NATIONAL RECONNAISSANCE OFFICE

The Economics of Rocket Reusability

ICEAA 2023

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- Rocket reusability concepts
- Performance tradeoffs
- Launch service value chain
- WBS and cost drivers
- Model assumptions
- Launch cadence and rate assumptions
- Results and Conclusions

Rocket Reusability Concepts

- Reuse Scope
  - 1st Stage
  - 2nd Stage
  - Fairing
- Recovery approach
  - Horizontal
    - Wings
    - Advanced Avionics
  - Vertical
    - Advanced Avionics
    - Flight Control Surfaces
    - Parachutes
    - Propulsive Landing
    - Landing Legs
    - Air Bags

Rocket Lab helicopter attempting mid air capture of Electron booster.

Rocket Reusability Performance

- Expendable launch vehicles have superior mass to orbit capability due to significant fuel mass required for a propulsive landing

Mass to Orbit Capability		
Launch Vehicle	**Expended (lbs.)**	**Reusable (lbs.)**
Falcon 9 LEO[1]	50,265	38,400
Falcon Heavy LEO[1]	140,660	60,000
Falcon Heavy GTO[1]	59,000	18,000
Neutron LEO[2]	33,100	17,600

SpaceX Falcon 9 booster landing on drone ship.

Launch Customer Questions

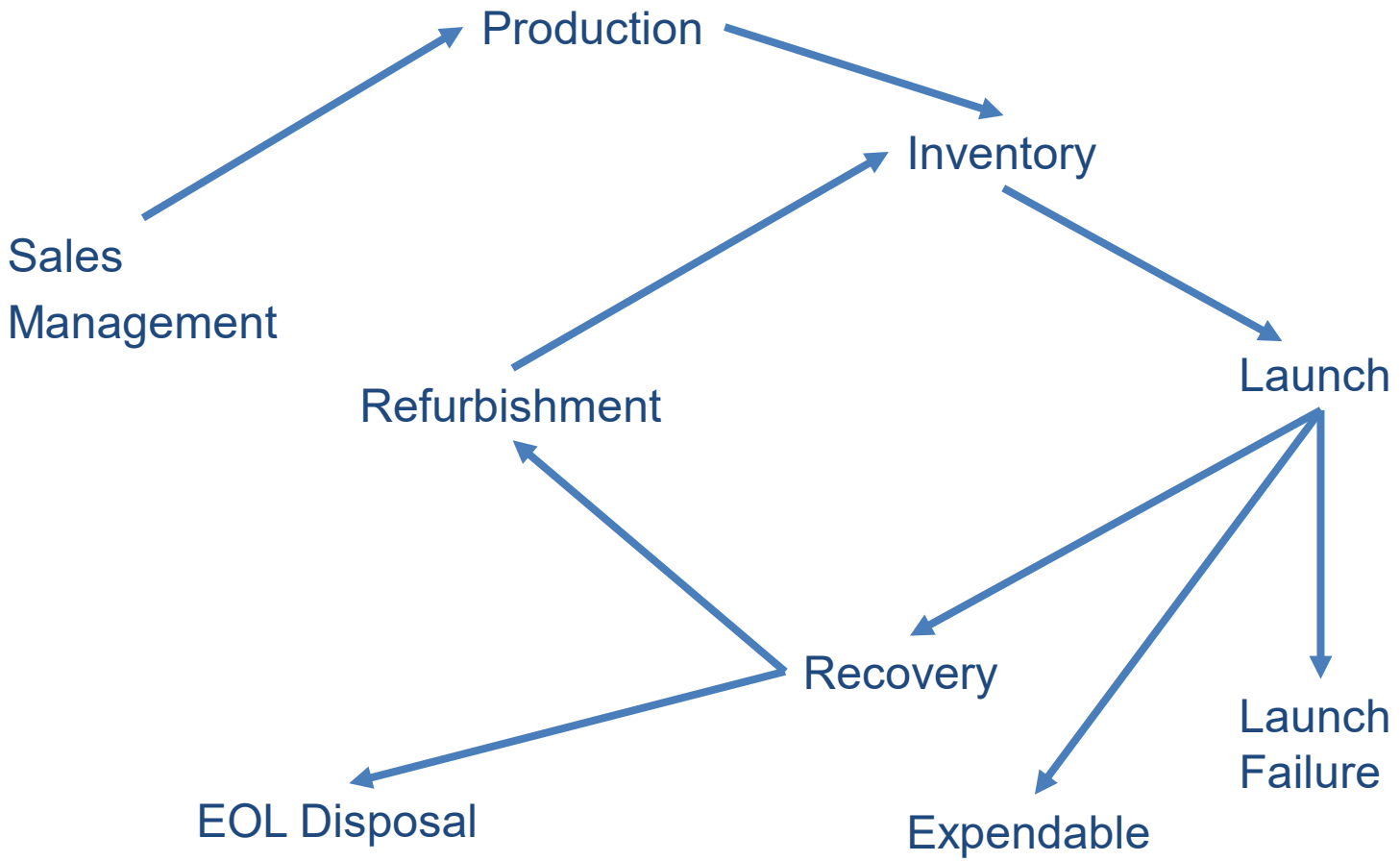
- What are the cost differences **per launch** between expendable and reusable launch services?
- What are the cost differences **per pound to orbit** between expendable and reusable launch services?
- How sensitive are launch costs to the maximum number of uses?
- How does reusability impact capital expenditure for production facilities?

