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Advanced Space Exploration

From Importing to Exporting:

The Impact of ISRU on Space Logistics

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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

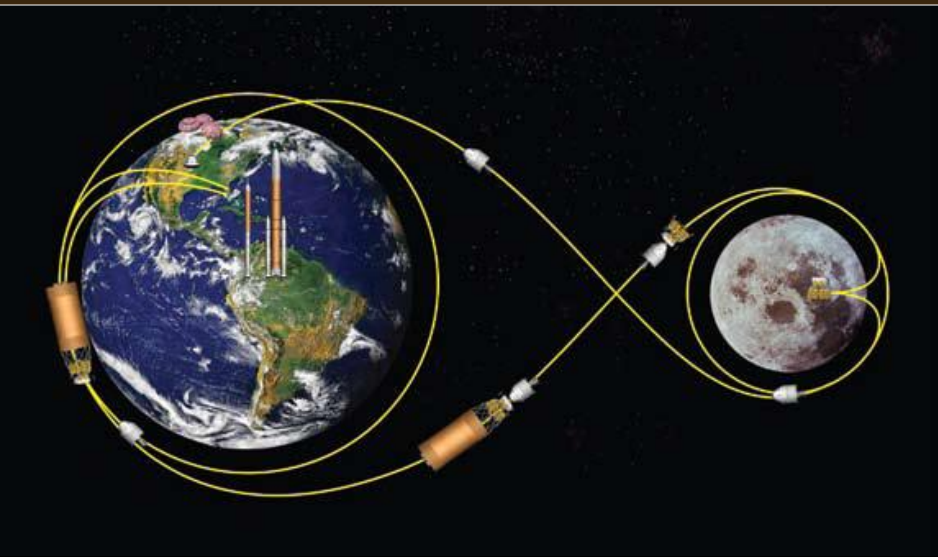
- **Bigelow Lunar Base**
- **Follows LEO Complex**
- **Lease to national agencies**
- **12 – 18 person occupancy**
- **Next decade**

- **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

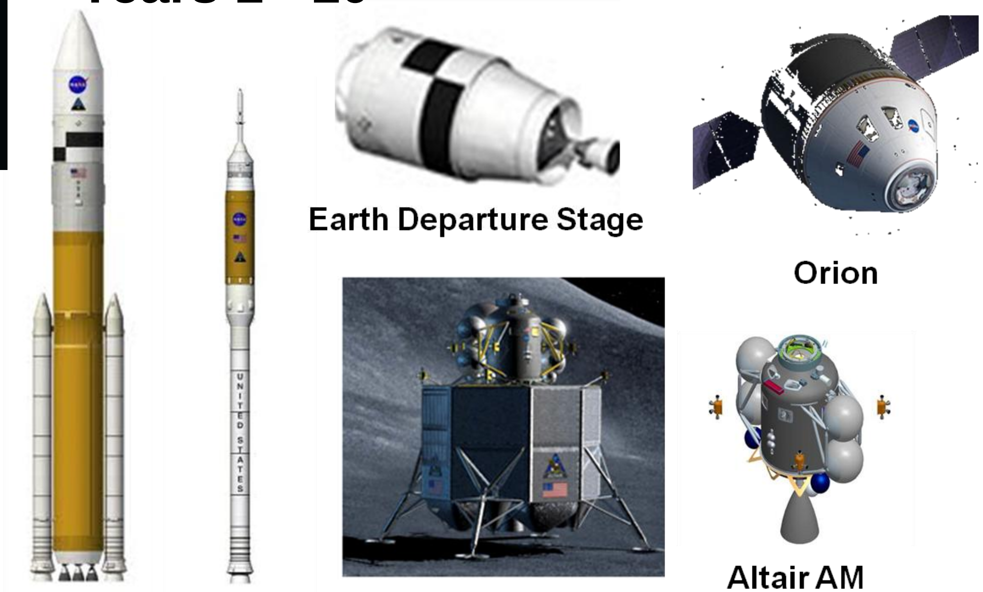
- Outpost is near accessible water ice deposits
- Outpost is permanently and continuously occupied
- 4-18 person Outpost population
- 2 personnel rotation missions per year
- 2 cargo deliveries per year
- 25 year scenario for comparison
- Depot and ISRU IOC in year 11

Constellation Provides Comparative Benchmark



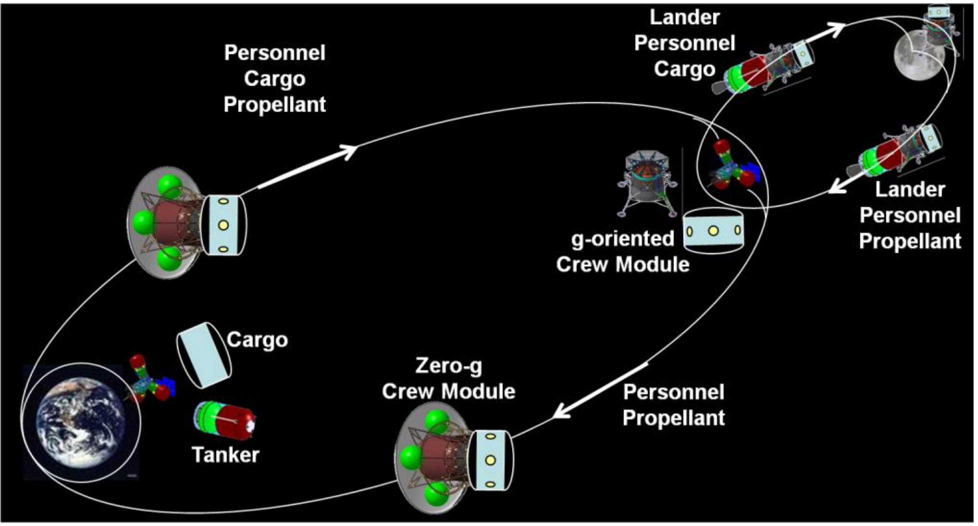
- LEO Depot added in year 11
- Two 4-person crew & 35 t cargo missions
- Years 11- 25

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



Ares V, Ares I, Earth Departure Stage, Orion, Altair, Altair AM

Reusable Cislunar Transportation Architecture for Earth and Moon Propellants

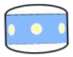


- **Two 4-person crew missions and two 25 t cargo missions**

OR

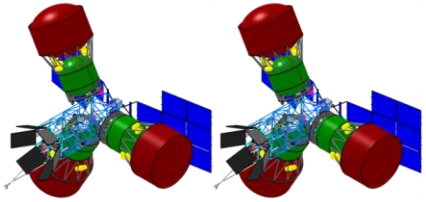
- **Two 4-person crew & 17 t cargo**
- **Years 1 - 10**

- **ISRU use begins in year 11**
- **Two 4-person crew & 25 t cargo missions**
- **Years 11- 25**

