Excavation System Comparison: Bucket Wheel vs. Bucket Ladder

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Excavation Equipment Comparison

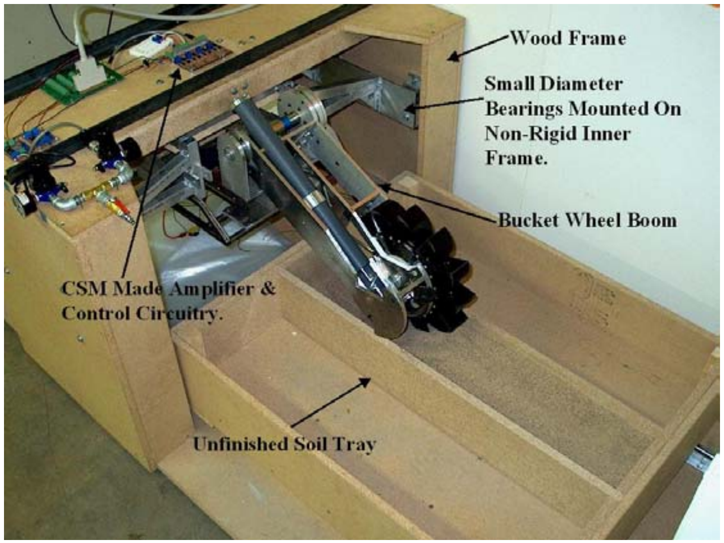
PILOT Project — COLORADO SCHOOL OF MINES

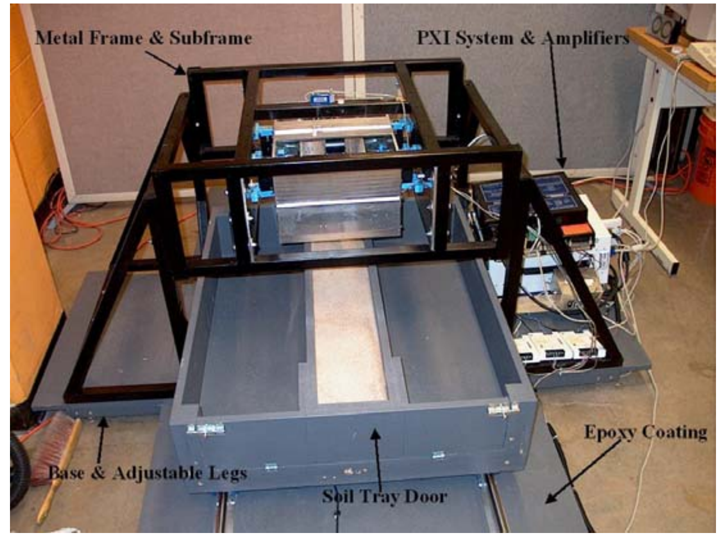
From King, SRR VII, 2005

Criteria

Primary	Secondary	Secondary Weight	Primary Weight	Bucket Wheel	Auger	Backhoe w/ Forklift	Backhoe & Truck	Boom Excavator w/ Forklift	Boom Excavator & Truck	Bucket Chain	Front-end Loader w/ Forklift	Front-end Loader & Truck	Front-end Loader & Rake	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	6	6	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	5	6	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	6[illegible]	93	79	66	66	89	81	77	62

