GROWLER – Grading and Rotating for Water in Lunar Excavated Regolith

3rd Place
Break the Ice Challenge

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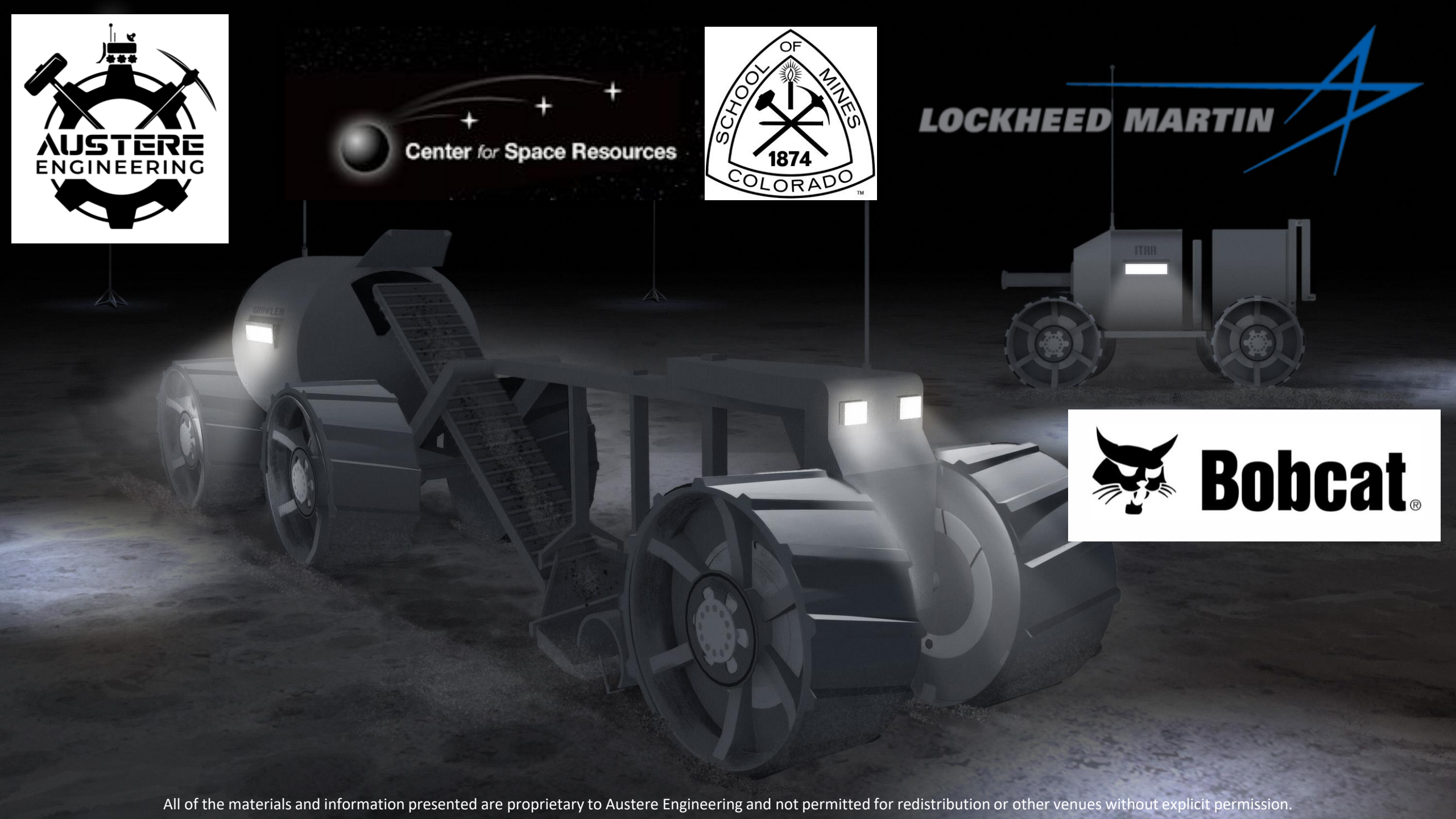
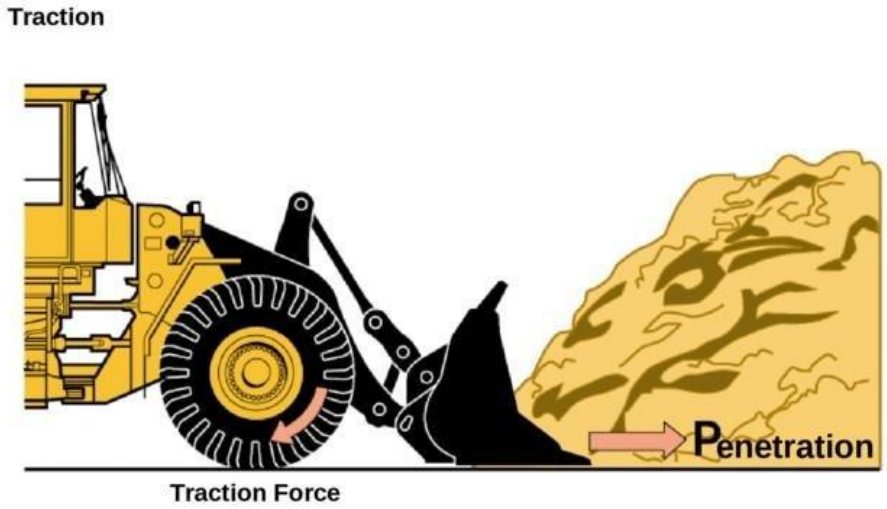
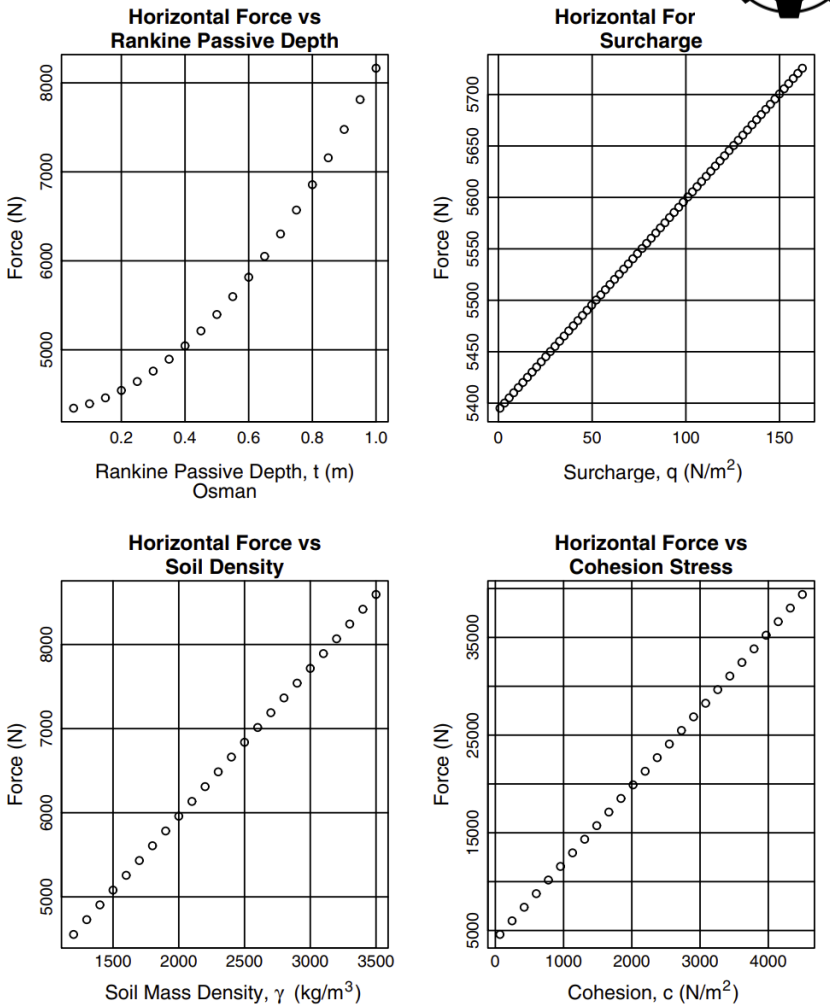


Is it hard to dig on the moon?