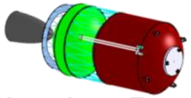


Personnel Modules
0-g and g-oriented

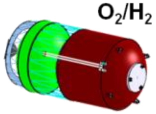
ETO
Reusable
Propellant Carrier



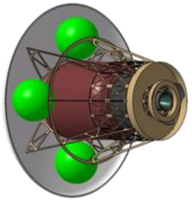
Modular Propellant Depots



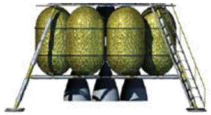
Reusable Circumlunar Transfer Vehicle
EML1 to Perilune delivery
O_2/H_2



Propellant Tank
Module

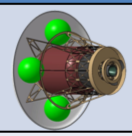
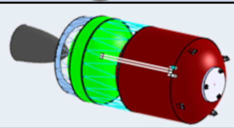
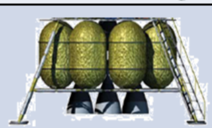
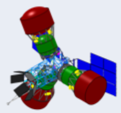
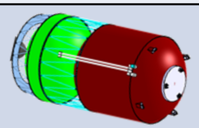
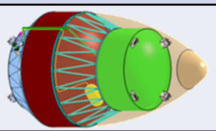


Reusable Aerocapture Transfer Vehicle
GTO and/or GEO delivery
O_2/H_2



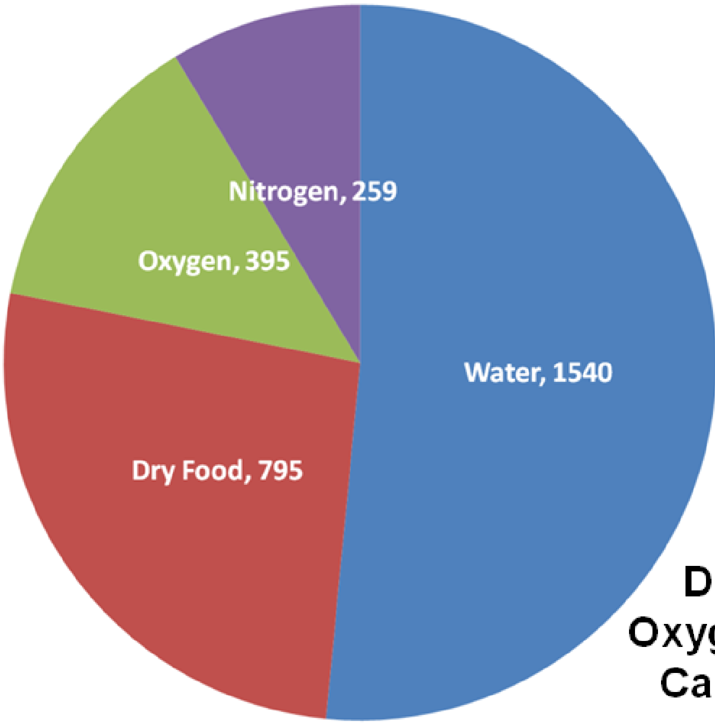
Reusable Lunar Lander
Perilune to Surface
O_2/H_2

RCTA Systems Sized to Deliver 25 t to Surface

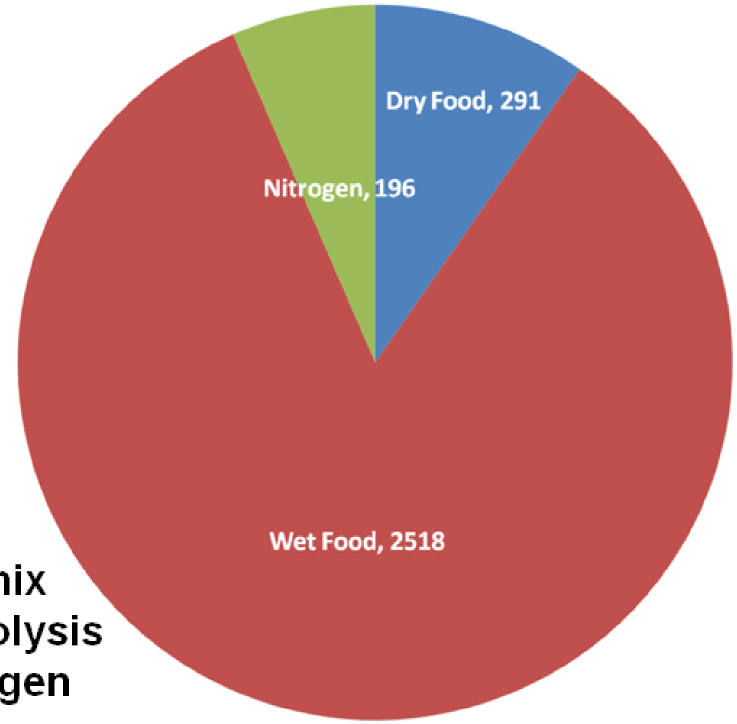
System		Inert Mass (kg)	Propellant Capacity (kg)
Reusable Aerocapture Transfer Vehicle		6,665	46,177
Reusable Circumlunar Transfer Vehicle		3,301	18,706
Reusable Lunar Lander		12,479	49,917
Propellant Depots		20,000	81,600
Propellant Tank Module		3,000	22,000
Reusable Propellant Carrier		6,400	25,600

- 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



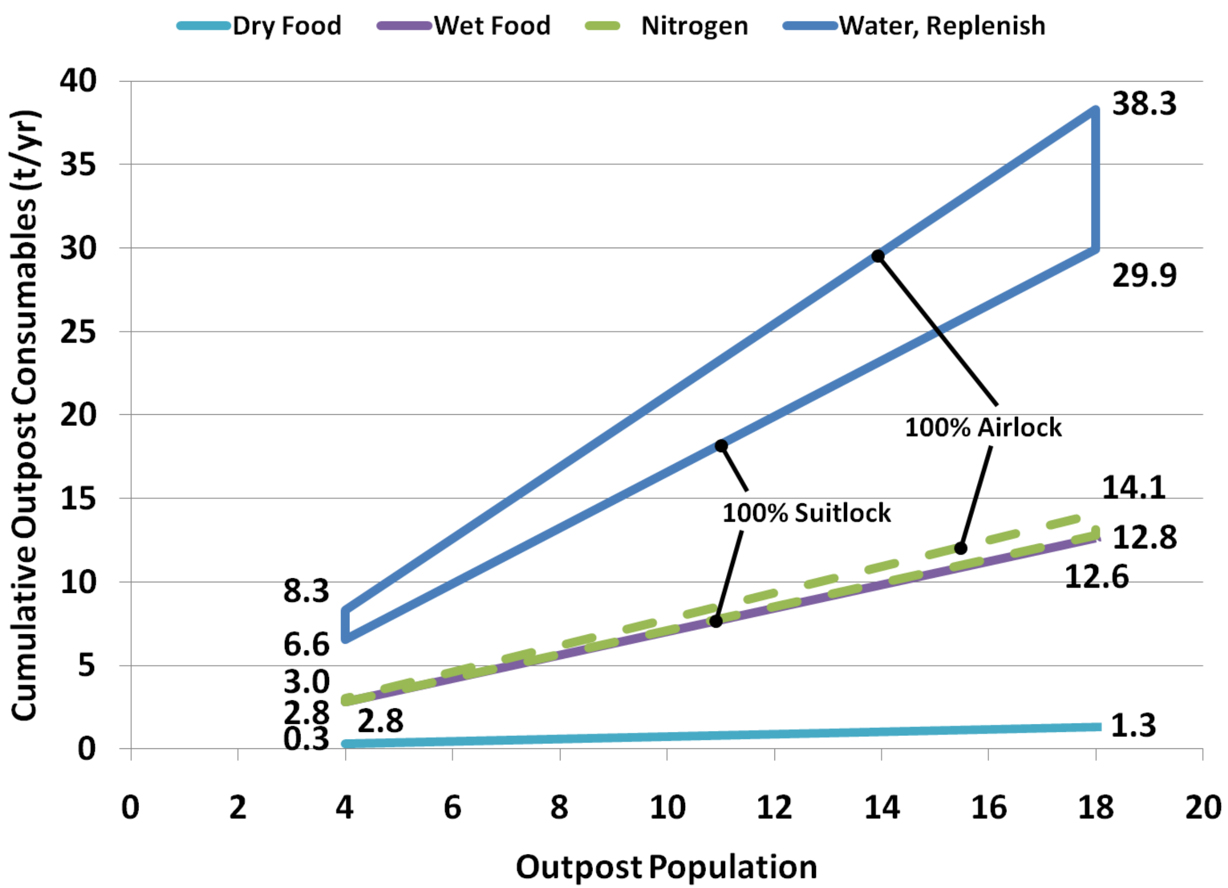
Dry food to wet/dry mix
Oxygen by water electrolysis
Capture excess hydrogen



