From Importing to Exporting:

The Impact of ISRU on Space Logistics

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Dallas Bienhoff
In-Space & Surface Systems
The Boeing Company
703-872-4004; 571-232-4554
Dallas.g.bienhoff@boeing.com
From Importing to Exporting: The Impact of ISRU on Space Logistics

- Lunar Development Plans
- Cislunar Transportation Architectures
- Impact on Outpost Consumables and Surface Payloads
- ETO Mass to Support Reference Mission Model
- Propellant Exports
- Architecture Comparative Assessment
- Reducing ISRU Production Requirements
Commercial Lunar Development Plans

- Bigelow Lunar Base
- Follows LEO Complex
- Lease to national agencies
- 12 – 18 person occupancy
- Next decade

- Shackleton Energy Company
- 12 – 18 person crew
- One-way deploy mission
- Water export for propellant
- 7 years after funding received
Reference Mission Model for Outpost Support

- Outpost is near accessible water ice deposits
- Outpost is permanently and continuously occupied
- 4-18 person Outpost population
- 2 personnel rotation missions per year
- 2 cargo deliveries per year
- 25 year scenario for comparison
- Depot and ISRU IOC in year 11
Constellation Provides Comparative Benchmark

- Two 4-person crew missions with limited cargo
- Two 20.9 t cargo missions
- Years 1 - 10

- LEO Depot added in year 11
- Two 4-person crew & 35 t cargo missions
- Years 11- 25
Reusable Cislunar Transportation Architecture for Earth and Moon Propellants

- Two 4-person crew missions and two 25 t cargo missions

OR

- Two 4-person crew & 17 t cargo

- Years 1 - 10

- ISRU use begins in year 11

- Two 4-person crew & 25 t cargo missions

- Years 11 - 25
# RCTA Systems Sized to Deliver 25 t to Surface

<table>
<thead>
<tr>
<th>System</th>
<th>Inert Mass (kg)</th>
<th>Propellant Capacity (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reusable Aerocapture Transfer Vehicle</td>
<td>6,665</td>
<td>46,177</td>
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<tr>
<td>Reusable Circumlunar Transfer Vehicle</td>
<td>3,301</td>
<td>18,706</td>
</tr>
<tr>
<td>Reusable Lunar Lander</td>
<td>12,479</td>
<td>49,917</td>
</tr>
<tr>
<td>Propellant Depots</td>
<td>20,000</td>
<td>81,600</td>
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<tr>
<td>Propellant Tank Module</td>
<td>3,000</td>
<td>22,000</td>
</tr>
<tr>
<td>Reusable Propellant Carrier</td>
<td>6,400</td>
<td>25,600</td>
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</tbody>
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- **RATV** (LEO to EML1 to LEO)
  - 25 t to EML1; 5 to LEO

- **RLL**
  - 25 t circumlunar to Moon; 0 Moon to circumlunar

- **RCTV**
  - 86 t EML1 departure with 12 t upon EML1 arrival
Water and Oxygen Can Be Eliminated From Earth-Supplied Consumables with ISRU

MFHE Life Support Consumables (kg):
- Water: 1540 kg
- Oxygen: 395 kg
- Nitrogen: 259 kg
- Dry Food: 795 kg

Life Support Consumables For Outpost with ISRU (kg):
- Wet Food: 2518 kg
- Dry Food: 291 kg
- Oxygen by water electrolysis Capture excess hydrogen

Dry food to wet/dry mix
ISRU Replenishes Hygiene and Cleansing Water
Lost in Recycling Process

- 90% water recycled
- 90% airlock recovered
- 50% US use assumed
  - Hygiene
  - Clothes
  - Dishes
- Egress approach drives range
  - Lower – All suitlock
  - Upper – All airlock
ISRU Maximizes Supportable Population and Surface Payloads for Fixed Cargo Capacity

### Maximum Populations

- **Constellation**
  - 19 – 25 no ISRU
  - 52 – 58 w ISRU

- **Constellation w Depot**
  - 33 – 43 no ISRU
  - 91 – 100 w ISRU

- **RCTA-A**
  - 23 – 30 no ISRU

- **RCTA-B**
  - 12 – 20 no ISRU

- **RCTA**
  - 63 – 70 w ISRU
Without LEO depot
- 757 t/yr to LEO
- 70% propellant
- 24.5% flt HW
- 5.5% cargo