NASA: Apollo 17 landscape

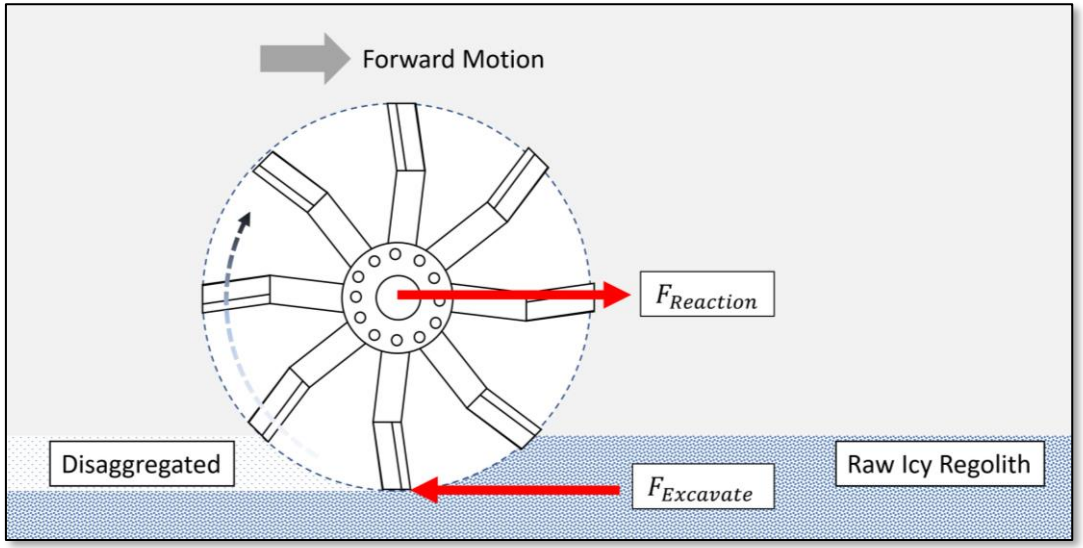


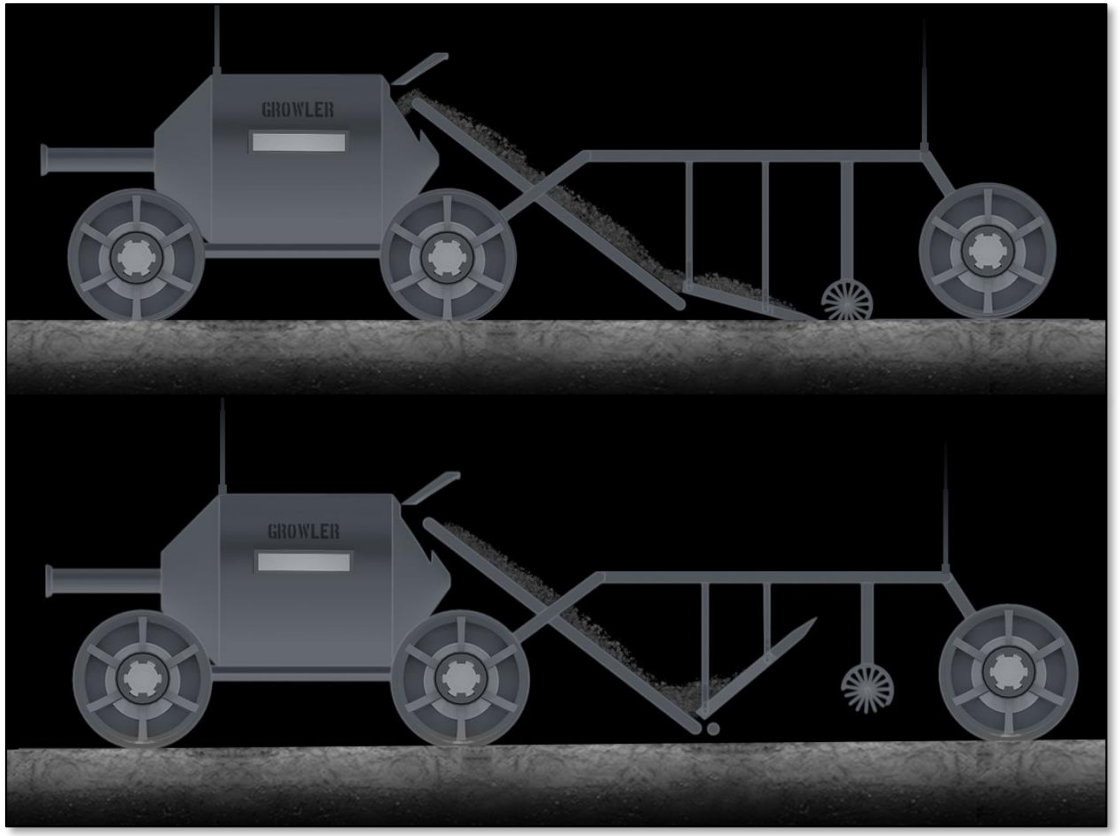
Wheel Loader Buckets & Digging Forces, (Ozgodan, 2019)



Digging and pushing lunar regolith: Classical soil mechanics and the forces needed for excavation and traction (Wilkinson, 2007)

Increasing Traction, Decreasing Penetration





Increasing Traction Force

1. 6x Wide Wheels
2. Rotary Tiller – Forward Reaction Force

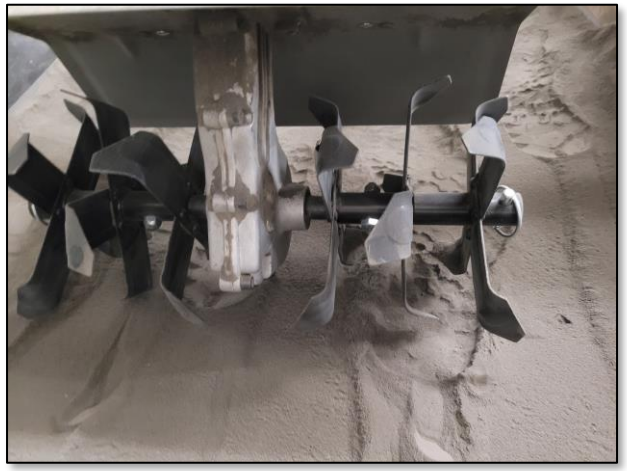
Con ops– Reducing Penetration Forces

1. Depth – Excavated at 5cm
2. Surcharge Pressure – Low gravity, articulating bucket

Rotary Tiller – Reducing Penetration Forces

1. Soil Density – Rotary Tiller reduces the density to $1.2\ g/cm^3$
2. Cohesion Stress – Rotary Tiller Disaggregates, reducing grain cohesion