Launch Service Value Chain

Non-Recurring Engineering

Facilities Capital Expense

- Factory
- Test Facilities
- Launch Pad
- Launch Ops Center



Notional Costs Disclaimer

- The cost model supporting this briefing has notional costs with gross approximations and assumptions for illustrative purposes only
- This briefing does not contain any proprietary information
- The model uses the Rocket Lab Neutron launch vehicle concept but is applicable to any reusability concept
- Rocket Lab is a publically traded company and discloses cost information and business plans in public quarterly reports and press releases

Launch WBS

WBS	WBS Description
1	Launch Vehicle System
1.1	Mission Integration
1.1.1	Mission Standard Integration
1.1.2	Mission Unique Integration
1.2	Mission Assurance
1.3	Supplier Readiness
1.4	Mission Unique Development/Design
1.5	System Engineering, Integration, Test, Program Management
1.6	Transportation
1.7	Launch Operations
1.7.1	Launch Support
1.7.1.1	Launch Crew (mate, checkout, launch)
1.7.1.2	P/L Encapsulation
1.7.2	Launch Operations SEPM
1.7.2.1	Launch Operations Program Management
1.7.2.2	Launch Operations System Engineering
1.7.3	Site Maintenance
1.7.3.1	Sustainment Propellants
1.7.3.2	Other Maintenance
1.7.4	Base Support
1.7.5	Range Operations Services
1.7.6	Propellants (Vehicle)

WBS	WBS Description
1.8	Launch Vehicle
1.8.2	Payload Accommodations
1.8.2.1	Payload Fairing
1.8.2.2	Payload Attach Fitting (Adapter)
1.8.2.3	Mission Unique Hardware
1.8.3	1st Stage
1.8.3.1	Booster Structure
1.8.3.2	Intertank Adapter & Skirts
1.8.3.3	Aft Transition Structure
1.8.3.4	Heat Shield
1.8.3.5	Booster Engines
1.8.3.6	Guidance and Control (Avionics)
1.8.4	2nd Stage
1.8.4.2	Interstage Adapters, Stub Adapters, Forward Adapters
1.8.4.3	Upper Stage Engine
1.8.4.4	Guidance and Control (Avionics)
1.8.7	Integration, Assembly, Test & Checkout (IAT&C)
1.8.8	Reuse
1.8.8.1	Capture
1.8.8.2	Refurbishment and Test
1.9	Training
1.10	Other (Amoritized NRE and Facilities)
1.10.1	NonRecurring Engineering
1.10.2	Facilities

Non-Recurring Costs

- Non-Recurring Engineering
  - Launch vehicle design
  - Engine design
  - Testing (static fire tests, pressurization tests, orbital test flights)

- Significant investment ($300M to $500M) for small or medium lift launch system[3]

Rocket Lab upper stage engine static fire.

Non-Recurring Costs

- Launch Complex
  - Launch Pad ($30M)[5]
  - Launch Operations Center ($16M)[5]

Rendering of Rocket Lab Launch Complex Wallops Island, VA

Rendering of Rocket Lab Neutron Production Facility at Wallops Island, VA.

- Production Facility ($160M)[4]
  - 250,000 sqft

Recurring Costs

- **Mission Integration**
  Mission Integration Control Documentation (ICD), mission design and performance definition, flight software parameters, environmental analysis, guidance system analysis, coupled loads analysis, thermal analysis, separation analysis, electrical analysis
- **Launch Operations**
  Receive, inspect, store, process, assemble, checkout, monitor, test, conduct launch operations, control, track, recover (as applicable)
- **Payload Accommodations**
  Considerations must be taken into account to protect the payload from unacceptable environmental conditions during flight
- **1st Stage Production**
  Structures and mechanisms, propulsion system (rocket engines), reaction control system, environmental controls, recovery system, avionics
- **2nd Stage Production**
  Structures and mechanisms, propulsion system (rocket engines), reaction control system, environmental controls, avionics
- **Fairing Production**
  Aerodynamic shroud and equipment mated to the launch vehicle that protects the Space Vehicle from external environments and contamination.
- **1st Stage Recovery and Refurbishment**
  Recovery, transportation, inspection, cleaning, repair, refurbishment, replacement, testing and/or checkout
- **Fuel**
  Propellant, oxidizer

Rocket Lab Neutron schematic.

Rate Assumptions and Constraints

- Model investigates the sensitivity of total cost and average cost per launch
  - Launch cadence (10-100 launches per year)
  - % of planned expendable launches
  - Max number of uses for 1st Stage/fairing

  } Variable assumptions

  - 1st Stage Refurbishment Rate
  - 1st Stage Production Rate
  - 2nd Stage Production Rate

  } Fixed assumptions

- Model incorporates a system of equations to determine the minimum production quantities and facilities investments required to meet rate constraints

Model Assumptions and Constraints

Facilities Capital Expense	Build Cost $M	Sqft	Amortization (years)
Neutron Production and Refurbishment Facility	160	250,000	10
Launch Pad	30		10
Launch Ops Center	16		10

Non-Recurring Engineering	Cost $M		Amortization (years)
NRE Development Costs	450		5