MFHE Life Support Consumables (kg)

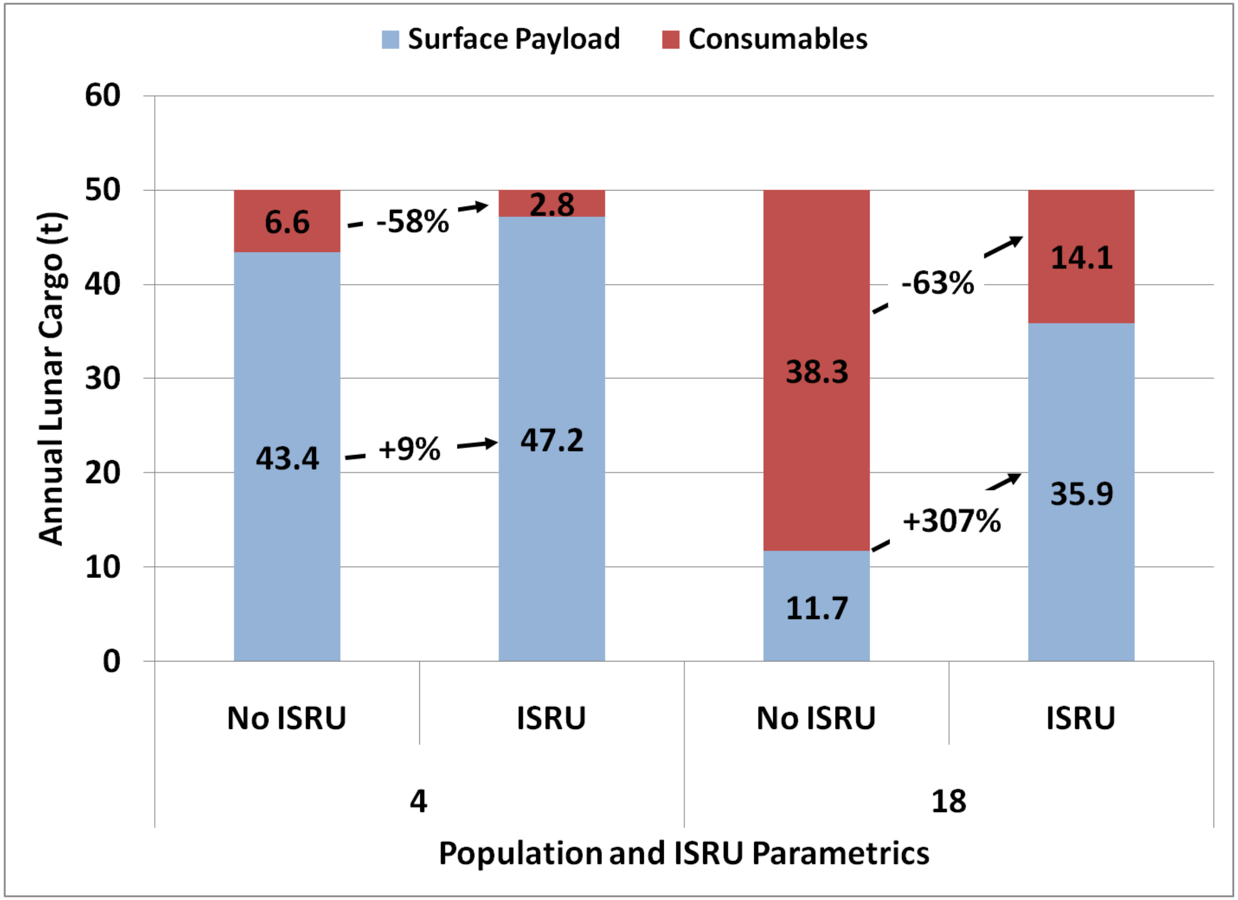
Life Support Consumables For Outpost with ISRU (kg)