Early Rotary Tiller Experiments

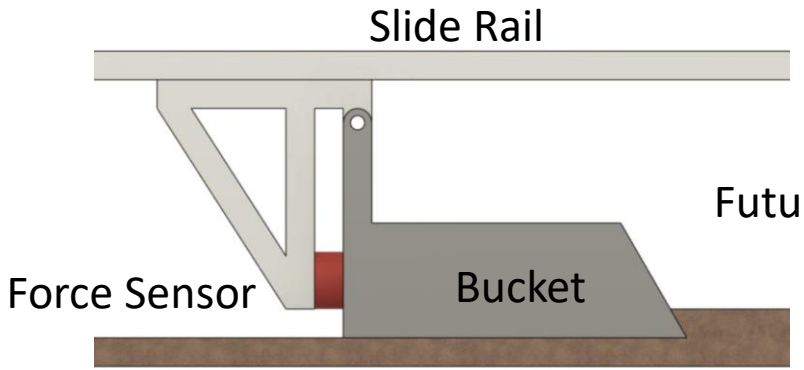


Colorado School of Mines
Lunar Test Bed

	Initially Density		Rotary Tiller
Density Decrease	$1.5\ g/cm^3$	→	$1.2\ \mathrm{g/cm^3}$
	$1.8 g/cm^3$	→	$1.2\ \mathrm{g/cm^3}$

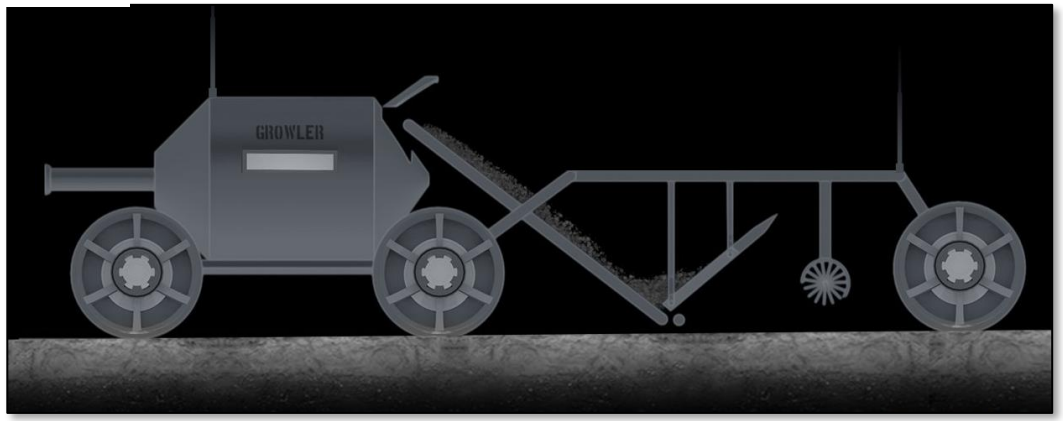
Penetrometer Pressure Decreases	$24\ kg/cm^2$	→	$4\ kg/cm^2$
	Depth: 0.25in		*Depth: 1in*

83% Reduction in penetrometer pressure



Future Bucket Experiments

Excavation Rates



Vehicle Speed: 0.45m/s (1 mph)
Excavating at Depth: 5cm
Bucket width: 1.5m

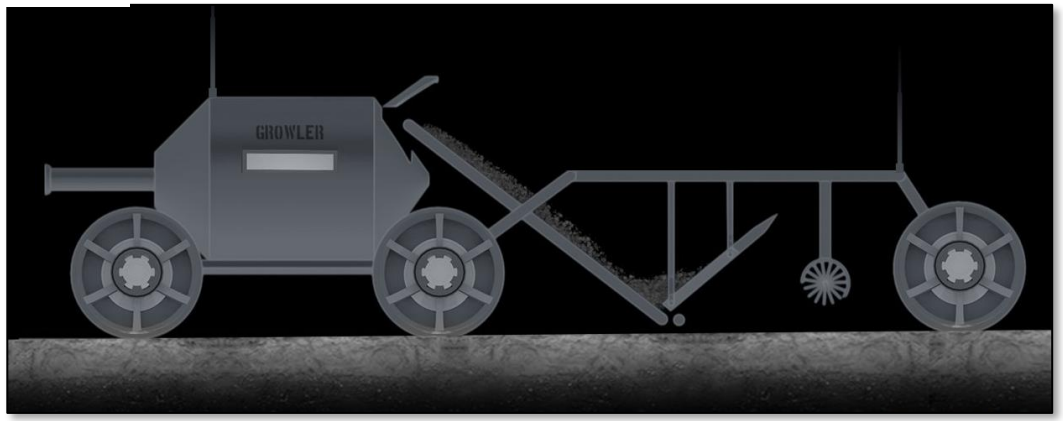
Excavation Rate
1000kg/10mins

Break the Ice Challenge

Objective 1. Excavate Icy Regolith Complete

Objective 2. Process the ice and deliver the ice outside of the PSR

Excavation Rates



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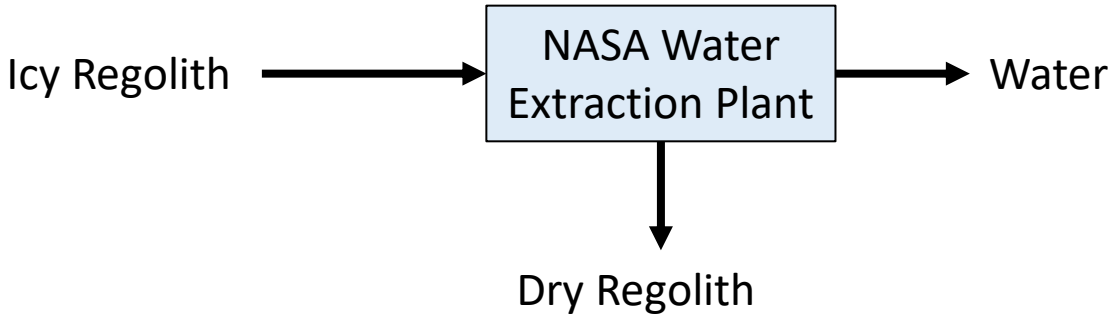
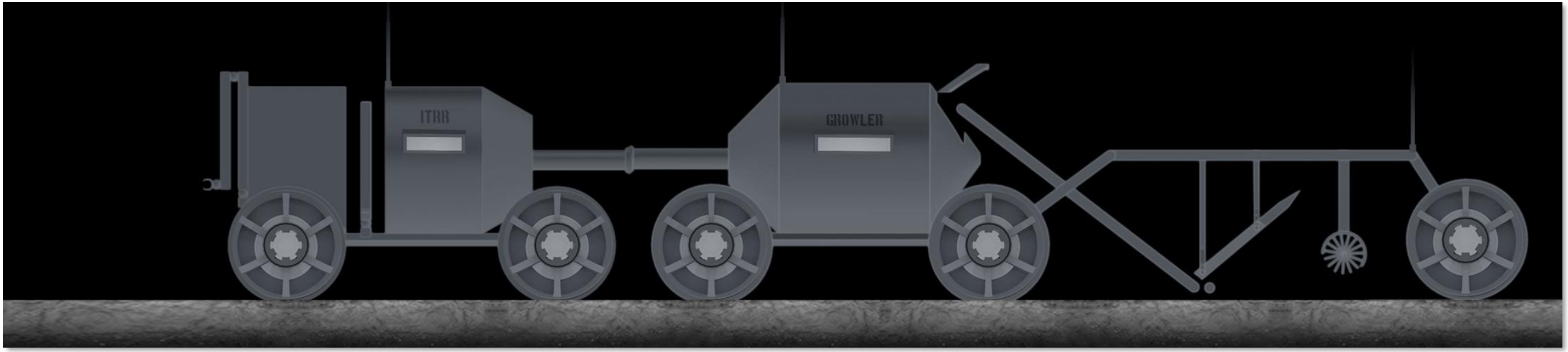
Excavation 6000kg/hr $\neq$ Icy Regolith Processing 100 kg/hr

Excavation 6000 kg/hr $\gg$ Icy Regolith Processing 100 kg/hr



60x Water Extraction Plants!