Recurring Costs	REC $M	T1 $M	Max Uses
Mission Integration	6		
Launch Operations	7		
Payload Accommodations	2		
1st Stage Production		80	20
2nd Stage Production		20	1
Fairing Production		w/ 1st Stage	20
1st Stage Refurbishment Cost	5		

Production Time Constraints per Facility		
Minimum Turn around per Launch Pad	7	days
Time to refurbish 1st stage	21	days
Time to produce 1st stage	30	days
Time to produce 2nd stage	10	days

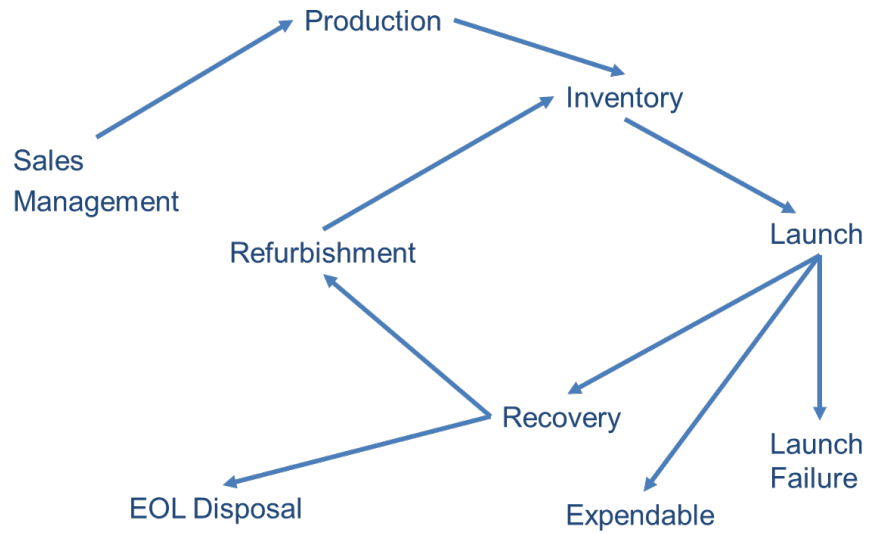
	CIC	
Cost Improvement Curve	0.85	

Launch Vehicle Performance to LEO		
Mass to Orbit Expended	33,100	lbs.
Mass to Orbit Reusable	17,600	lbs.

Non-Recurring Engineering

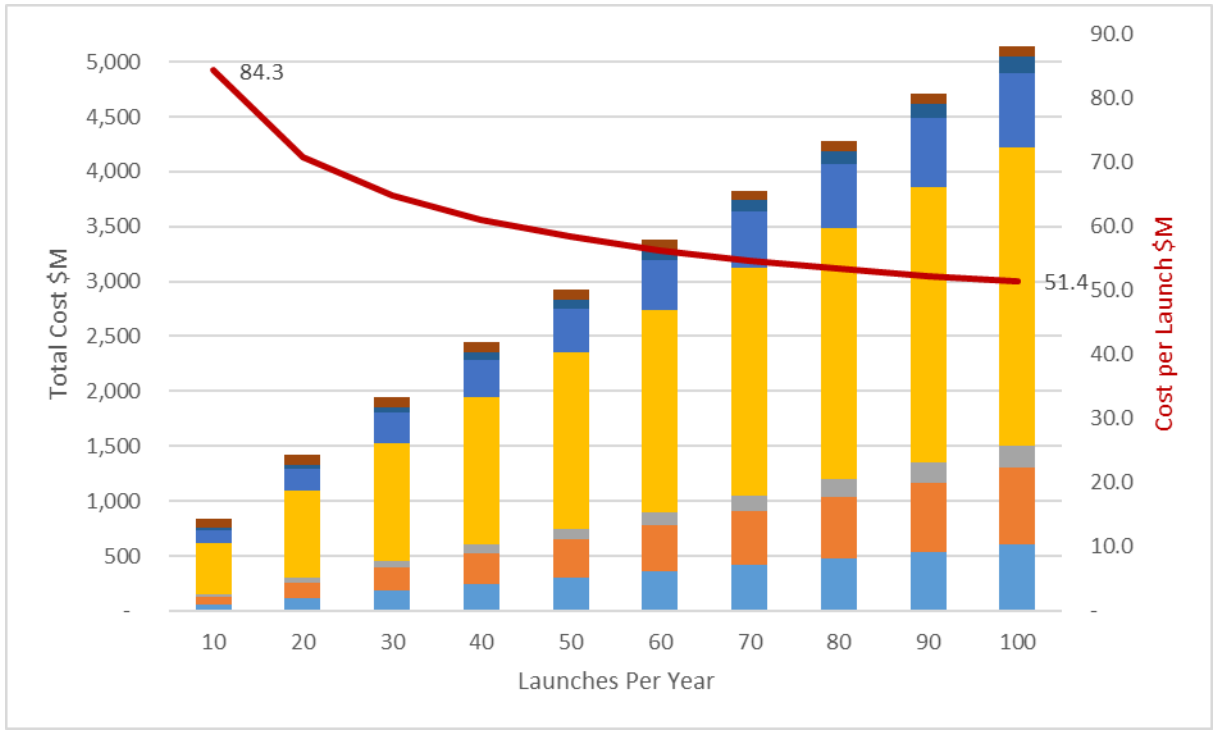
Facilities Capital Expense
- Factory
- Test Facilities
- Launch Pad
- Launch Ops Center

