EVALUATION OF LUNAR-REGOLIGH EXCAVATOR CONCEPTS FOR A SMALL, ISRU OXYGEN PLANT. R. H. King,[1] M. B. Duke[2], and L. Johnson[3] [1]Engineering Division, 279 Brown Hall, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 rking@mines.edu), [2] NASA Institute for Resource 234D RL, Colorado School of Mines, 1500 Illinois, Golden, CO 80401 mduke@mines.edu.

Introduction: The Precursor In-situ Lunar Oxygen Testbed (PILOT) program is developing a system to produce 2 kg of liquid oxygen per day from the lunar regolith. During Phase 1, candidate technologies for three subsystems, resource collection, oxygen extraction, and oxygen storage, are being analyzed and evaluated to develop a preliminary design that will meet the following goals:

- 60 kg LOX per month, minimum
- 120 kg LOX per month target
- 400 kg system mass – Includes Excavators; includes power production; LOX storage
- Power <3 kWatt
- Operational life > 2 years
- Storage capacity - 300kg

With the following mass budget:

- Power Generation – 50kg
- Regolith Excavator – 80kg
- Oxygen Production – 140kg
- LOX Storage – 100kg
- Margin – 20kg

This paper reports on an evaluation of candidate concepts for the resource collection subsystem. The results are displayed in a decision matrix in Table 1.

Table 1. Lunar Excavator Concept Decision Matrix

Primary	Secondary		Secondary Weight	Primary Weight	Bucket Wheel	Auger	Backhoe w/ Forklift	Backhoe & Truck	Front Bkhoe Excavator w/ Forklift	Front Bkhoe Excavator & Truck	Bucket Chain	Front Bkhoe Loader w/ Forklift	Front Bkhoe Loader & Truck	Overshot Loader	Scraper	Shovel w/ Forklift	Shovel & Truck
Capable				**17**	**16**	**13**	**16**	**14**	**16**	**14**	**15**	**16**	**13**	**15**	**13**	**7.5**	**16**	**14**
	horizontal reaction force		**40**		39	36	40	37	40	37	38	40	37	38	37	20	40	37
	vertical reaction force		**45**		42	33	45	31	45	31	38	44	29	38	29	20	45	31
	ease of internal material handling		**5**		3	5	5	5	5	5	4	5	5	5	5	2	5	5
	maximum particle size		**5**		5	0	5	5	5	5	5	5	5	5	5	0	5	5
	sizing capability		**5**		5	2	2	2	2	2	2	2	2	2	2	2	2	2
Integrateable	ease of material transfer			**14**	**14**	**14**	**10**	**7**	**10**	**7**	**14**	**10**	**7**	**7**	**14**	**14**	**10**	**7**
Reliable				**14**	**12**	**11**	**13**	**11**	**12**	**11**	**13**	**13**	**11**	**9**	**13**	**11**	**13**	**11**
	number of major subsystems		**30**		15	23	23	23	23	23	23	23	23	15	23	30	23	23
	number of motors		**30**		28	29	27	16	27	15	29	29	18	17	29	30	27	16
	proven technology		**20**		20	10	15	20	10	15	10	15	20	10	15	10	15	20
	material transfer points		**15**		12	0	15	15	15	15	15	15	15	15	15	0	15	15
	dust generation		**15**		12	15	15	8	15	8	15	12	8	8	12	12	15	8
Stable	tipping forces when loaded			**14**	**14**	**14**	**6**	**8**	**6**	**8**	**14**	**10**	**12**	**12**	**14**	**14**	**6**	**8**
Controllable	telerobotic			**10**	**10**	**10**	**8**	**4**	**8**	**4**	**10**	**6**	**2**	**2**	**8**	**8**	**8**	**2**
Productive	cycle time			**8**	**8**	**8**	**4**	**4**	**4**	**4**	**8**	**4**	**4**	**4**	**6**	**6**	**4**	**4**
Cost effective				**7**	**6**	**6**	**6**	**4**	**6**	**4**	**6**	**6**	**4**	**4**	**7**	**7**	**6**	**4**
Multi-functional				**7**	**5**	**4**	**6**	**7**	**6**	**7**	**9**	**8**	**7**	**7**	**6**	**4**	**6**	**7**
	dispose of reactor waste		**50**		40	40	40	50	40	50	40	40	50	50	40	40	40	50
	support habitat construction		**25**		10	5	20	25	20	25	10	20	25	25	20	5	20	25
	explore		**25**		15	5	20	25	20	25	15	20	25	25	20	5	20	25
Power efficient				**7**	**6**	**7**	**6**	**4**	**6**	**4**	**7**	**7**	**4**	**4**	**7**	**7**	**6**	**4**
Maintainable	suited or robotic			**2**	**2**	**2**	**2**	**1**	**2**	**1**	**2**	**2**	**1**	**2**	**2**	**2**	**2**	**1**
Total			**100**	**93**	**88**	**77**	**64**	**77**	**63**	**93**	**79**	**66**	**66**	**89**	**81**	**77**	**62**	

Method: The decision matrix was developed with an eight-step hierarchical multiple criteria decision analysis process:

1. Specify the product design
2. Develop a hierarchy of criteria from the specification.
3. Generate alternative concepts.
4. Get information about each concept that can be used to quantitatively score it for each criterion.
5. Give each criterion a weight using the pair-wise comparison method.
6. Evaluate with a decision matrix. Compare the sum of scores of each alternative.
7. Revise the concepts (eliminating, combining, modifying)
8. Re evaluate iteratively until the group of evaluators is satisfied

There is considerable experience on earth with surface mining that was applied to the problem. However the special constraints of lunar operation (low gravity, high cost to deploy, no infrastructure, no human presence, extreme thermal environment, dust adhesion, and solar radiation) required rethinking earth mining equipment. Therefore the concepts used a baseline extraterrestrial bucket-wheel excavator (BWE)in Figure 1 a dramatic modification to the terrestrial BWE.

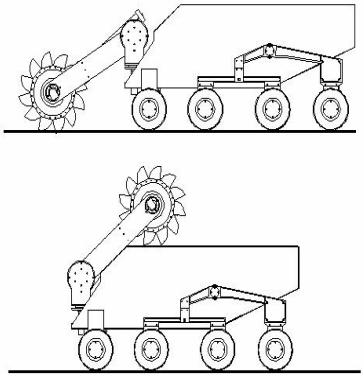

Figure 1. Lunar Bucket Wheel Excavator Concept Sketch

We analyzed the purpose, enabling characteristics, functional requirements, functional constraints, performance metrics to develop the list of criteria shown in Table 1 assuming a set of common capabilities for all concepts:

- Mobility Platform – Similar to the Sojourner.
- Power – On-board batteries recharged by solar.
- Reaction Forces – 0.4 * Load/wheel in lunar gravity.
- Material Transfer – dump bed
- Waste Dumping – dump bed on return trip.

We developed a specification table for each concept that provided input data to models that calculated evaluation scores shown in Table 1. The scores where multiplied by the criteria weights and summed.

Results: The three-highest scoring concepts, BWE, Bucket Chain, and Overshot Loader will move to the next stage of the process, computer simulation and modeling.