System Description: BucketWheel



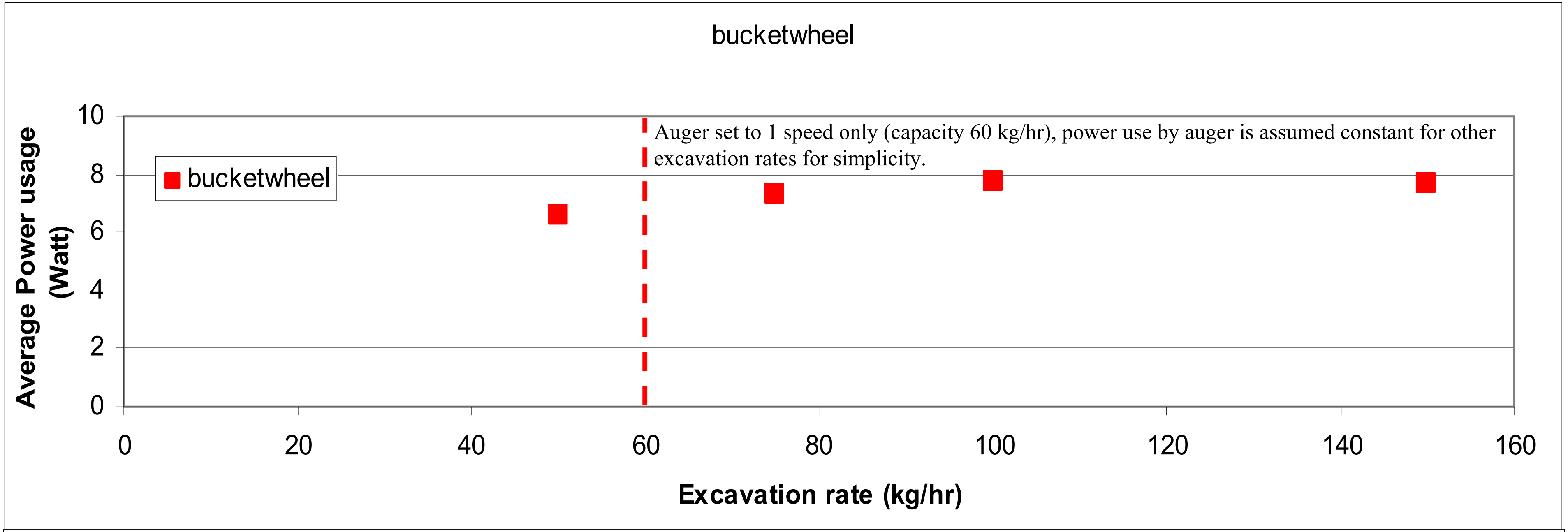


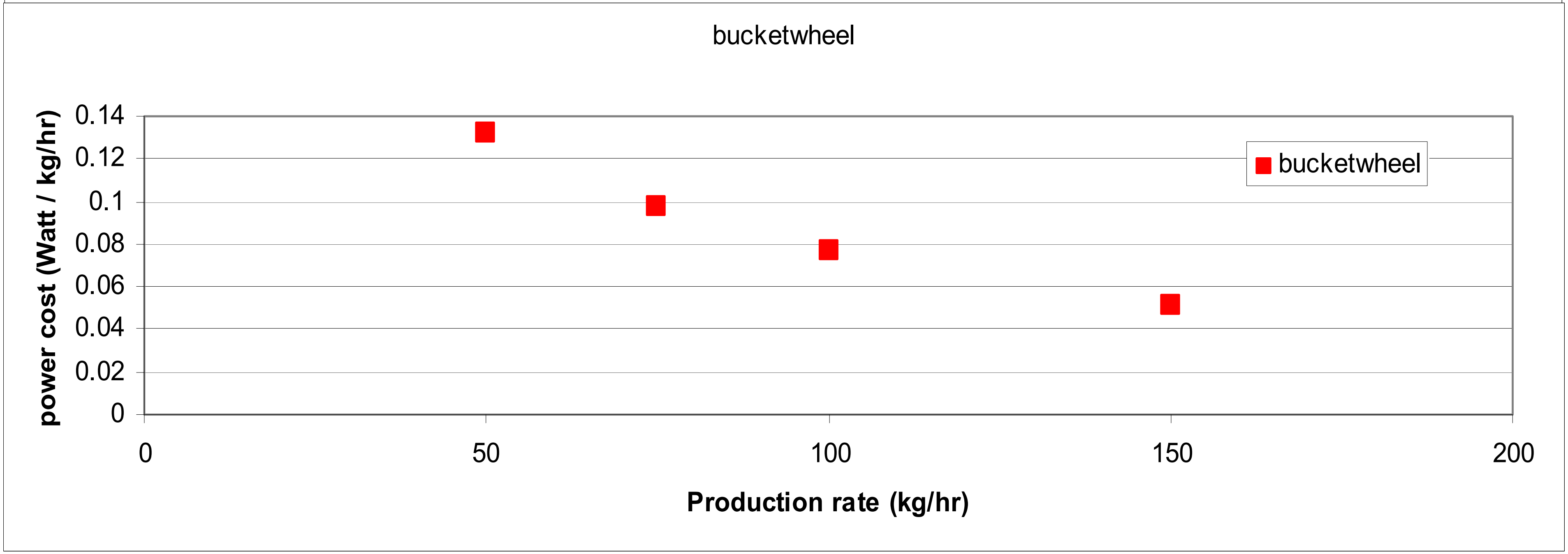
Bucket wheel system is based on actual overburden removal equipment used in the coal mining industry. Scaled to 15 cm diameter with 5 cm wide buckets and a production rate of 50 kg/hr. Tested up to 150 kg/hr.