Launch Service Value Chain

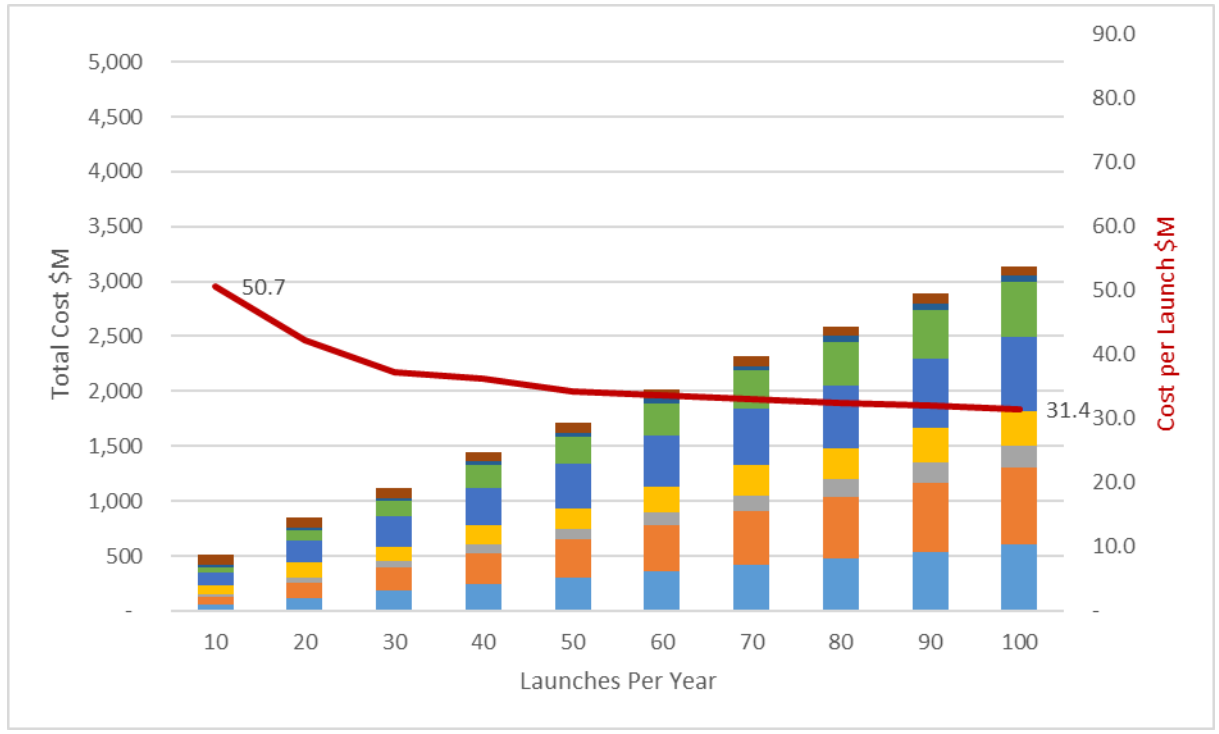


Model – 100% Expendable vs Reuse

100% Expendable



100% Reuse (20 uses max per booster)



- Mission Integration
- Payload Accommodations
- 2nd Stage
- Facilities
- Average Cost Per Launch
- Launch Ops
- 1st Stage
- Reuse- Capture & Refurbishment
- NRE-Amortization

Model – Cost per lb to LEO

	10	20	30	40	50	60	70	80	90	100
100% Exp	$2,548	$2,141	$1,958	$1,845	$1,766	$1,698	$1,652	$1,614	$1,581	$1,552
Reuse 5	$3,200	$2,670	$2,455	$2,330	$2,264	$2,199	$2,151	$2,110	$2,075	$2,055
Reuse 10	$2,881	$2,400	$2,209	$2,100	$2,046	$1,990	$1,949	$1,914	$1,885	$1,870
Reuse 20	$2,881	$2,400	$2,115	$2,035	$1,945	$1,867	$1,849	$1,830	$1,787	$1,784