With LEO Depot
- 773 t/yr to LEO
- 75% propellant
- 16% new flt HW
- 9% cargo
RCTA-A ETO Mass Through Year 10
55% Greater than Constellation

- All Earth Propellant
  - 1177 t/yr to LEO
  - 92% propellant
  - 4.4% flt HW
  - 4.2% cargo

- All Moon Propellant
  - 87 t/yr avg to LEO
  - 0% propellant
  - 42% new flt HW
  - 58% cargo
  - 2588 t/yr ISRU water
RCTA-A ETO Mass Through Year 10
5% Greater than Constellation

- All Earth Propellant
  - 788 t/yr to LEO
  - 91% propellant
  - 4.3% flt HW
  - 4.3% cargo

- All Moon Propellant
  - 87 t/yr avg to LEO
  - 0% propellant
  - 42% new flt HW
  - 58% cargo
  - 2588 t/yr ISRU water
Propellant to Move Propellant Plus Loss Rate Exceeds Support Missions Propellant

- All Earth-A Propellant
  - 34% support missions
  - 21% propellant moved
  - 22% propellant to move
  - 23% loss
  - 138% ISRU water

- All Earth-B Propellant
  - 31% support missions
  - 21% propellant moved
  - 26% propellant to move
  - 23% loss

- All Moon Propellant
  - 12% support missions
  - 61% propellant moved
  - 12% propellant to move
  - 14% loss
  - 138% ISRU water

ISRU water = 220% All Earth-A prop = 361% All Earth-B prop
ISRU for RLL Only (Min and Max) are Most Propellant Efficient RCTA ConOps

- All Earth-A: 222%
- All Earth-B: 135%
- RLL Min: 103%
- RLL Max: 103%
- L1 Prop: 196%
- All Moon: 352%
ISRU Greatly Reduces ETO and Hardware Mass

- RCTA-A
  - Hardware: 25.7%
  - ETO: 81.0%

- RCTA-B
  - Hardware: 22.1%
  - ETO: 60.7%
Stoichiometric Rocket Engines in RCTA Minimizes ISRU Production Requirement

- 38% LLOx by-product eliminated
- Precludes water transport with depot propellant production
- Maximizes loss rate as all transfers are cryogenic

<table>
<thead>
<tr>
<th>Mixture Ratio (O:H)</th>
<th>Propellant</th>
<th>LOx Byproduct</th>
<th>LH Byproduct</th>
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<tbody>
<tr>
<td>5.5</td>
<td>0.38</td>
<td></td>
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</tr>
<tr>
<td>6.0</td>
<td>0.29</td>
<td></td>
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</tr>
<tr>
<td>8.0</td>
<td></td>
<td></td>
<td>0.038</td>
</tr>
<tr>
<td>12.0</td>
<td></td>
<td></td>
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Normalized ISRU Production
10 & 20 t of ISRU Water Required per t Exported to L1 & LEO with 5.5 MR; 6 t & 9 t with 8.0 MR

Export to L1
5.5 MR; 10% Loss
LOx/LH Transfer
10% net export (11 t)

35% less ISRU Water

Export to L1
8.0 MR; 1% Loss
Water Transfer
17% net export (12.5 t)

Export to LEO
5.5 MR; 10% Loss
LOx/LH Transfer
5% net export (41 t)

44% less ISRU Water

Export to LEO
8.0 MR; 1% Loss
Water Transfer
11% net export (49 t)
26-34% Reduction in ISRU Production Possible

- Total Propellant Needs
  - 20-22% less propellant if MR = 8.0 vs 5.5
  - 34-41% less propellant if MR = 8.0 with water transport and 1% loss rate

- Lunar Water Production
  - 26% less if MR = 8.0, water transport, and 10% loss rate
  - 34% less if MR = 8.0, water transport, and 1% loss rate
ISRU Impact on Lunar Outpost Logistics

- 90% reduction in ETO requirement wrt Constellation
- >50% reduction in new hardware wrt Constellation
- 2 – 6 times maximum population with ISRU
- 10% and 5% ISRU water exported to L1 and LEO
- ISRU Water ~2.2 x Earth propellant for 5.5 MR RCTA
- 34% ISRU reduction if 8:1 MR, water transport, and 1% loss rate