Extract water through a Rotary Extraction Drum (RED)



Water Storage

RED

Excavation

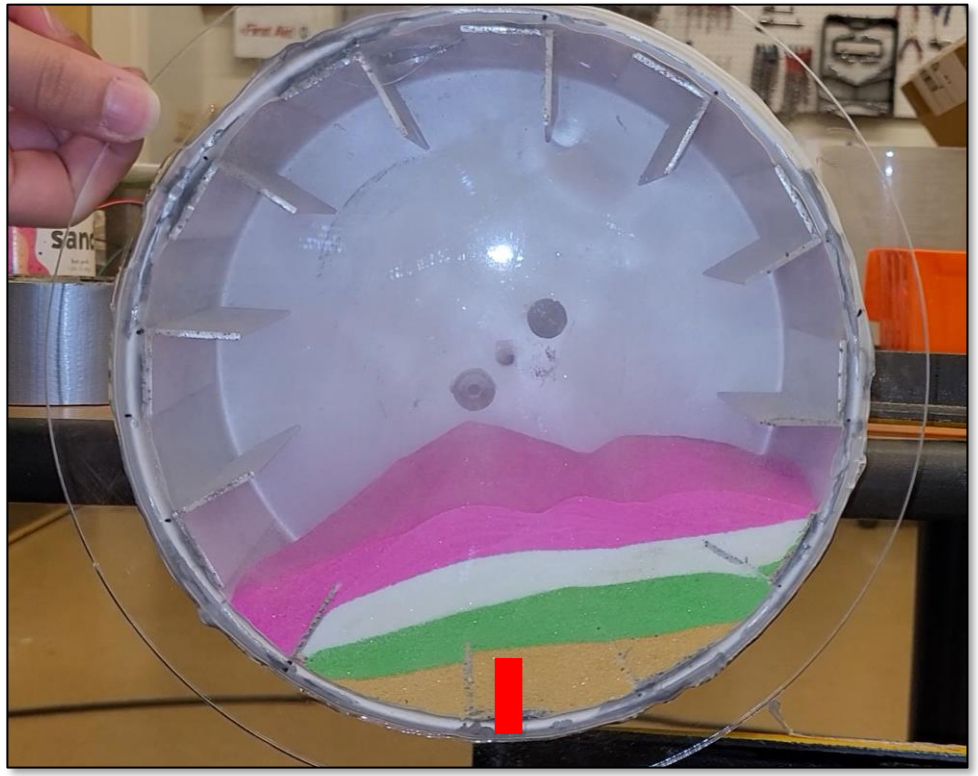
Hot Trap…

At <u>full scale</u>, $850 kg/hr$
99.5% Volatile Recovery Rate
4%ww yields water $34\ kg/hr$

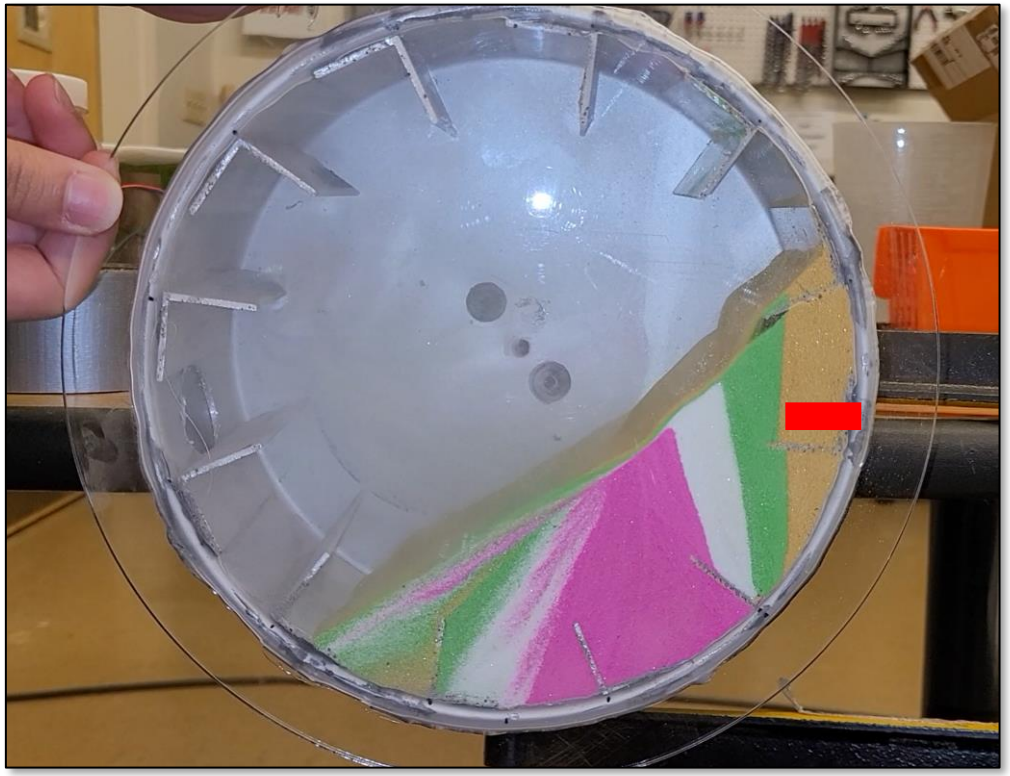
Excavation
6000kg/hr

Allows GROWLER to be scaled down

Extract water through a Rotary Extraction Drum (RED)



Starting Position: 0°

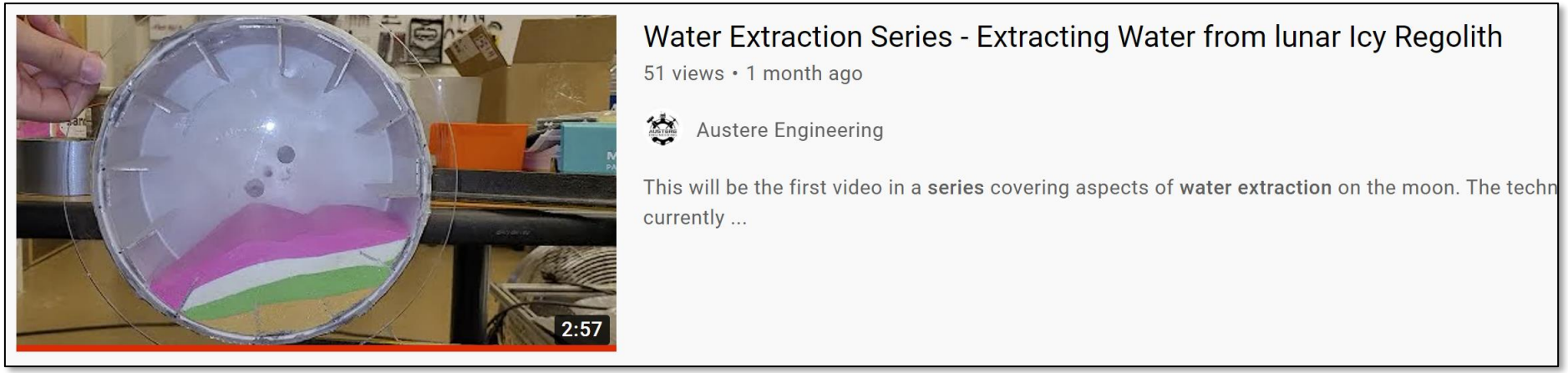


Rotation: 90°

1. Estimated Revolution – 1hr/revolution
2. All material cycles – every 150 degrees
3. Full Revolution – 2.4x Material Turnover