Mass to Orbit Capability		
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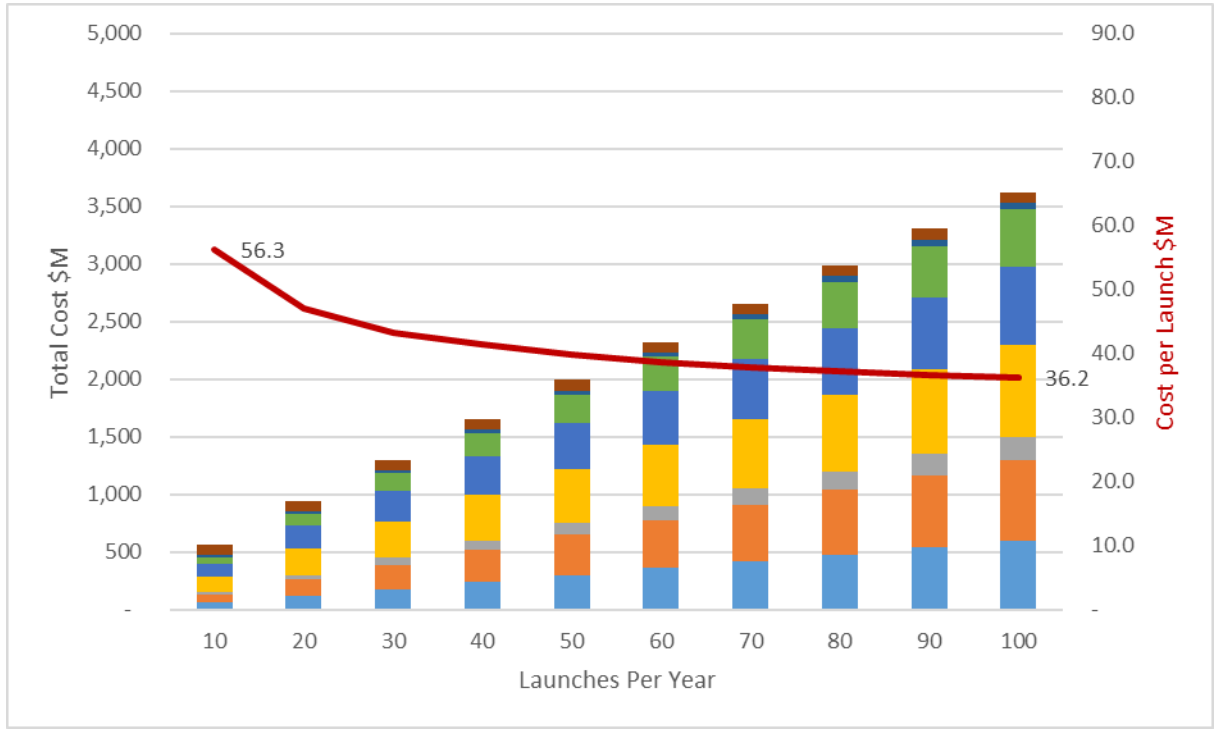
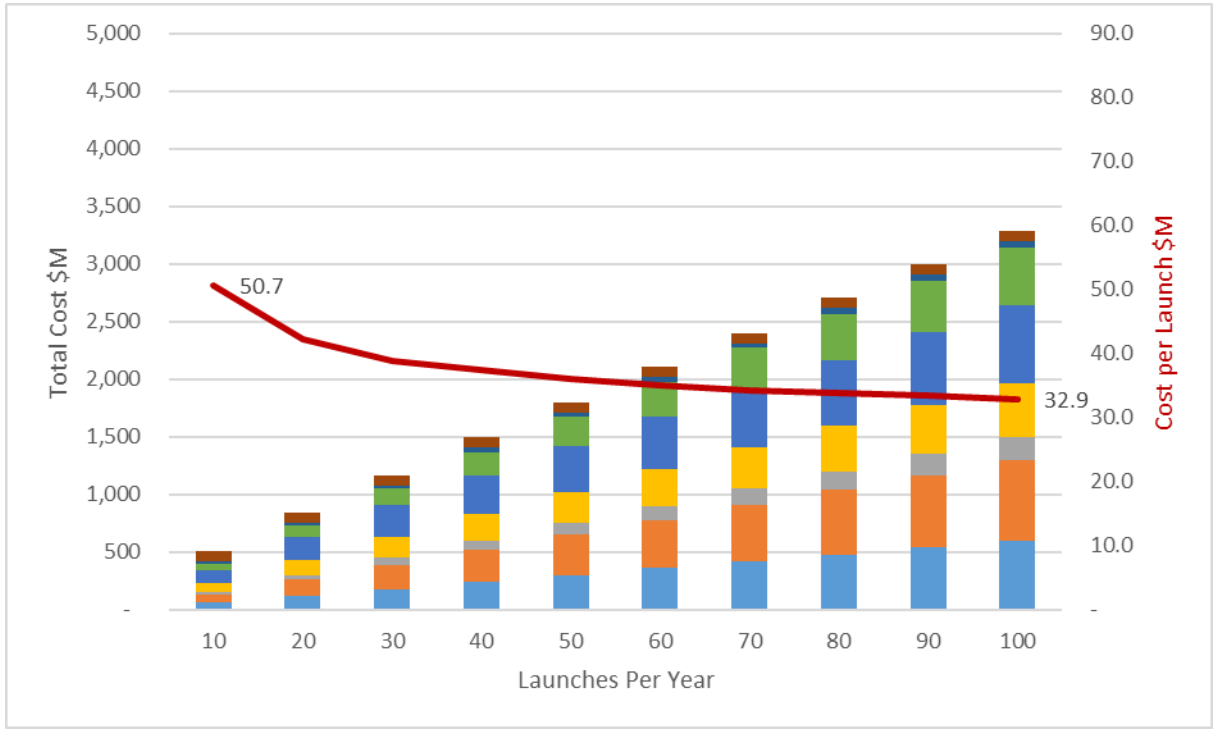
Sensitivity to # of reuses

100% Reuse (5 uses max per booster)



