In Situ Resource Utilization and the Global Exploration Roadmap

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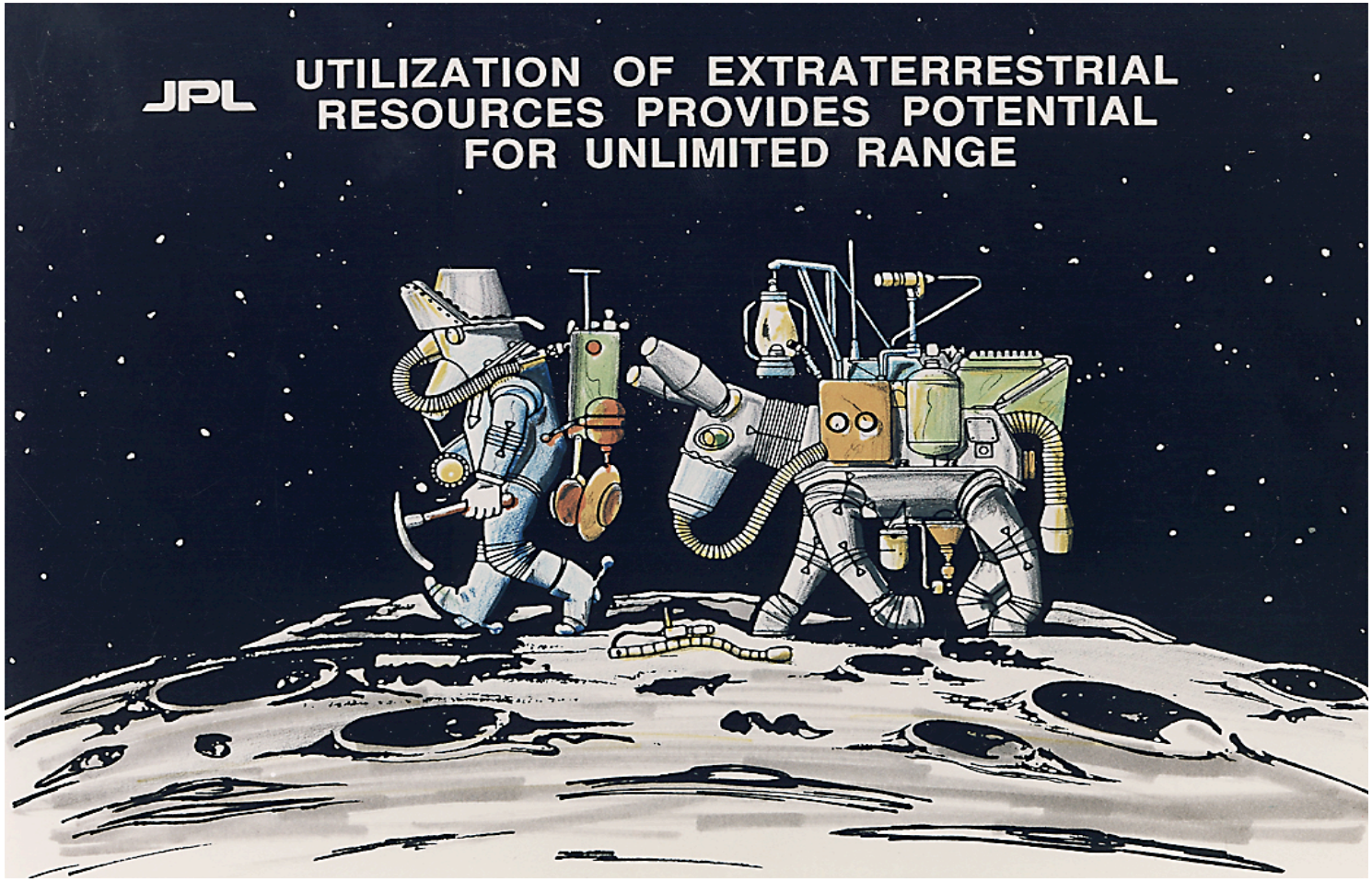
Neptec Design Group

- Privately held Canadian Company
- In business since 1990
- Prime contractor to NASA and CSA on shuttle and ISS
- Historically have provided vision systems and sensors for ISS assembly, shuttle inspection, rendezvous and docking
- Also working on surface mobility systems and other exploration technologies
- Working with RESOLVE team to develop a robotic precursor volatile extraction experiment

What is ISRU


JPL
UTILIZATION OF EXTRATERRESTRIAL
RESOURCES PROVIDES POTENTIAL
FOR UNLIMITED RANGE

Where ISRU fits in the GER

- Page 11 – Key Supporting Objectives Table
  - Extend Human Presence
    - Increase the self-sufficiency of humans in space.
  - Develop Exploration Technologies and Capabilities
    - Develop and validate tools, technologies, and systems that extract, process, and utilize resources to enable exploration missions.
  - Perform Science to Support Human Exploration

    Characterize available resources at destinations.