Water 34 kg/hr
38mT Water/1st Year

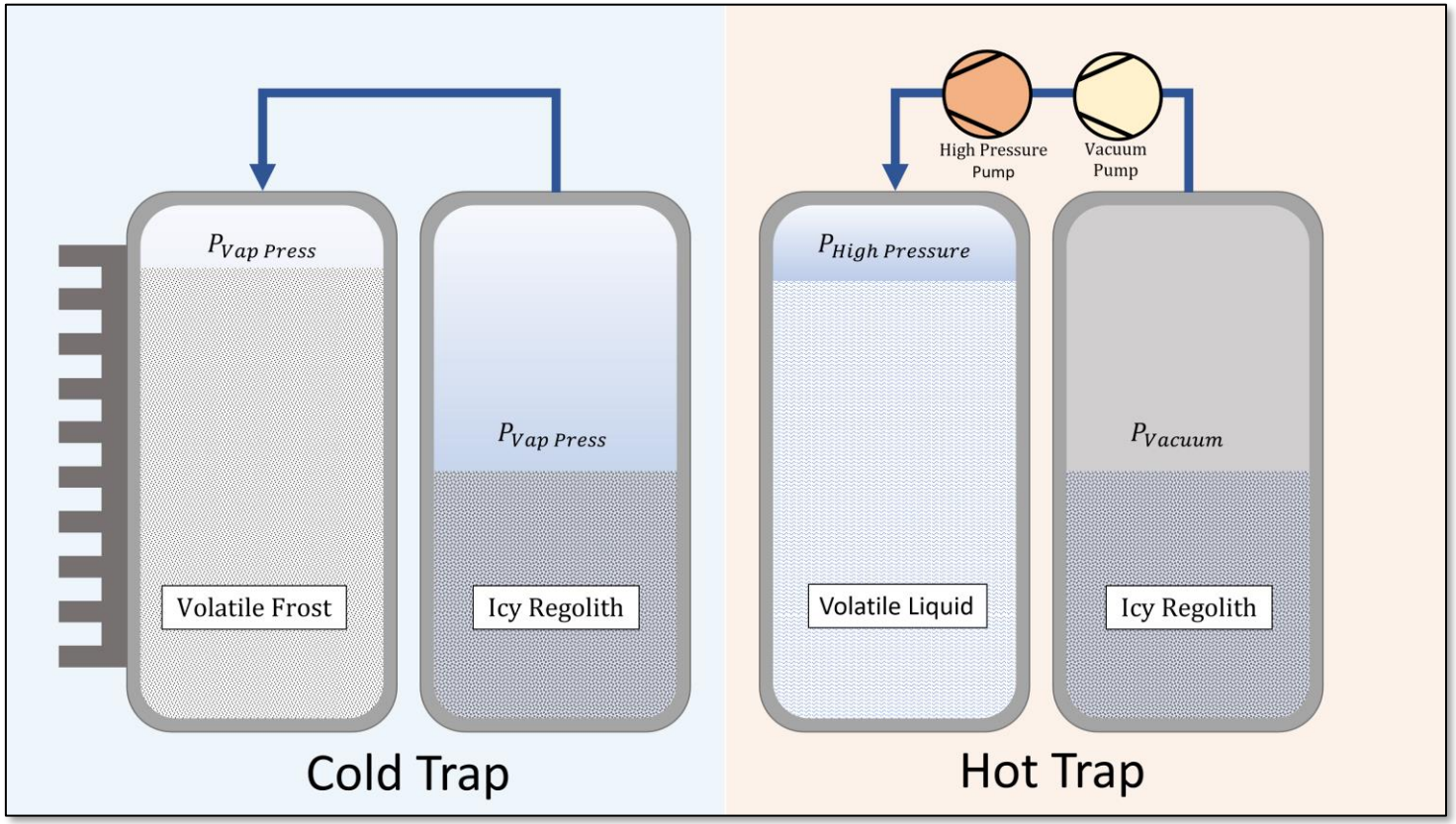
Rotary Extraction Drum (RED)



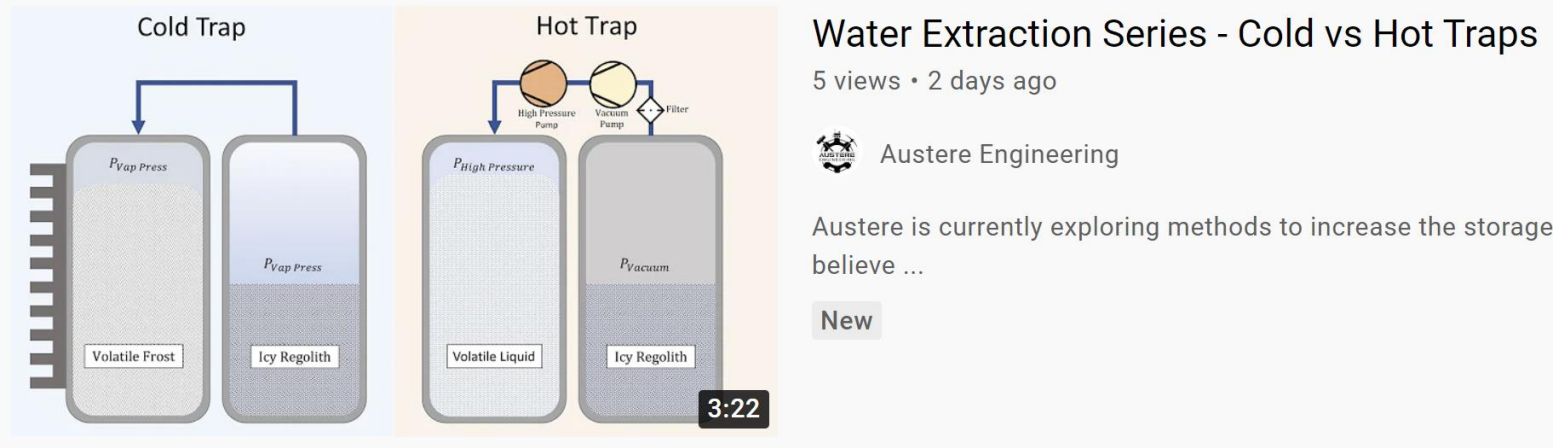
Water Extraction Series - Extracting Water from lunar Icy Regolith

Water Storage ‘Hot Trap’

Property	Cold Trap	Hot Trap
Storage Rate	0.22 kg/hr	20 kg/hr $(40kg/hr)$
Product Density	50-400 kg/m^3	997 kg/m^3
Post Processing	Solid (Frost)	Liquid/Vapor



Water Storage ‘Hot Trap’

