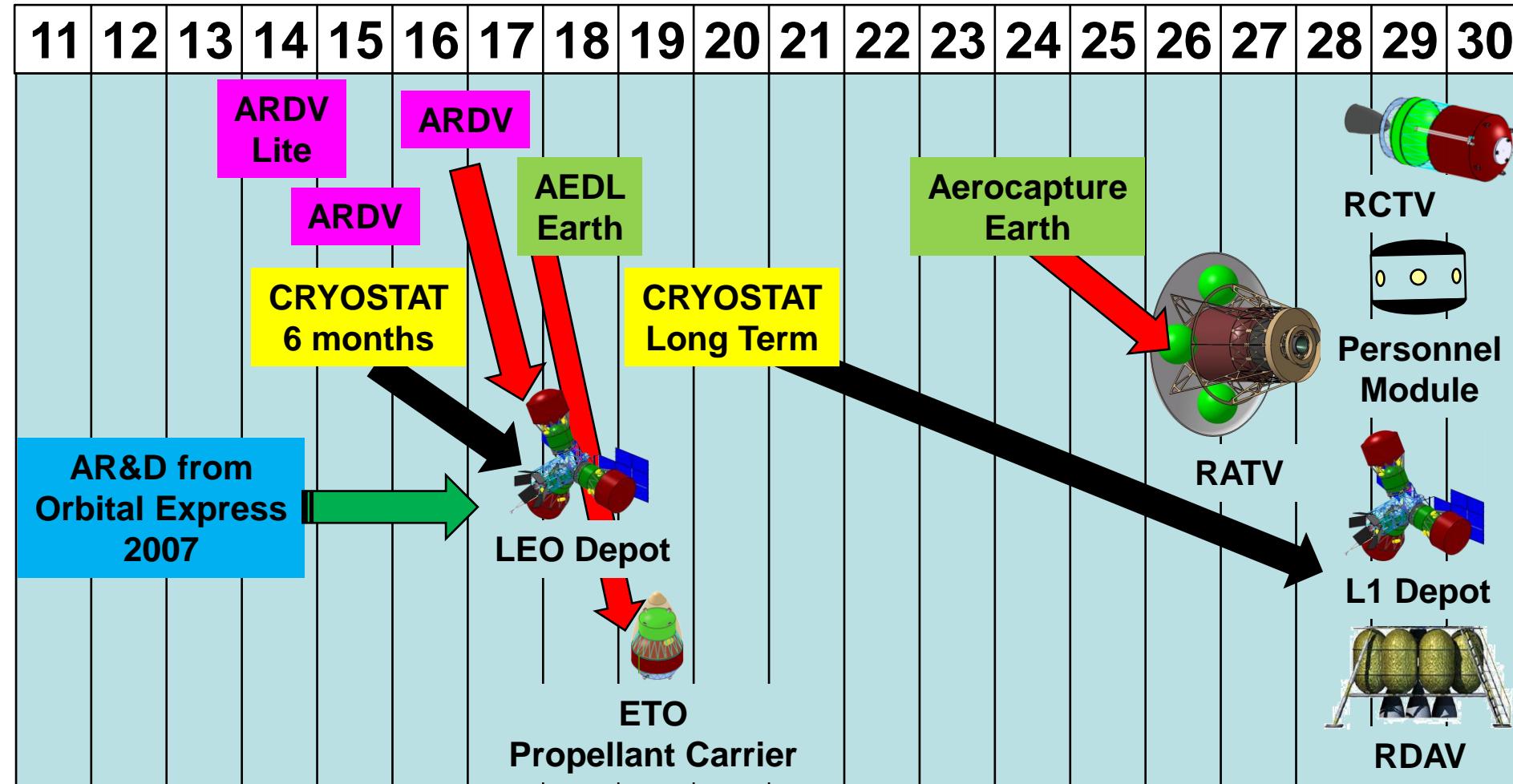
Top 10 Technologies for Reusable Cislunar Transportation

2. Zero-g cryogenic fluid transfer (CFT).
3. Long-term zero-g cryogenic storage.
4. Aero-assisted entry, descent, and landing (AEDL).
5. Long-life reusable O₂/H₂ Space rocket engine.
6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

Top 10 Technologies for Reusable Cislunar Transportation

1. Zero-g cryogenic fluid management (CFM).
2. Zero-g cryogenic fluid transfer (CFT).
3. Long-term zero-g cryogenic storage.
4. Aero-assisted entry, descent, and landing (AEDL).
5. Long-life reusable O₂/H₂ Space rocket engine.
6. Aerocapture.
7. Deep Space autonomous rendezvous and docking (AR&D).
8. Low-g water electrolysis.
9. Low-g and zero-g O₂/H₂ liquefaction.
10. Variable mixture ratio O₂/H₂ Space rocket engine.