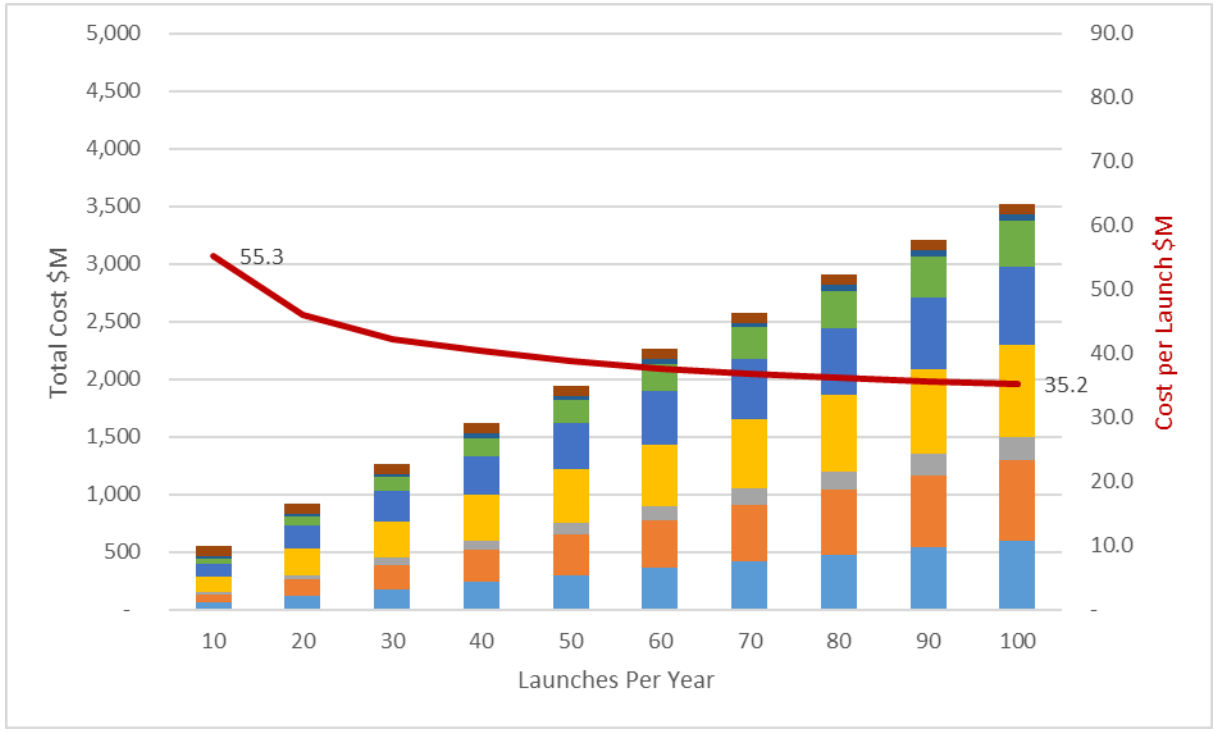
100% Reuse (10 uses max per booster)



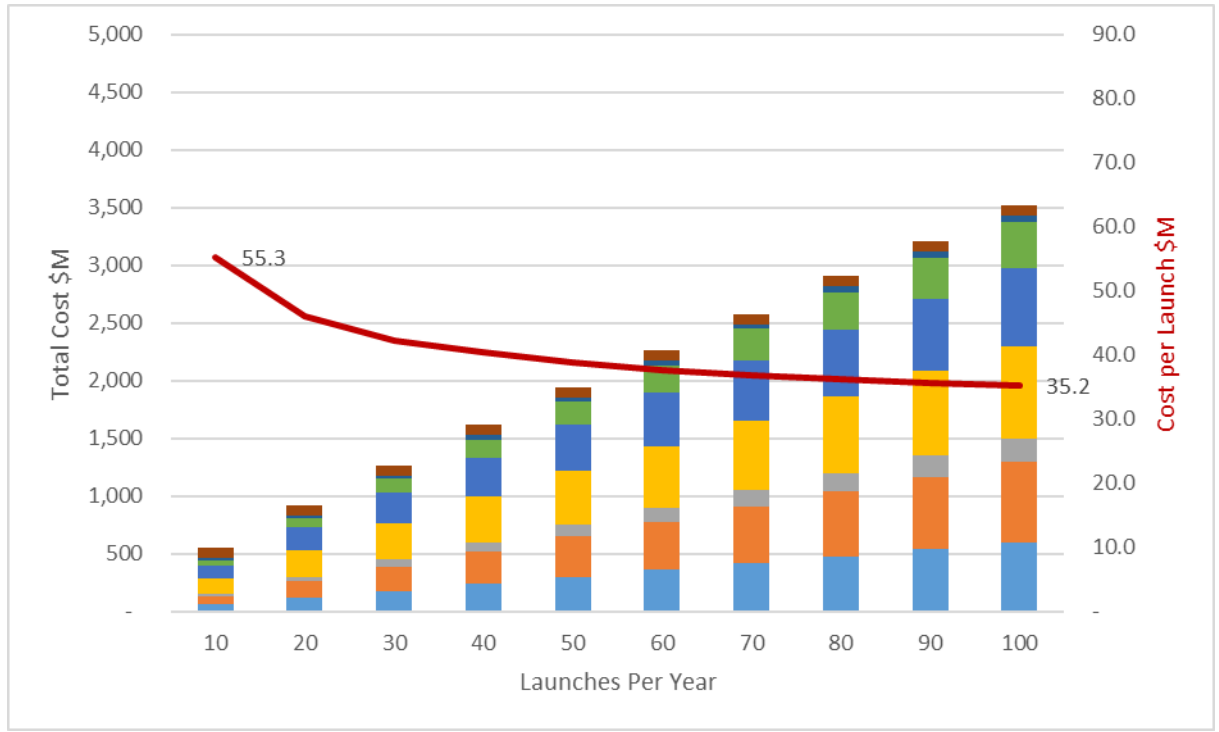
- Mission Integration
- Payload Accommodations
- 2nd Stage
- Facilities
- Average Cost Per Launch
- Launch Ops
- 1st Stage
- Reuse- Capture & Refurbishment
- NRE-Amortization