BucketWheel Video

Video omitted for size reasons

Results of BucketWheel





System Description: BucketLadder

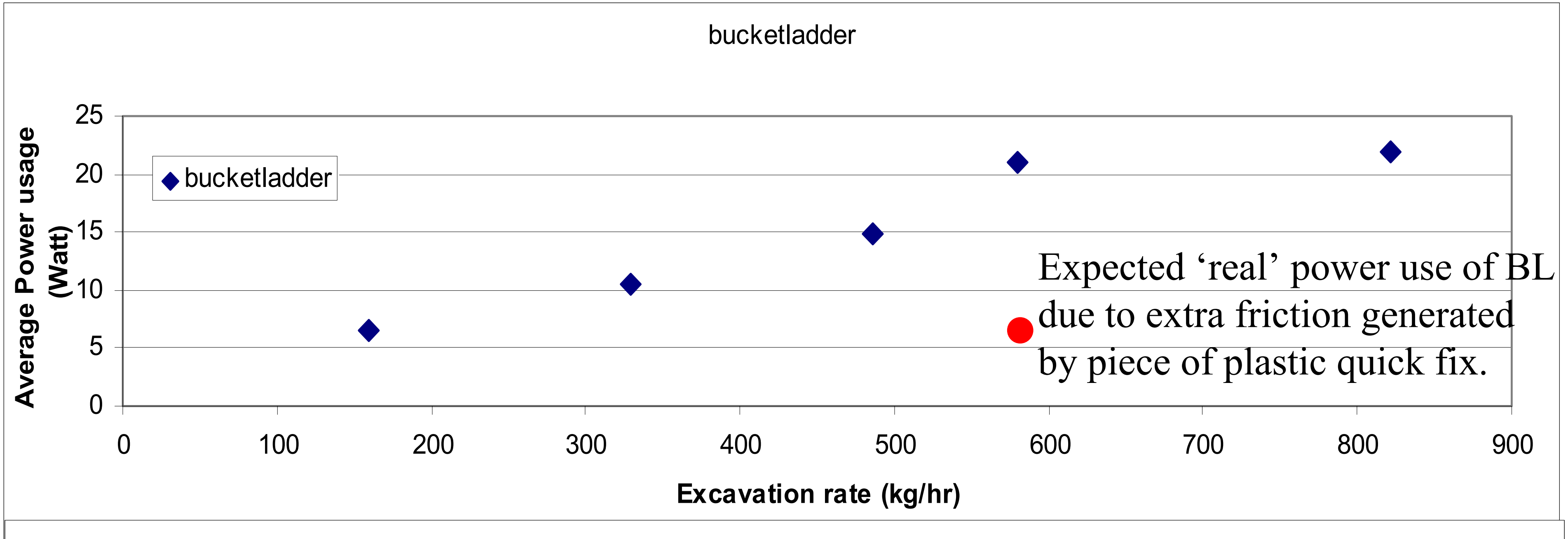
- Goal: merge digging and transportation function to make it more efficient as a system
- **Design goals and actual experienced characteristics**