NASA FTDs Support Some Reusable Cislunar Architecture Needs But Schedule Too Long



Top 10 Technologies Not Covered by NASA FTDs

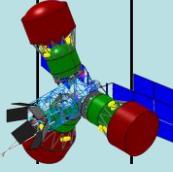
5. Long-life reusable O₂/H₂ Space rocket engine.
7. Deep Space autonomous rendezvous and docking (AR&D).
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10. Variable mixture ratio O₂/H₂ Space rocket engine.

Needed Technologies Defined

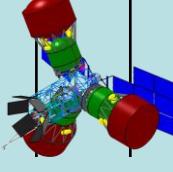
- **Long-life reusable O₂/H₂ Space rocket engine**
 - Unlimited starts
 - Multi-year operations
- **Deep Space autonomous rendezvous and docking (AR&D)**
 - Locate and rendezvous without GPS
- **Low-g water electrolysis**
 - Water dissociation into O₂ and H₂ in 1/6 and 1/3 g fields
- **Low-g and zero-g O₂/H₂ liquefaction**
 - Liquefy gasses in 1/6 and 1/3 g fields
- **Variable mixture ratio O₂/H₂ Space rocket engine**
 - Operate at mixture ratios between 5 and 11

Technology Needs Driven by Timely Cislunar Transportation

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30



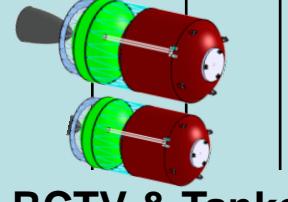
LEO Depot



L1 Depot



LEO Depot
Tanker



RCTV & Tanker



RDAV



Personnel
Module

- Needed Now
 - Zero-g Cryo fluid management
 - Zero-g cryo transfer
 - Zero-g cryo storage
- 2012
 - AEDL
- 2013
 - Aerocapture
 - Long-life O₂/H₂ Space engines
- 2014
 - Deep Space AR&D
- 2019
 - Low & zero-g electrolysis
 - Low & zero-g O₂/H₂ liquefaction
 - Variable MR O₂/H₂ Space engines

NASA Budget for Technology Maturation

● S.3729 NASA Authorization Act of 2010

- Title I – Authorization of Appropriations

- Sec 101 FY 2011 (1) (C) \$250,000,000 for Exploration Technology Development
- Sec 102 FY 2012 (1) (C) \$437,300,000 for Exploration Technology Development
- Sec 103 FY 2013 (1) (C) \$449,000,000 for Exploration Technology Development

- Title III – Expansion of Human Space Flight Beyond the ISS and LEO

- Sec. 308 – Development of Technologies and robotic elements for human space flight and exploration
 - (a) (2) In-space capabilities...refueling and storage...orbital transfer stages...
 - (b) (1) In-space technologies...propellant depots, in situ resource utilization...
 - (b) (2) In-space transfer vehicle...
 - (b) (4) in technologies and capabilities relating to...propulsion...
 - (b) (6) in technologies and capabilities relating to...in situ resource utilization...
 - (c) Utilization of ISS as Testbed

Top 10 Technologies Impact on Space Development

1 – 3 Zero-g cryo fluid management, storage, & transfer

- 2 – 3 times current HEO and Deep Space mission capability
- Enables reusable Space transportation systems
- Enables cryogenic propellant depots

4 AEDL

- Enhances reusable ETO propellant tankers

5 Long-life O₂/H₂ Space rocket engines

- Enables operationally efficient reusable Space transfer vehicles

6 Aerocapture

- ~7 t less propellant for 25 t cargo on LEO-EML1-LEO leg
- ~21 t less propellant for 5 t crew module on LEO-EML1-LEO leg
- ~1 t RATV stage inert mass increase

Top 10 Technologies Impact on Space Development

7 Deep Space AR&D

- Enables EML1 depot assembly and operations
- Enables lander and transfer stage mating

8 & 9 Low-g and zero-g water electrolysis & liquefaction

- Enables lunar propellant use for lander departure
- Enables water transport from Moon to EML1 and LEO depots
- ~16 t less propellant for 25 t cargo to Moon
- ~25 t less propellant for 5 t crew module to/from Moon

10 Variable mixture ratio O₂/H₂ Space rocket engine

- Enables full use of water-derived O₂/H₂ propellants

Top 10 Technologies for Reusable Cislunar Transportation...

- Provide 2-3x capability mission capability with full current systems in LEO
- Enable reusable Space transportation systems
- Enhance reusable Space systems operational efficiency
 - Aerobrake saves up to 21 t propellant for return to Earth orbit
 - Moon propellant saves up to 25 t propellant for lander & RCTV
- Enable O₂/H₂ propellant production from Moon water