What We Know About Volatiles On The Moon

	Apollo Samples	Lunar Prospector Lunar Recon Orbiter (LRO)-LEND	Moon Mineralogical Mapper (M^3)	Lunar Crater Observation & Sensing Sat. (LCROSS)	Clementine Chandrayaan LRO Mini SAR/RF
	Core Derived Water	**Solar Wind**	**Water/Hydroxyl**	**Polar Volatiles**	**Polar Ice**
Instrument	Apollo samples	Apollo samples Neutron Spectrometer	M3	LCROSS	Mini SAR/RF
Concentration	0.1 to 0.3 wt % water in Apatite 0 to 50 ppm water in volcanic glass	Hydrogen (50 to 150ppm) Carbon (100 to 150 ppm) Helium (3 to 50 ppm)	0.1 to 1% water	3 to 10% Water equivalent Solar wind & cometary Volatiles (CO, H_2, NH_3, organics)	Ice layers
Location	Regolith; Apatite	Regolith everywhere	Upper latitudes	Poles	Poles; Permanent shadowed craters
Environment	Sunlit	Sunlit	Low sun angle	Low or no sunlight; Temperatures sustained at <106 K	<100 K, no sunlight
Depth	Top 10's of meters	Top several meters; Gardened	Top mm's of regolith	Below 10 to 20 cm of desiccated layer	Top 2 meters

Potential Lunar Ore Resources

Potential Lunar Ore Resources

Major and Minor Components	Siderophile Elements	Incompatible Trace Elements	Vapor-Mobilized Elements
O, Si, Al, Fe, Mg, Ca, Na, Ti, P, Sc, V, Cr, Mn, Ga, Sr	Fe, Co, Ni, Ge, Mo, Ru, Rh, Pd, Sb, W, Re, Os, Ir, Pt, Au	Alkali Elements (not Na) Alkaline-Earth (except Ca) **Rare Earth Elements (REE),** B, Zr, Nb, Sn, Hf, Ta, U, Th	S, the halogens, Cu, Zn, As, Se, **Ag, Cd, In, Te,** Hg, Ti, Pb, Bi

	Lunar Basalt	Lunar Breccias	Lunar Soil	Earth Crust
Pr	13	---	7	9.2
Nd	63	40	39	41.5
Sm	21	14	13	7.05
Eu	2.2	1.9	1.7	2
Gd	27	20	15	6.2

Note: all values in ppm

	Lunar Basalt	Lunar Breccias	Lunar Soil	Earth Crust
Ag	1.5	18	9	75
Cd	10	100	50	150
In	3	5	<10	25
Te	16	72	---	1
Se	700	1600	800	50

Note: all values in ppb

Haskin, La, Ro Colson, DT Vaniman and SL Gillett, "A geochemical Assessment of Possible Lunar Ore Formation", Resources of Near Earth Space, 1993.

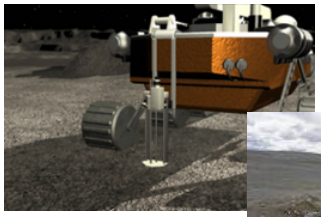
Why is ISRU important to the GER

- Benefits of In-Situ Resource Utilization (ISRU):
  - Mission critical consumables, spare parts, radiation shields, civil works such as landing pads
  - Substantial impact on the mass, cost, and risk of individual missions and architectures for the Moon and Mars
  - Oxygen production for life support, EVA, and propulsion (>75% of propellant mass is oxygen for O2/methane and O2/hydrogen systems)
  - Water extraction would eliminate need to bring rocket fuel from Earth
  - Manipulation of lunar regolith is beneficial for dust mitigation, shielding, & construction, but lunar regolith is highly abrasive and excavation and processing may be difficult
- Compare to cost of bringing/sending consumables
  - Cost per kg to soft landing on moon - ROM 100,000 USD
  - Cost per kg for soft landing on Mars – ROM ???

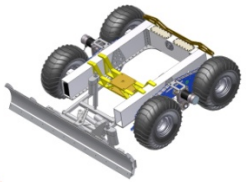
ISRU Required Capabilities

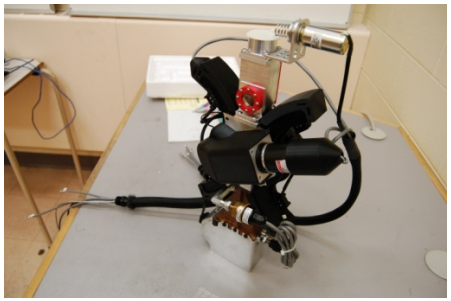
Remote Survey

Resource Prospecting and Definition

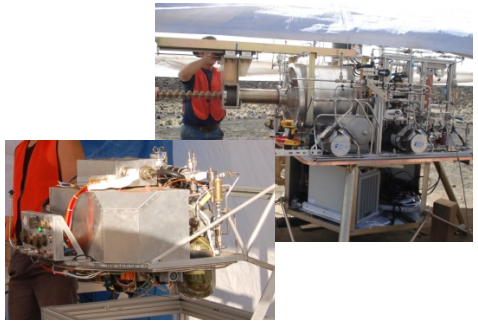


Extraction Mining





Beneficiation



Processing

Product

Waste