Model – 20% Expendable

20% Expendable (5 uses max per booster)

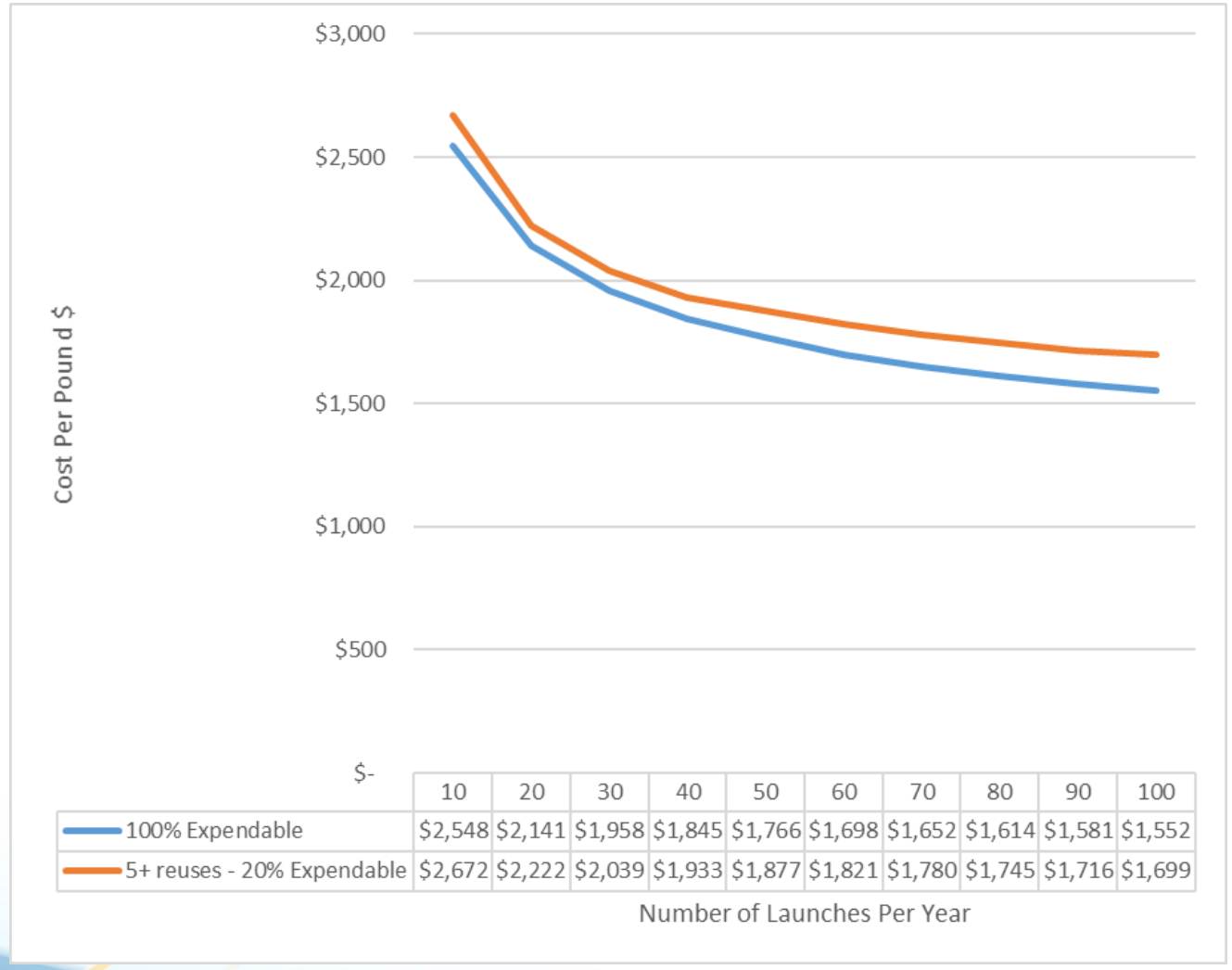


20% Expendable (10 uses max per booster)



If a sizeable portion of your manifest uses expended launch vehicles, then higher max reuses do not reduce launch costs.