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

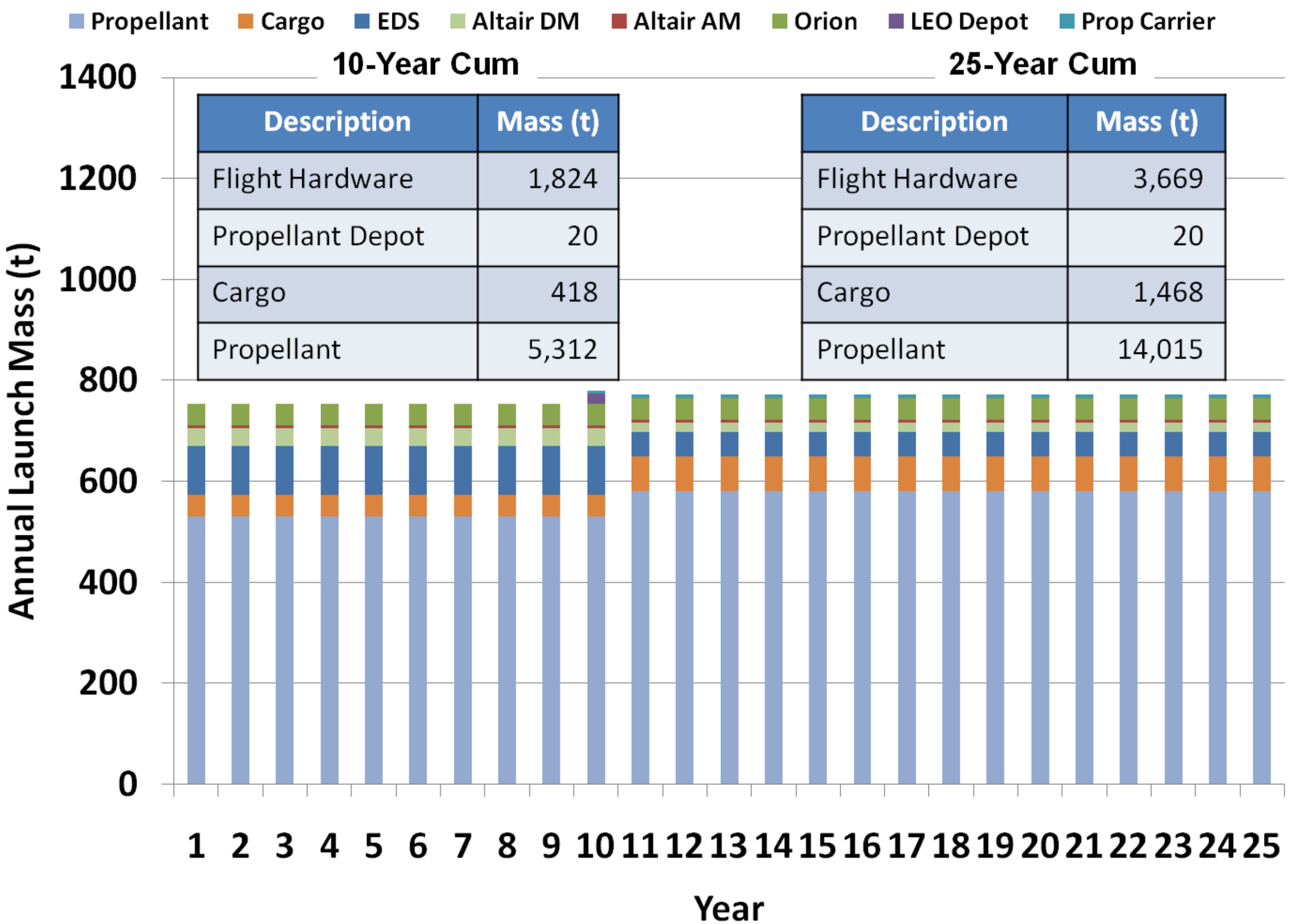
ISRU Maximizes Supportable Population and Surface Payloads for Fixed Cargo Capacity



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

Constellation with Depot IOC in Year 11 Sets Comparative Benchmark



10-Year Cum

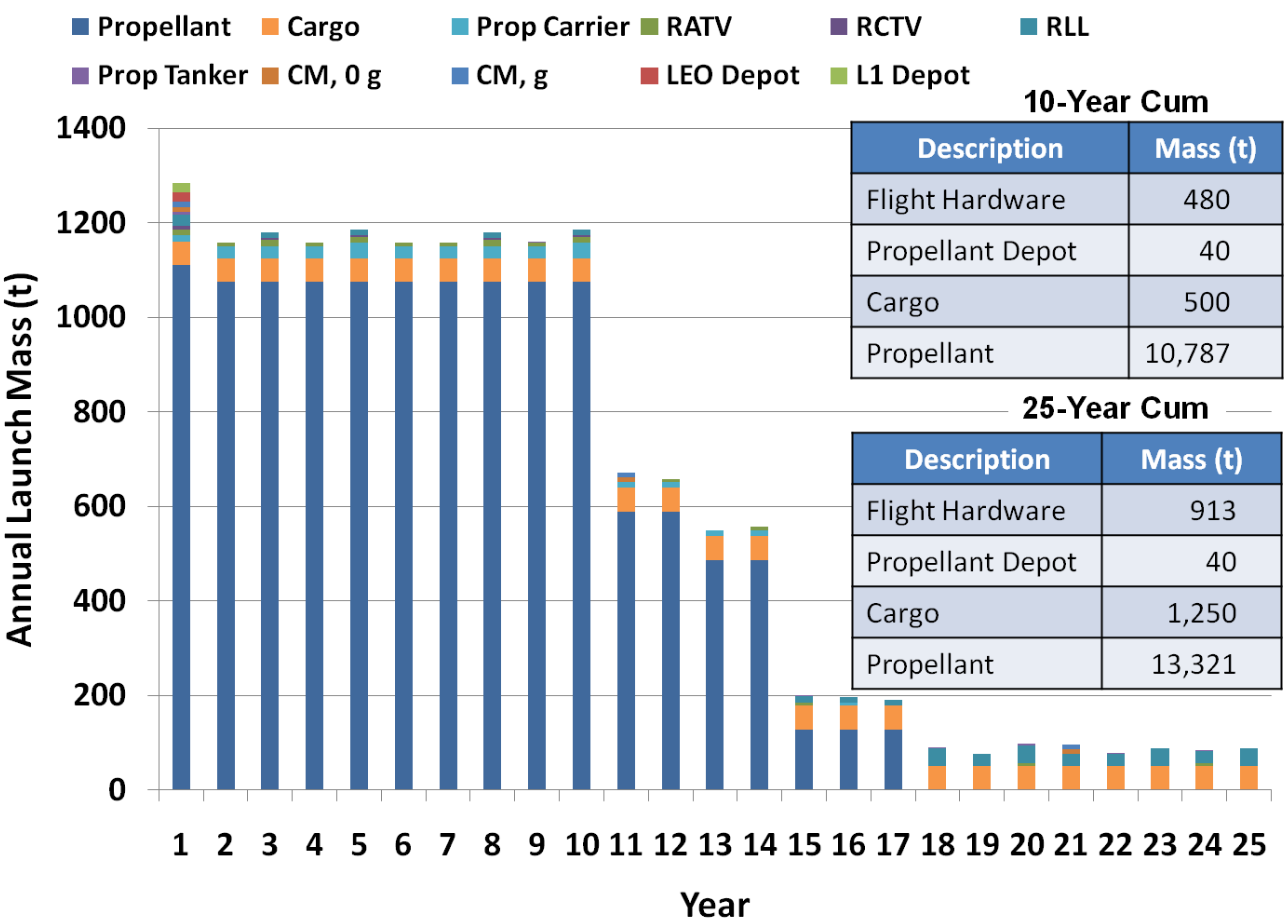
Description	Mass (t)
Flight Hardware	1,824
Propellant Depot	20
Cargo	418
Propellant	5,312

25-Year Cum

Description	Mass (t)
Flight Hardware	3,669
Propellant Depot	20
Cargo	1,468
Propellant	14,015