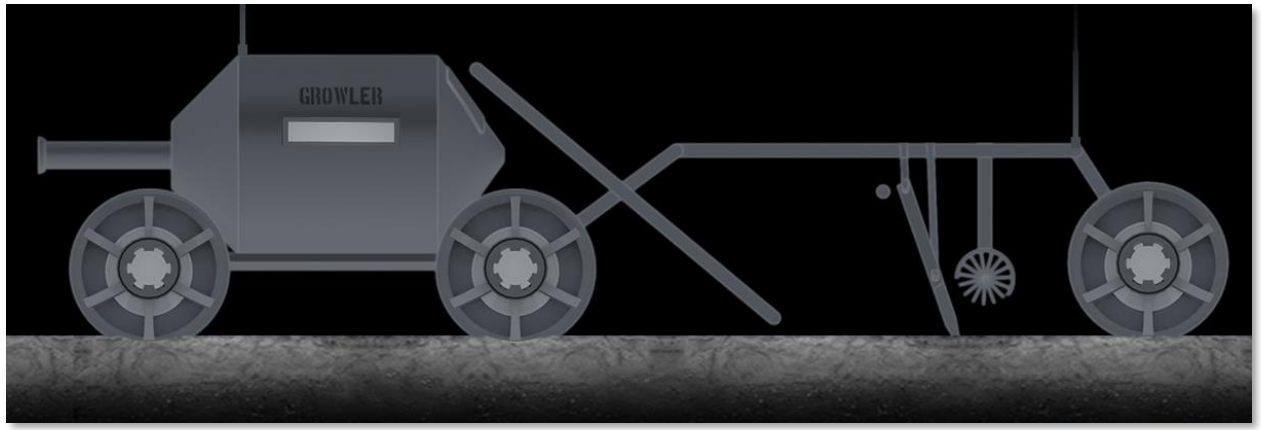


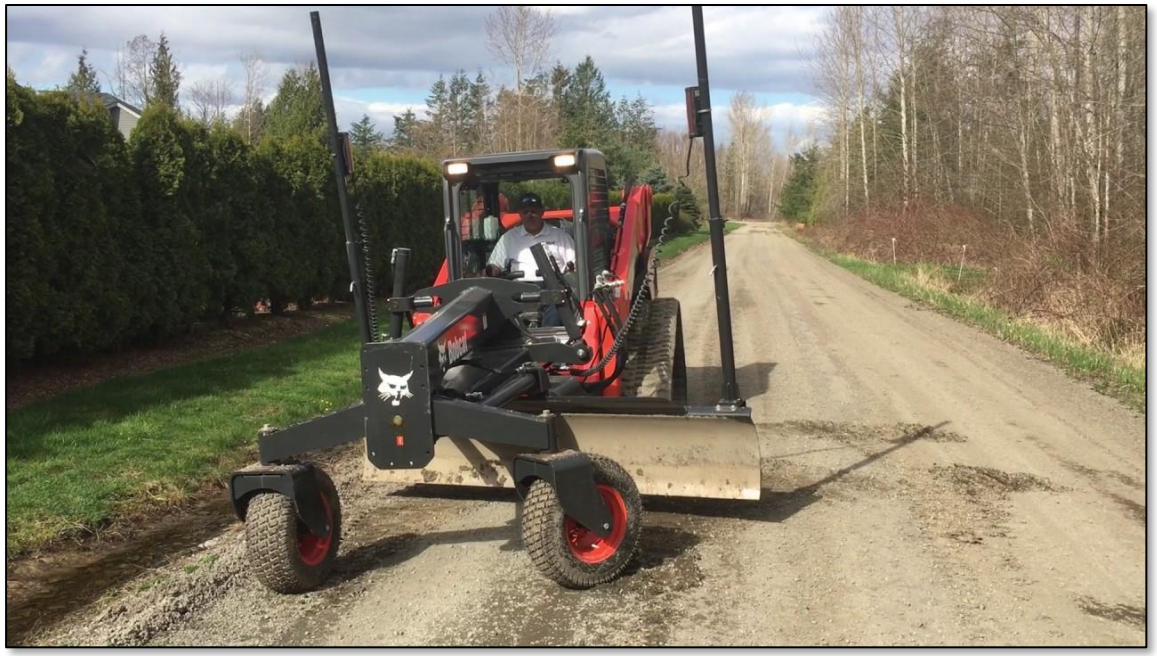
Water Extraction Series – Cold vs Hot Traps

<u>Hot Traps</u>

1. Moving Parts
2. More Energy Efficient
3. Less time Consumption
4. Produces a product that’s ready for further processing

GROWLER - Road Production

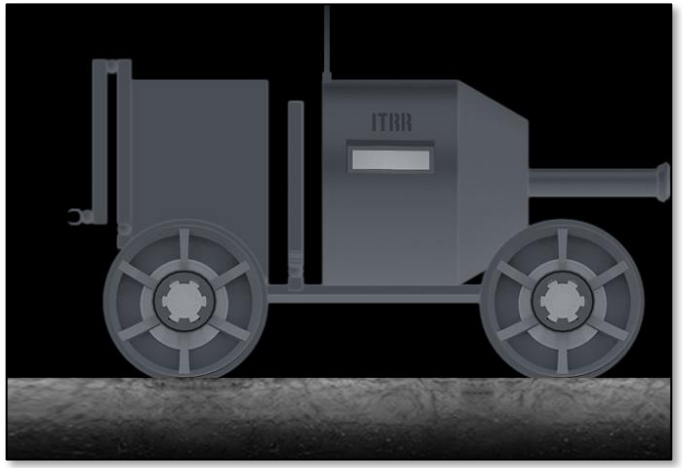




Future Attachments
Fork Lift
Excavator Arms

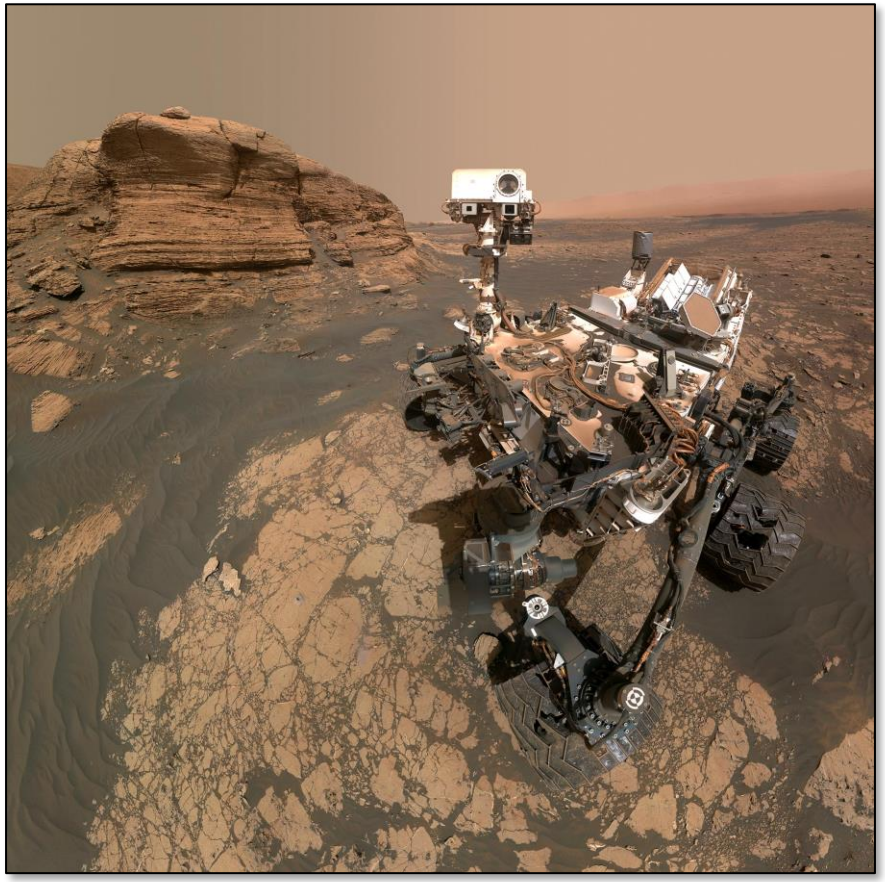
Maintenance on the Moon

Ice Transportation and Maintenance Rover (ITMR)



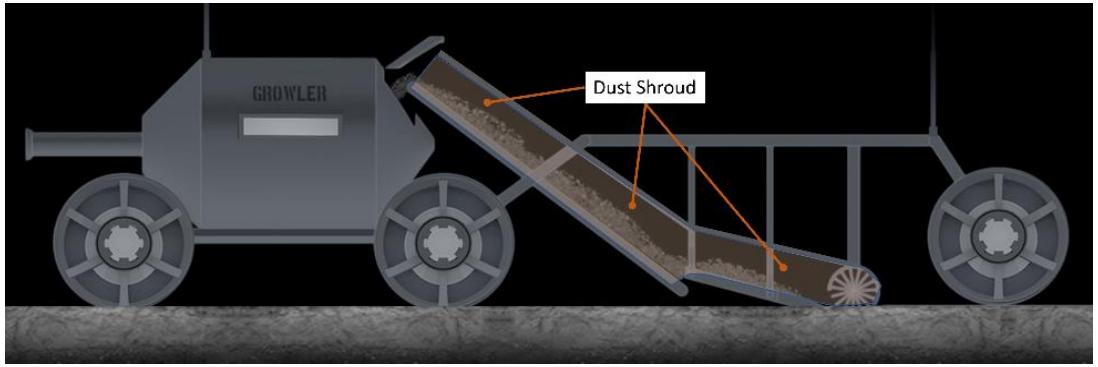
1x Aft 6m Robotic Arm
2x Lateral 6m Robotic Arms