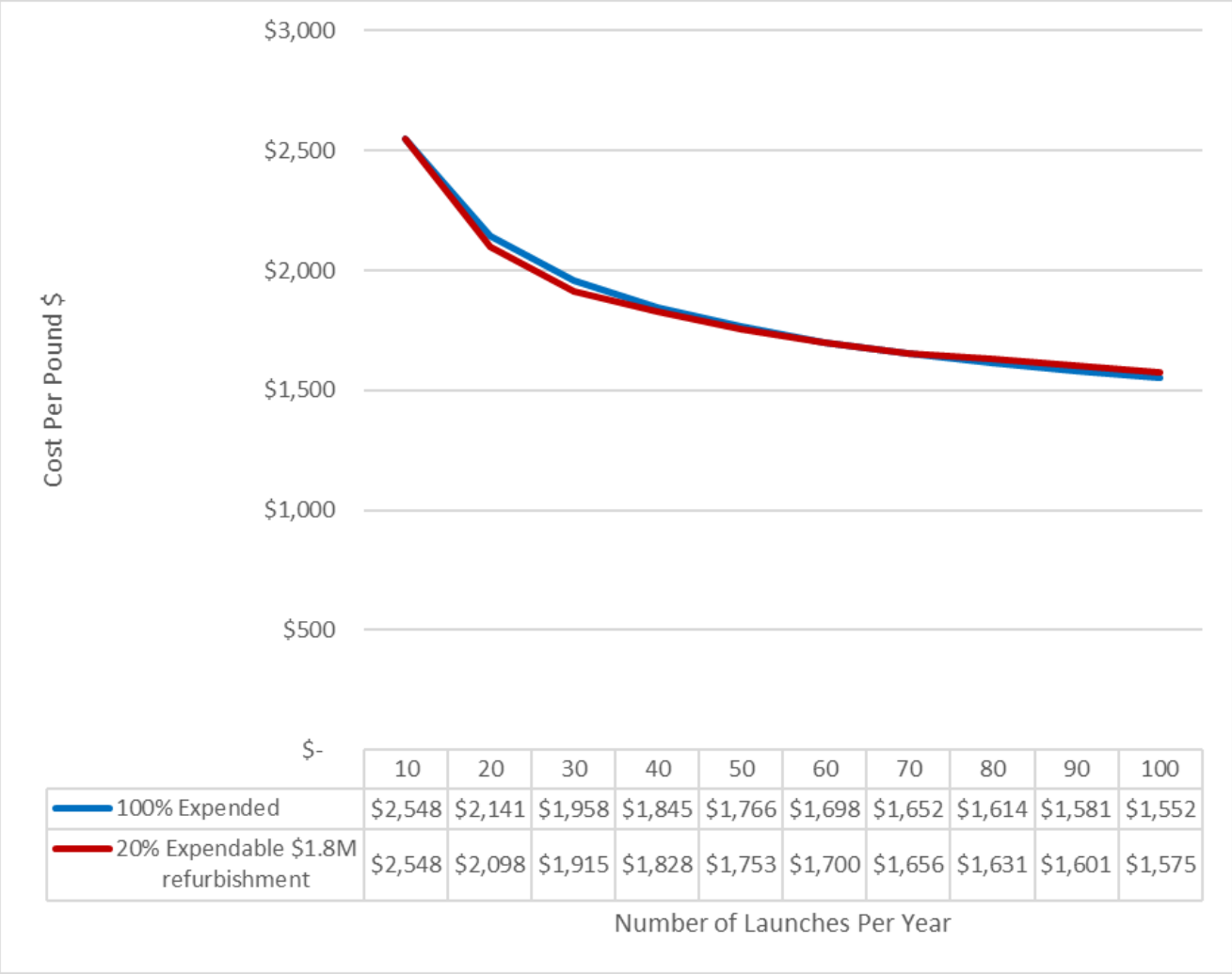
Model – Cost per lb. to LEO



	10	20	30	40	50	60	70	80	90	100
100% Expendable	$2,548	$2,141	$1,958	$1,845	$1,766	$1,698	$1,652	$1,614	$1,581	$1,552
5+ reuses - 20% Expendable	$2,672	$2,222	$2,039	$1,933	$1,877	$1,821	$1,780	$1,745	$1,716	$1,699

5+ reuses and 20% expendable reduces cost/lb. but does not get lower per lb. than 100% expended

Model – Cost per lb. to LEO



	10	20	30	40	50	60	70	80	90	100
100% Expended	$2,548	$2,141	$1,958	$1,845	$1,766	$1,698	$1,652	$1,614	$1,581	$1,552
20% Expendable $1.8M refurbishment	$2,548	$2,098	$1,915	$1,828	$1,753	$1,700	$1,656	$1,631	$1,601	$1,575

Reducing $5M refurbishment to $1.8M is the break even point for cost/lb. between 100% expended and 20% expended scenarios

Conclusion

- Rocket reusability can reduce launch costs on a per launch basis after accounting for competing cost pressures from cost improvement curves, facilities CAPEX, and refurbishment
- Reusability can reduce the cost of expended missions assuming they are using a previously flown booster
- Cost of mass to orbit ($/lb.) may be lower for fully expended launch vehicles than those flying recoverable boosters*

* If we are using entire vehicle capability

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References

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2. "Rocket Lab Unveils Plans for New 8-Ton Class Reusable Rocket for Mega-Constellation Deployment" (Press release). Business Wire. 1 March 2021.
3. "SpaceX goes there-seeks government funds for deep space". Ars Technica. 13 July 2017.
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6. “Rocket Lab targets $50 million launch price for Neutron rocket to challenge SpaceX's Falcon 9”. CNBC. March 24, 2023.

Acronym List

BPO – Business Plans and Operations
CAAG – Cost and Acquisition Assessment Group
CAPEX – Capital Expense
EOL – End of life
GTO – Geosynchronous transfer orbit
LEO – Low earth orbit
OPS – Operations