- **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



10-Year Cum

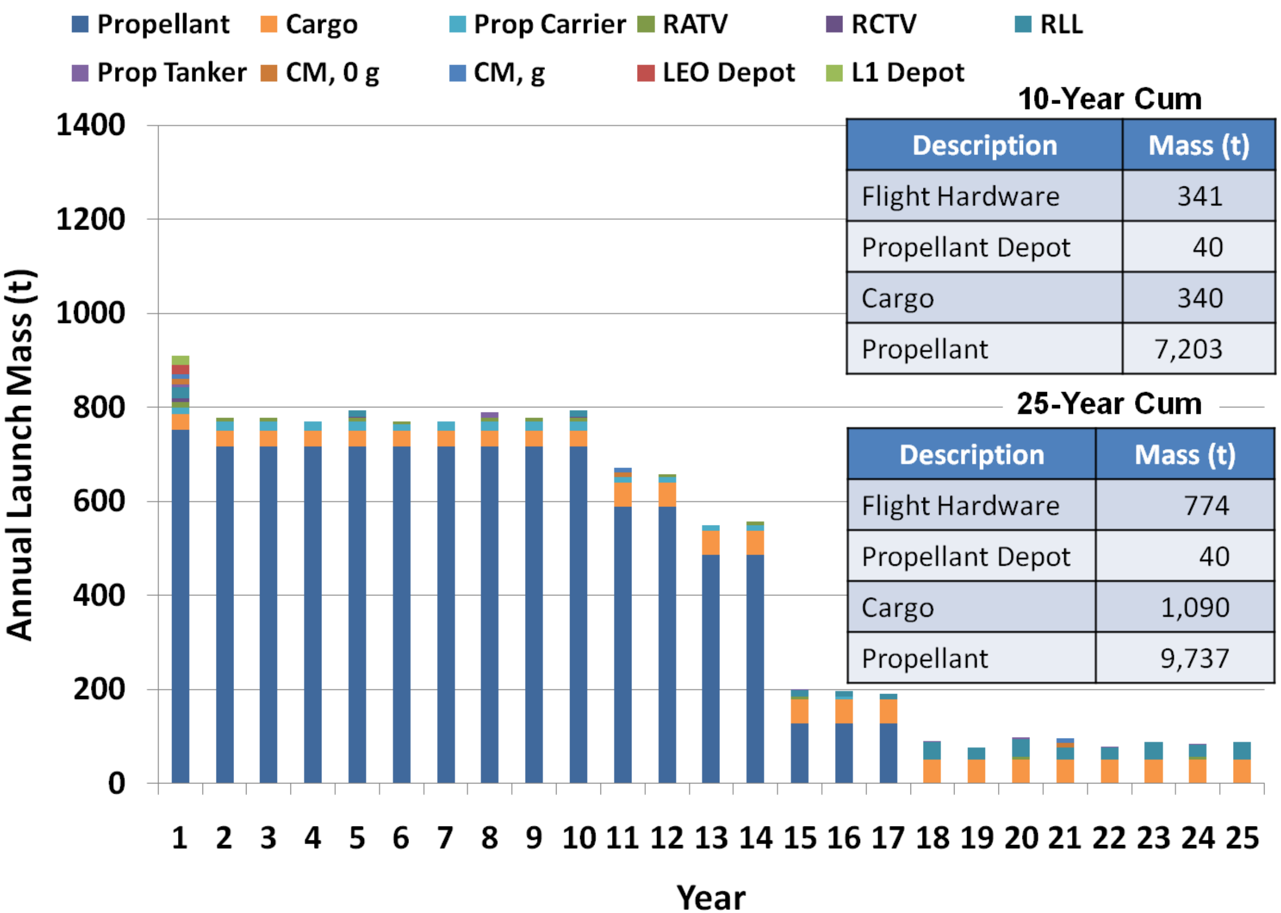
Description	Mass (t)
Flight Hardware	480
Propellant Depot	40
Cargo	500
Propellant	10,787

25-Year Cum

Description	Mass (t)
Flight Hardware	913
Propellant Depot	40
Cargo	1,250
Propellant	13,321

- **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



10-Year Cum

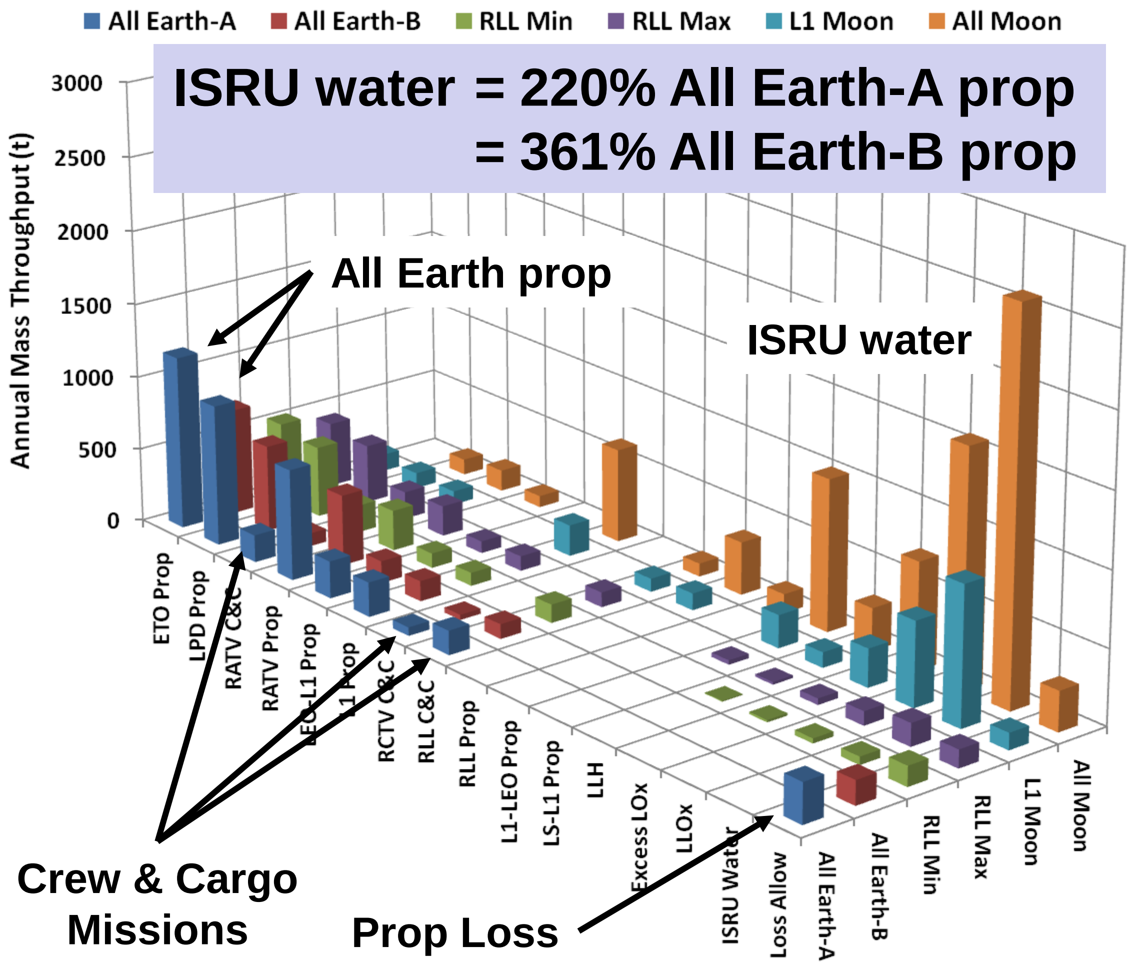
Description	Mass (t)
Flight Hardware	341
Propellant Depot	40
Cargo	340
Propellant	7,203