Terrestrial Mines total Expenses:
11% Maintenance

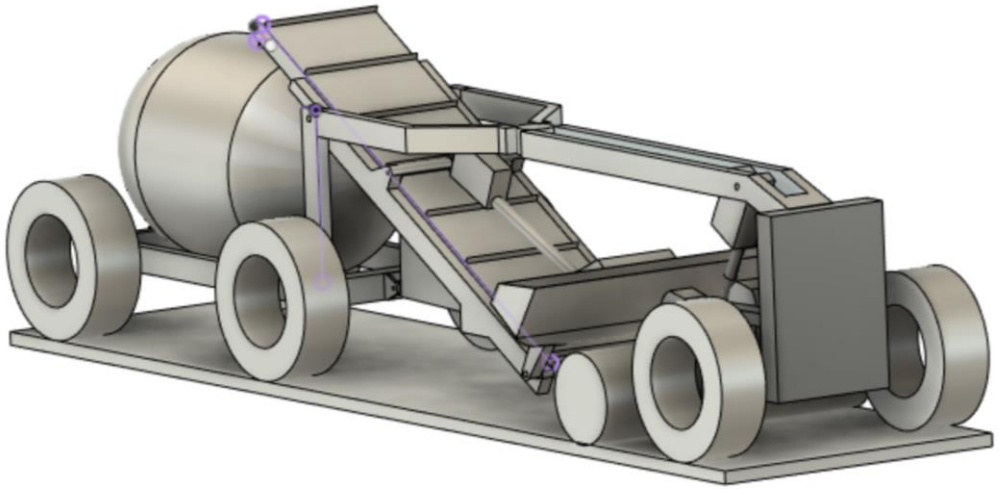


NASA Curiosity

GROWLER – Dust Shroud

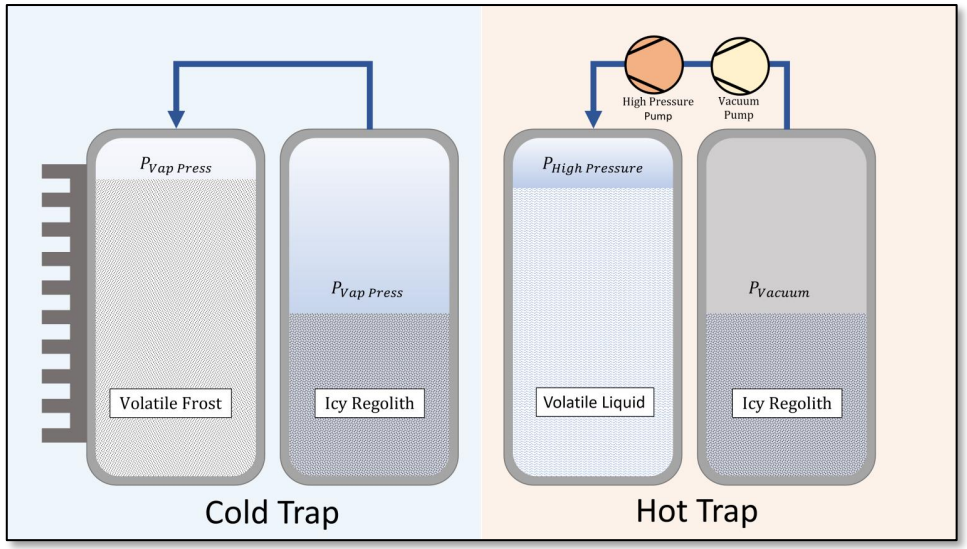


Path forward - Prototypes



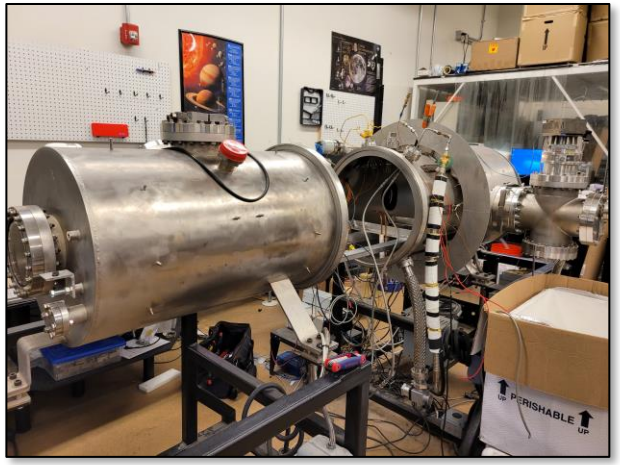
GROWLER – Volatile Production
2.4m x 0.6m x 1m – Prototype