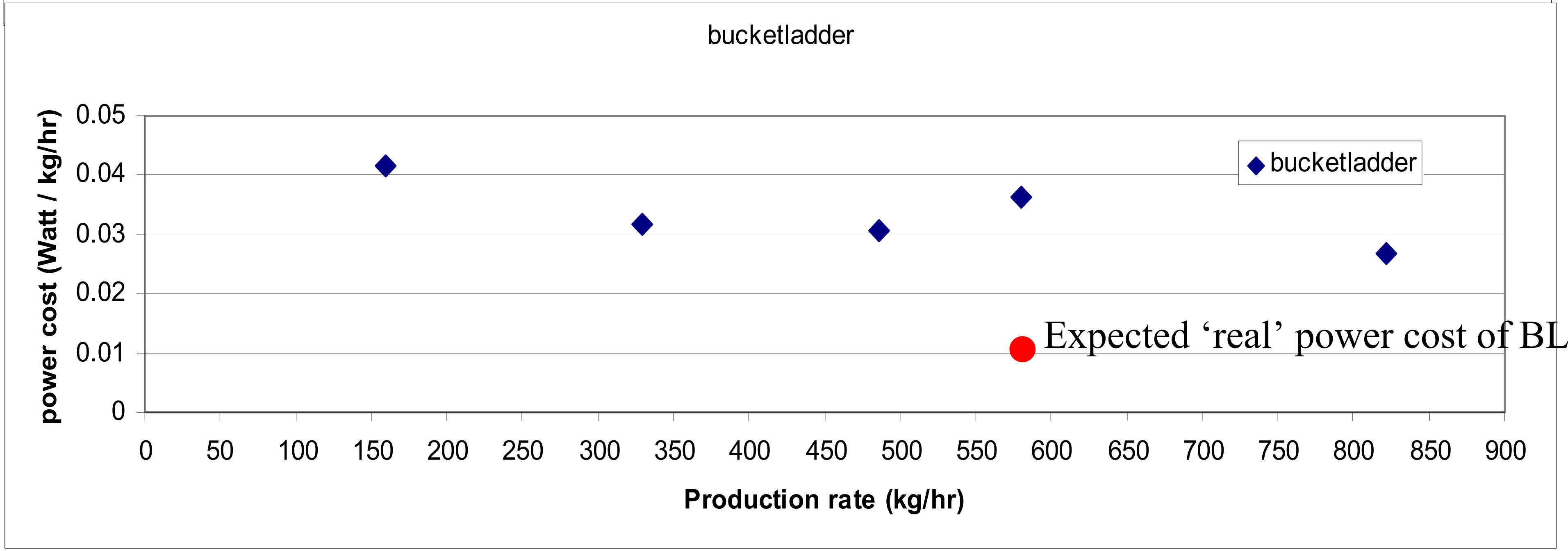
Design goals	and	actual experienced characteristics
500 kg/hr	→	actual 580 kg/hr (821 kg/hr = 1800 lbs/hr at 30 V)
10 kg	→	actually around 40 kg (cheap materials)
Dust resistant	→	works decently, no parts directly dust contaminated, except the chain
Easy maintenance	→	not yet easy enough
Cheap	→	$1800 for materials