25-Year Cum

Description	Mass (t)
Flight Hardware	774
Propellant Depot	40
Cargo	1,090
Propellant	9,737

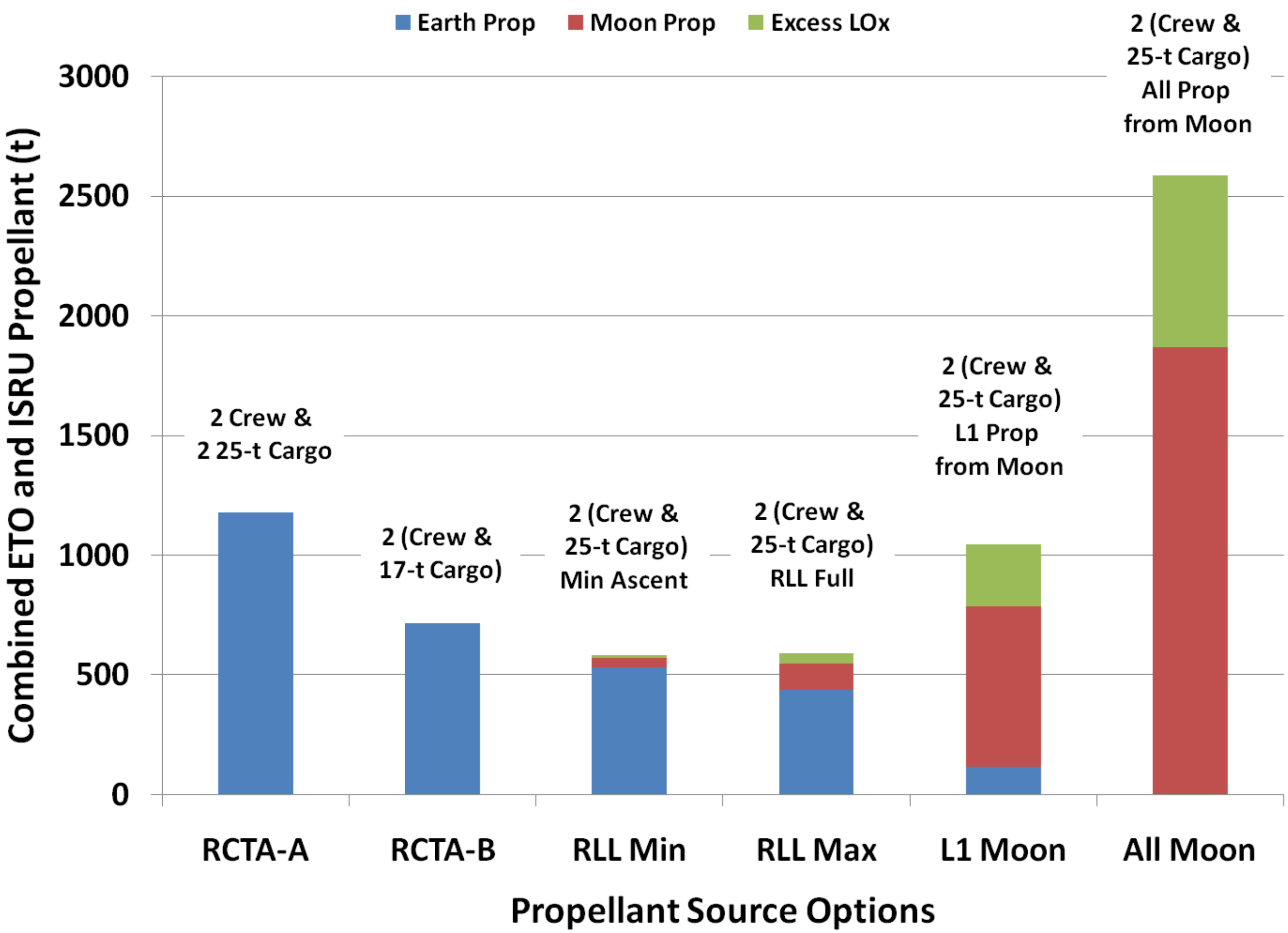
- **All Earth Propellant**
  - **788 t/yr to LEO**
  - **91% propellant**
  - **4.3% flt HW**
  - **4.3% cargo**
- **All Moon Propellant**
  - **87 t/yr avg to LEO**
  - **0% propellant**
  - **42% new flt HW**
  - **58% cargo**
  - **2588 t/yr ISRU water**

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
- 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

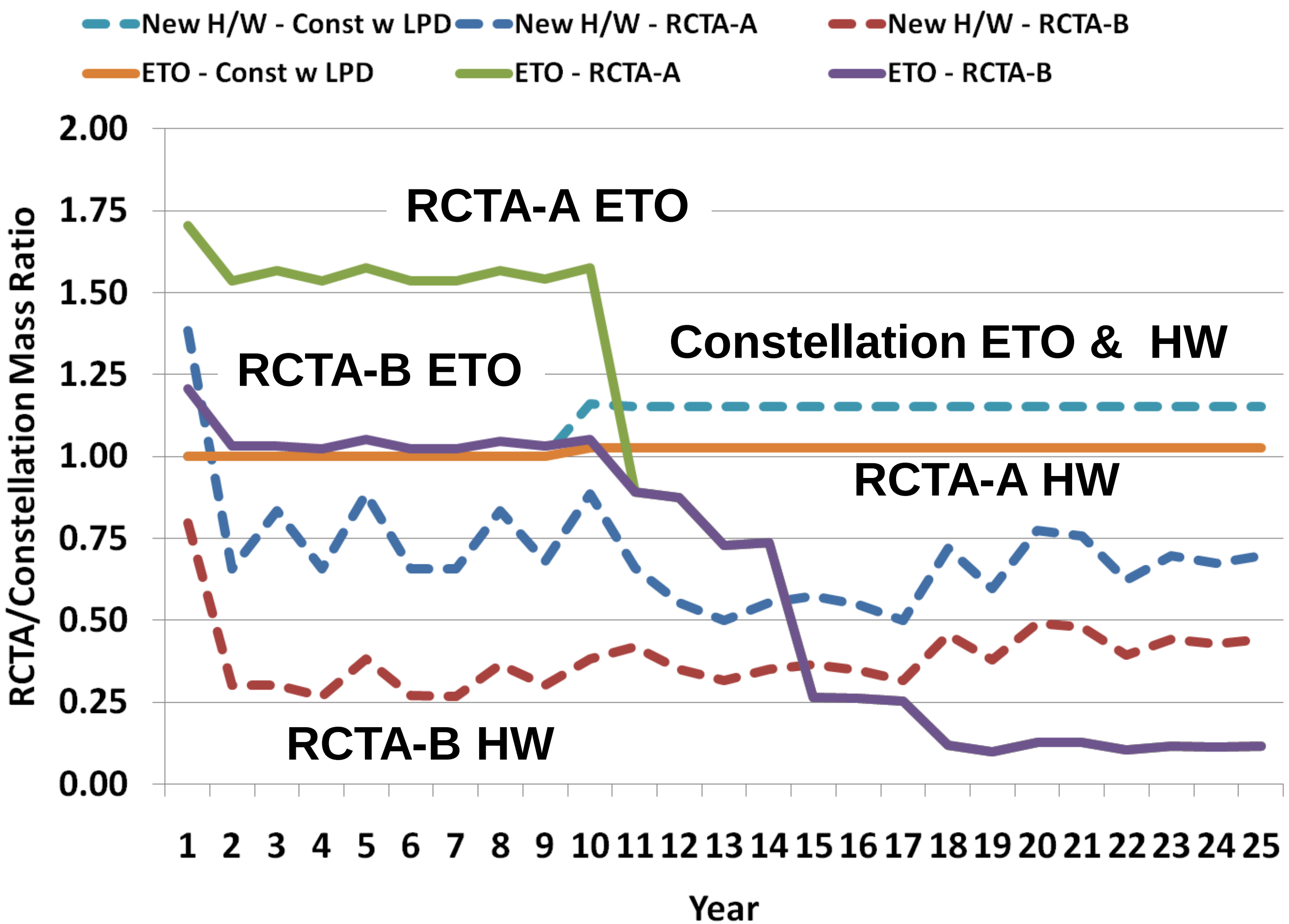
ISRU for RLL Only (Min and Max) are Most Propellant Efficient RCTA ConOps