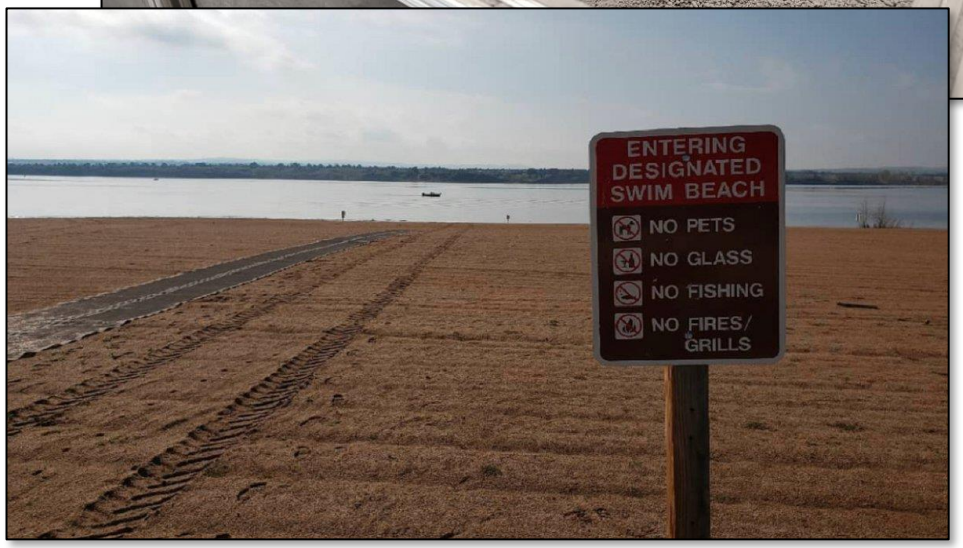
4.5m x 1m x 1.5m – Full Scale



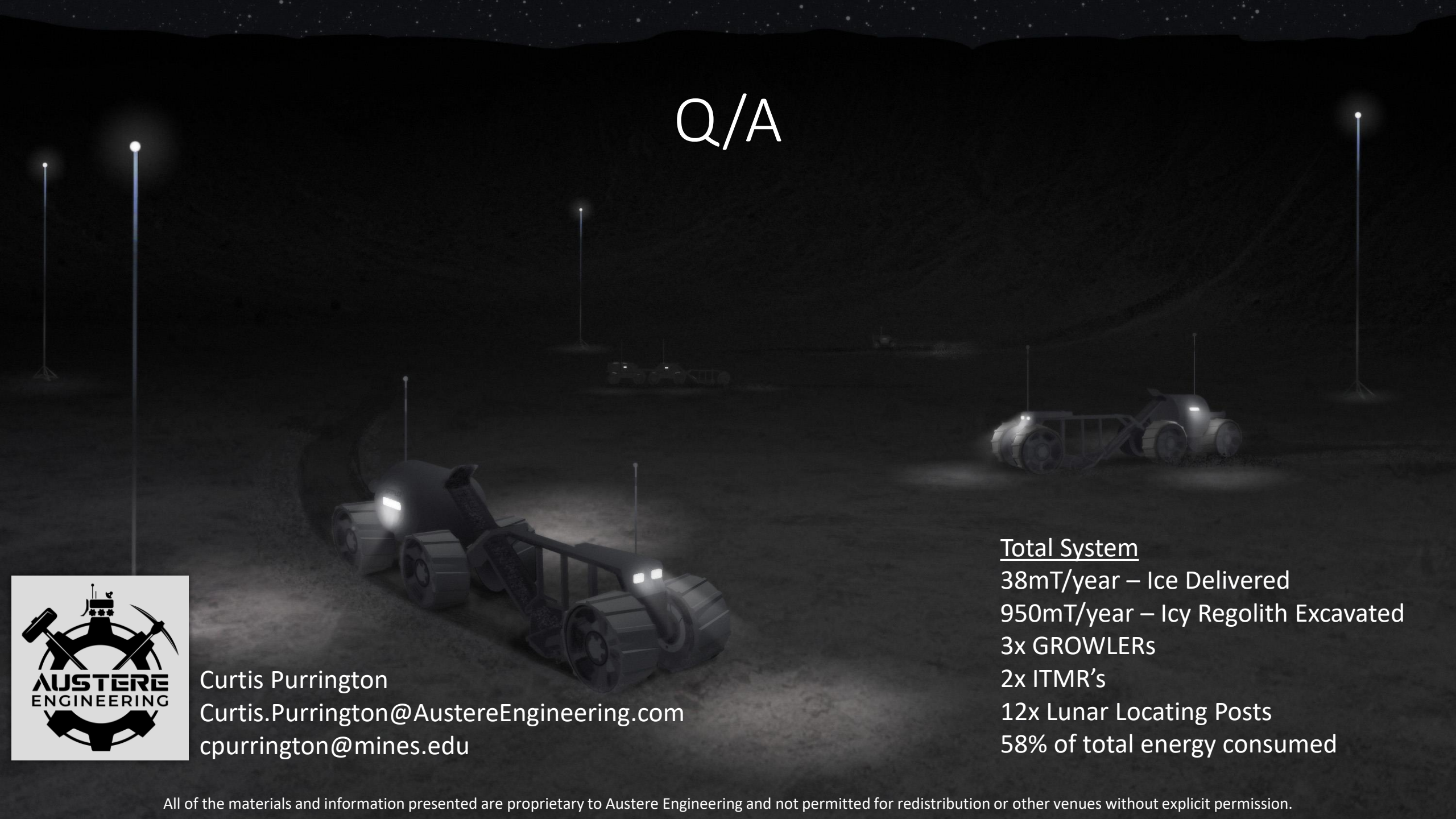
Testing Facilities

- Lunar Test Bed (CSM)
  - Rotary Tiller
  - Bucket Mechanics
- Chatfield State Park (Park Rangers)
  - Large Scale Excavation
- Vacuum Chambers (CSM)
  - Rotary Extraction Drum
  - Hot Trap





Q/A



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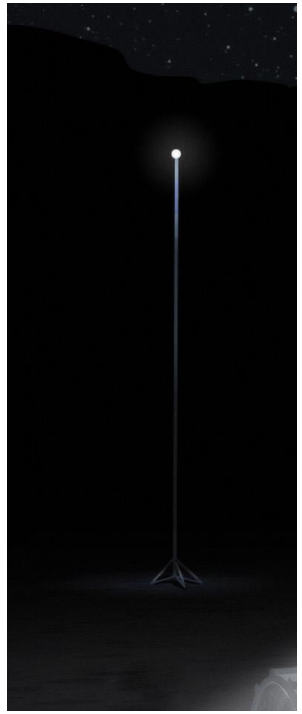
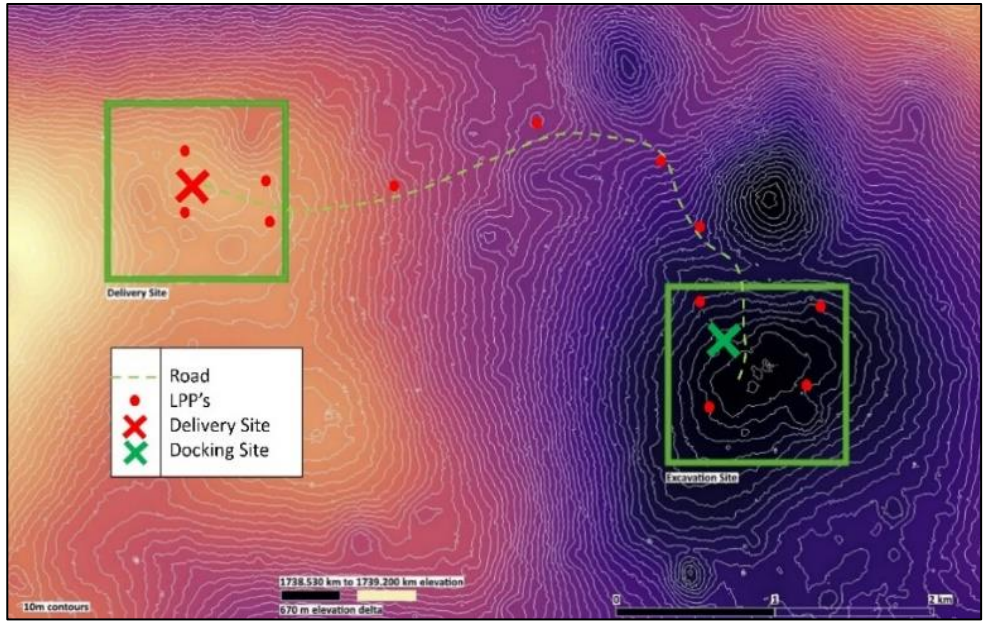
Total System
38mT/year – Ice Delivered
950mT/year – Icy Regolith Excavated
3x GROWLERs
2x ITMR’s
12x Lunar Locating Posts
58% of total energy consumed

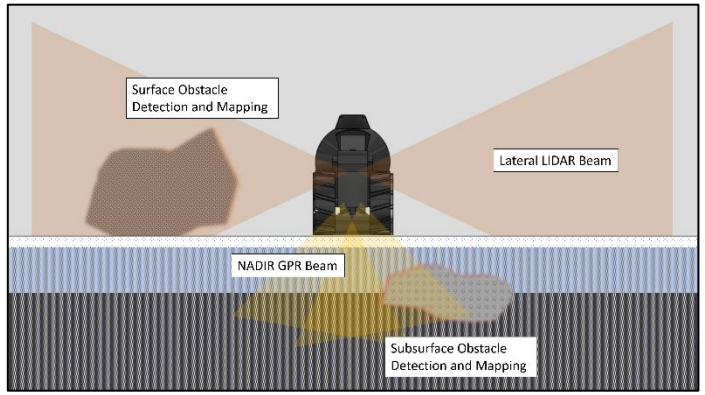
Navigation on the Moon

GROWLER – Lunar Locating Post





GROWLER – Obstacle Avoidance



Lunar Locating Posts – (LPP's)
Low Power – Still partially functional no power
3x LPP's visible from any where in the AO