Bucket Ladder Video

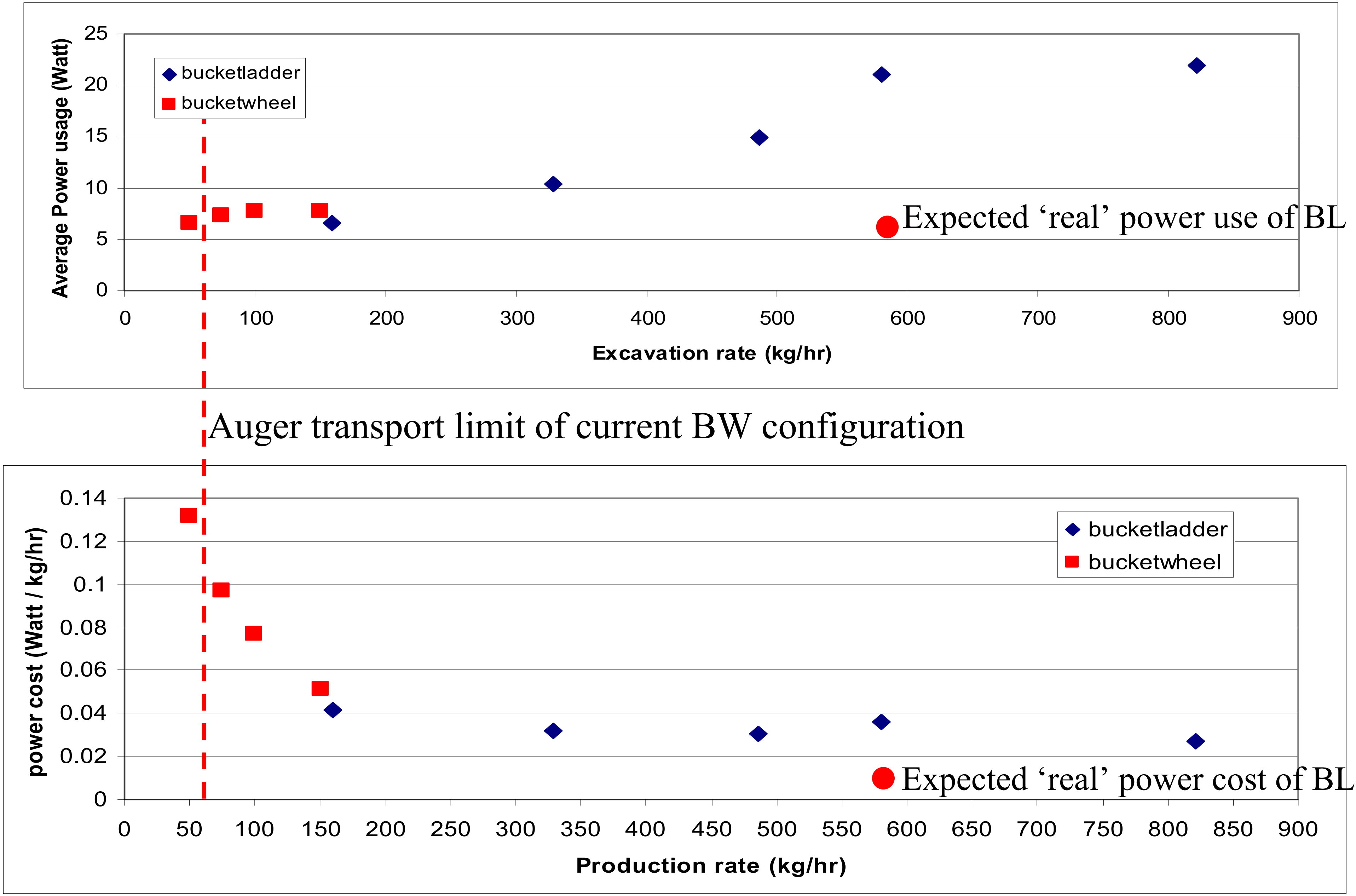
Video omitted for size reasons

Results of BucketLadder





Comparison BucketWheel & Bucketladder



Production Characteristics List

- Power usage per kg/hr using playsand
  - Bucket Wheel: 0.11 W/kg/hr at max. auger capacity
  - Bucket Ladder: 0.035 W/kg/hr on average
- Mass of current systems
  - Bucket Wheel/arm/auger around 20 kg
  - Bucket Ladder around 35 kg
- Motors required, used
  - Bucket Wheel has 4 (wheel rotation, auger, arm elevation, arm slew)
  - Bucket Ladder has 3 (Chain rotation, frame lateral movement, frame rotation) add a 4^{th} for slew of the arm

Design flaws of current prototypes

- BucketWheel
  - Bucket wheel bearing wear and material loss during discharge.
  - Auger prone to jamming, wear and tear
  - Auger has limited capacity
  - Increased rotation speed of wheel does not increase capacity of auger
  - Less convenient for other construction purposes
- BucketLadder
  - Too massive (cheap materials, not optimal)
  - Dumps sand on chain
  - Chains scrape over top of aluminum cover
  - Motor to chain axle connection has too much spacing
  - Not long enough
  - Chain type
  - Generates more dust when discharging

Operational Versatility

- Illustrate possible functions for each
  - Bucket Wheel
    - Selective excavation around obstacles with arm.
    - Load truck bin or processing hopper
  - Bucket Ladder
    - Digging holes, trenches and filling them as well
    - Making roads, berms
    - Covering objectives (e.g. habitats, cables)
    - Smoothing surface (e.g. road)
    - Load truck bin or processing hopper

Back of the Envelope numbers

- Trench (5km long, 0.5m deep, 0.2m wide) → 500 m3 (42 days)
- Road clearing (5km long, 3m wide, 5cm deep) → 750 m3 x2 (125 days)
- Foundation hole (1m x 1m x 1m, 35 deg slope) → 7 m3 (14 hours)
- Foundation (5m x 5m x 1m, 35 deg) →43.5 m3 (3.6 days)
- Berm (25m long, 3m high, 1m wide on top, 35 deg) →395 m3 (33 days)
- Cover habitat (5m diameter, 10 m long, 3 m layer half buried) →300 m3 (23 days)
- Astroparticle hole (10mx10mx10m+ramp) → 1275 m3 (106 days)