% Constellation Prop

- All Earth-A 222%
- All Earth-B 135%
- RLL Min 103%
- RLL Max 103%
- L1 Prop 196%
- All Moon 352%

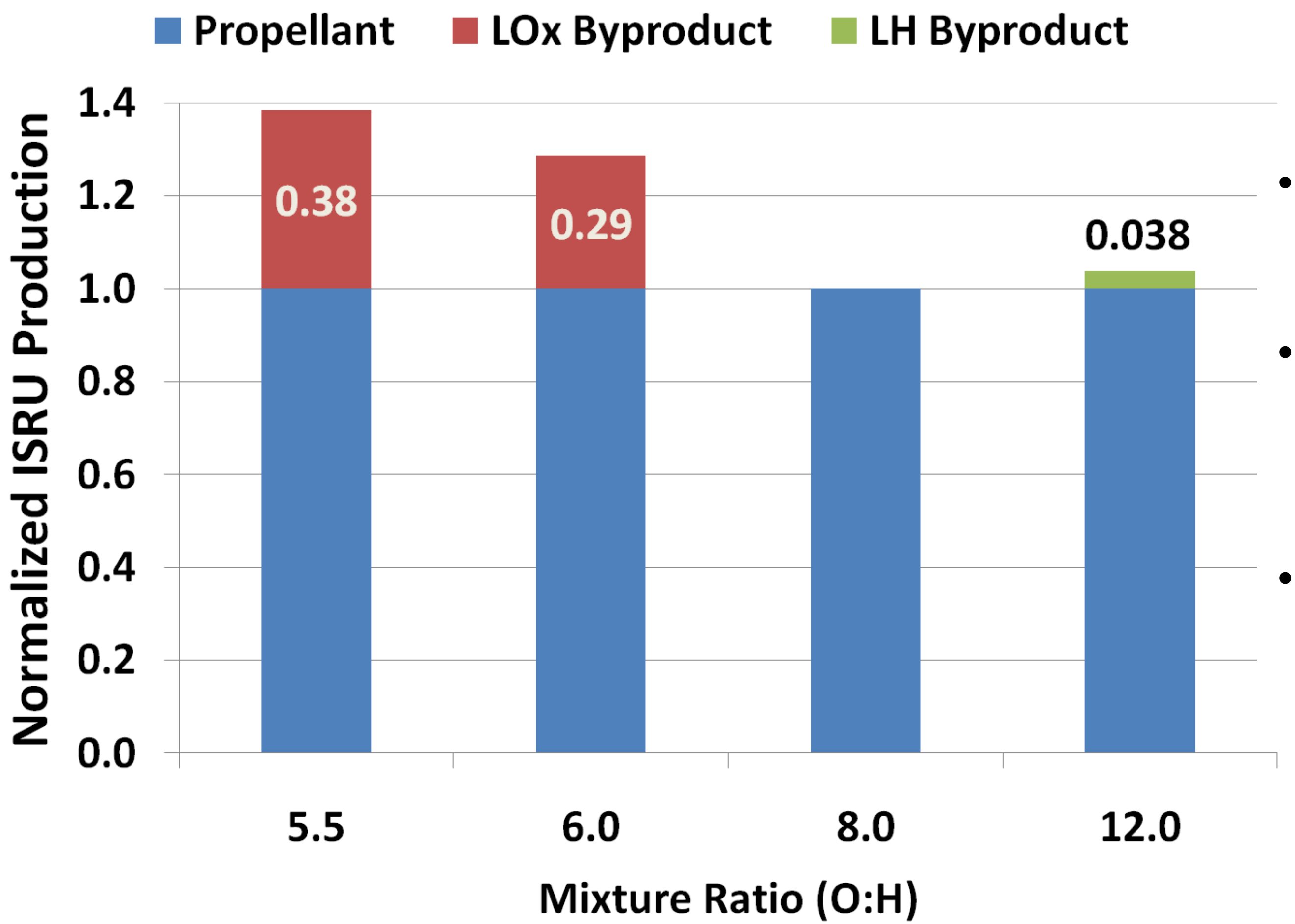
ISRU Greatly Reduces ETO and Hardware Mass



% Constellation

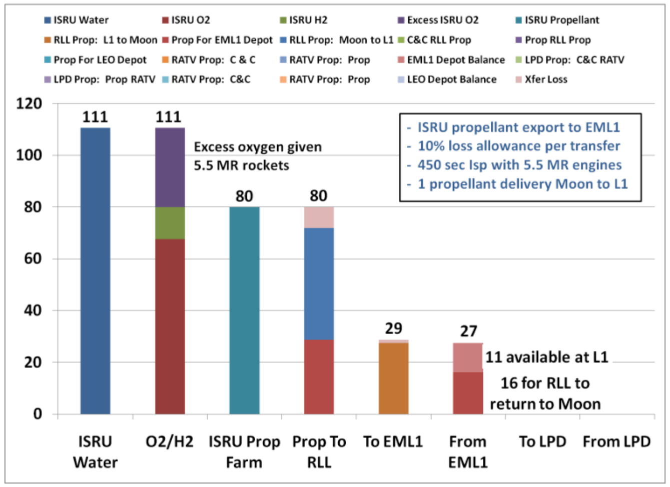
- RCTA-A
  - Hardware 25.7%
  - ETO 81.0%
- RCTA-B
  - Hardware 22.1%
  - ETO 60.7%

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**

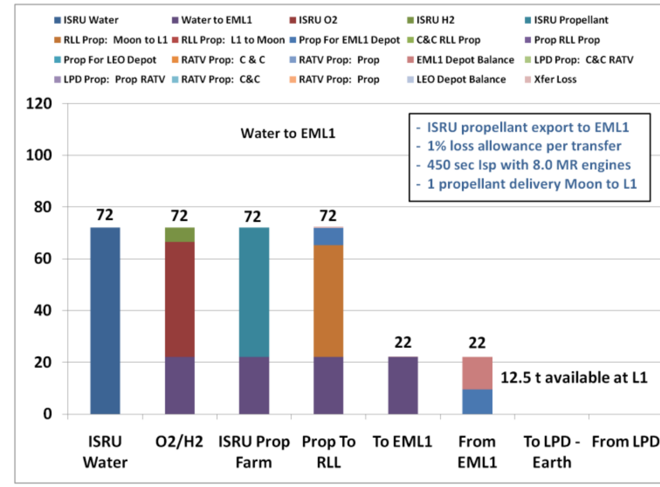
10 & 20 t of ISRU Water Required per t Exported to L1 & LEO with 5.5 MR; 6 t & 9 t with 8.0 MR

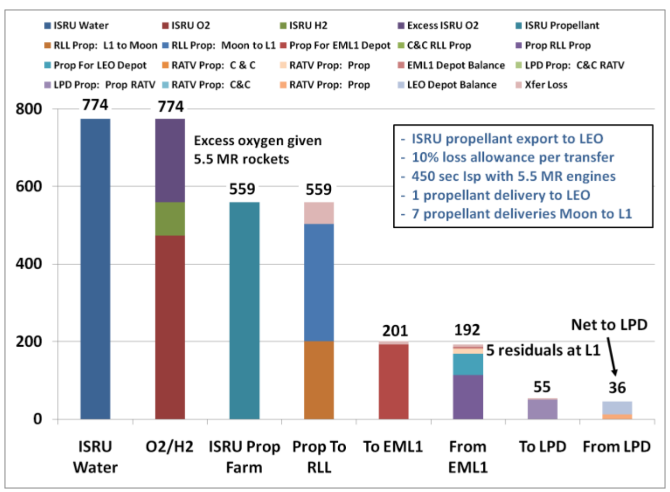


Export to L1
5.5 MR; 10% Loss
LOx/LH Transfer
10% net export (11 t)

35% less ISRU Water

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

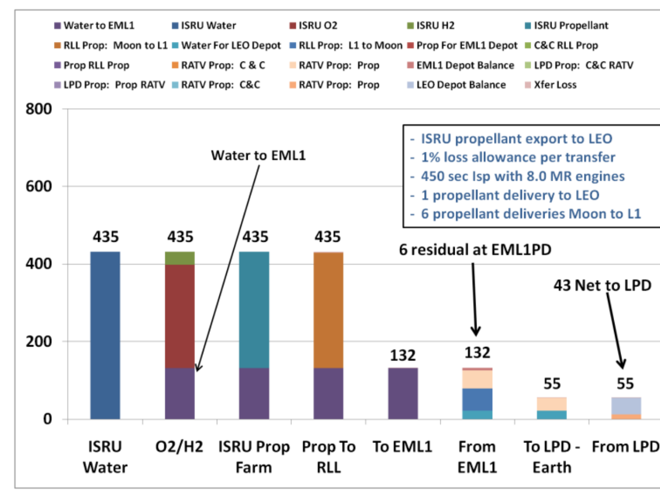




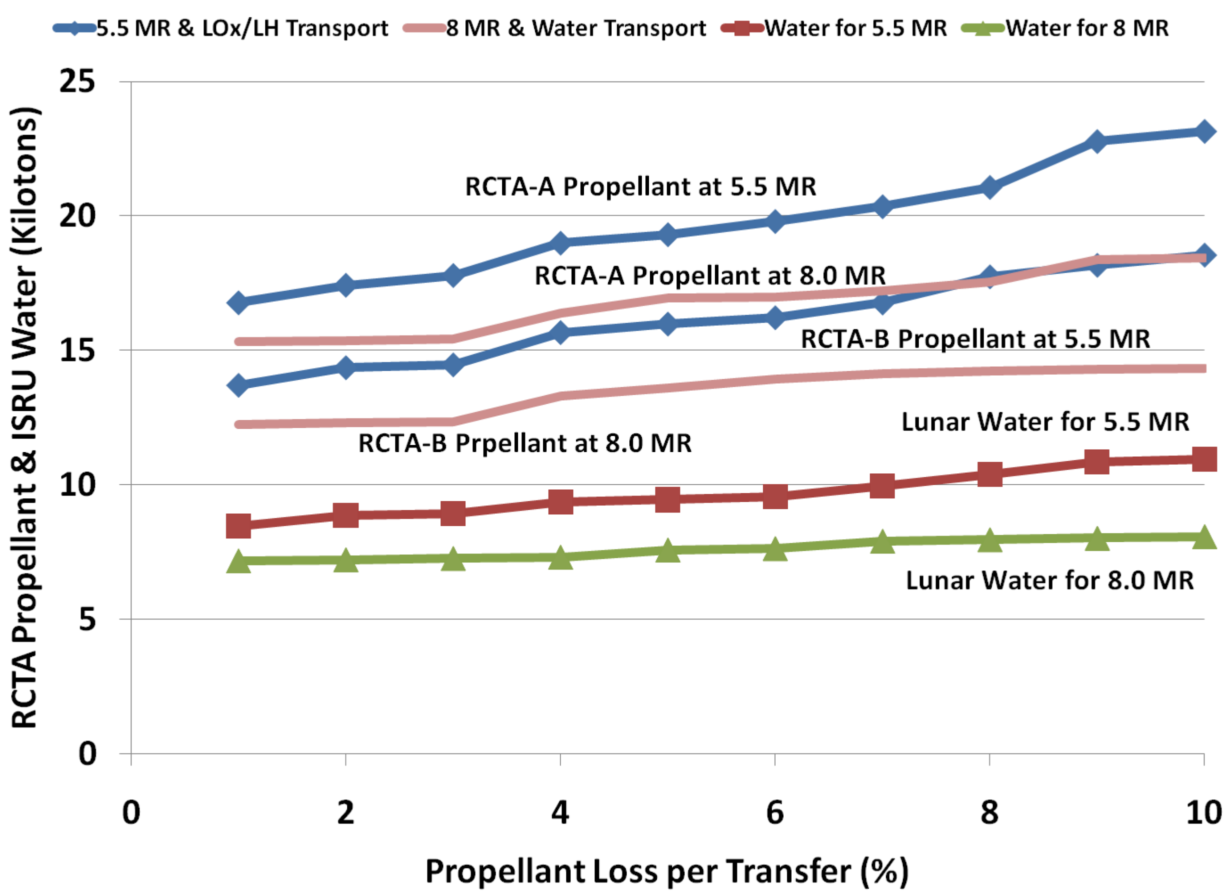
Export to LEO
5.5 MR; 10% Loss
LOx/LH Transfer
5% net export (41 t)

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**