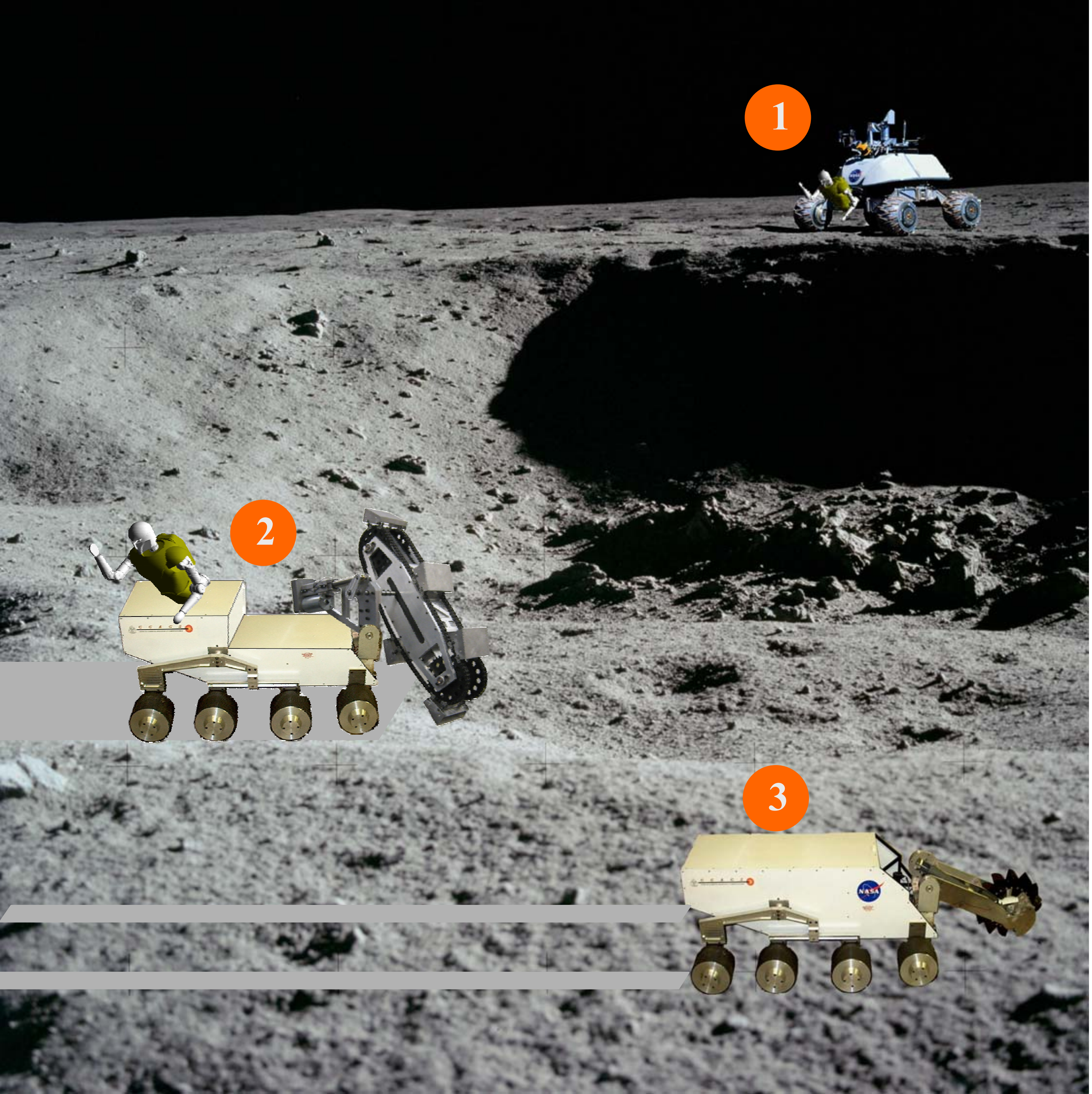
DUST generation illustration

Video omitted for size reasons

Note: dust is suspended in air, on Moon would follow ballistic trajectory.

Future Work

- Bucket Wheel
  - 2nd prototype:
    - Better bucket wheel design to reduce wear on bearings and motor power.
    - Optimize bucket shape/size and discharge for increased production rate, lower power and less material loss/plugging.
    - Inverse auger for material transport.
- Bucket Ladder
  - 2nd prototype:
    - Better connection between chain motor and axle
    - Optimize bucket shape/size and discharge for increased production rate, lower power and less dust contamination of the chain.
    - Make body smaller and main cogs significantly lighter.
    - Study dust contamination and wear of system components
    - Make the whole system longer



Example of robots operating on the lunar surface:

1

Scouting and mapping local terrain as well as enironment and engineering properties determination

2

Site preparation: road construction, laser range finder placement, digging and filling holes, cable trenches, berms, mining, etc.

3

Mining local resources for oxygen / hydrogen production (or other products)

Conclusions

- Both systems still in infancy and first or second generation prototypes
- Both systems show promise for interplanetary applications
- Bucketladder has significantly higher production rates
- Combination of excavation and transportation in the bucketladder pays of in less wear and tear and optimized power consumption required for transportation
- Bucketladder has significantly more versatility in use for construction and general applications.
- Further testing under different situations and in different applications of both systems is required
- Testing using different materials (simulant) is required
- System integration with a mobility platform is required