Emerging US Space Launch Trends and Space Solar Power

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Contents

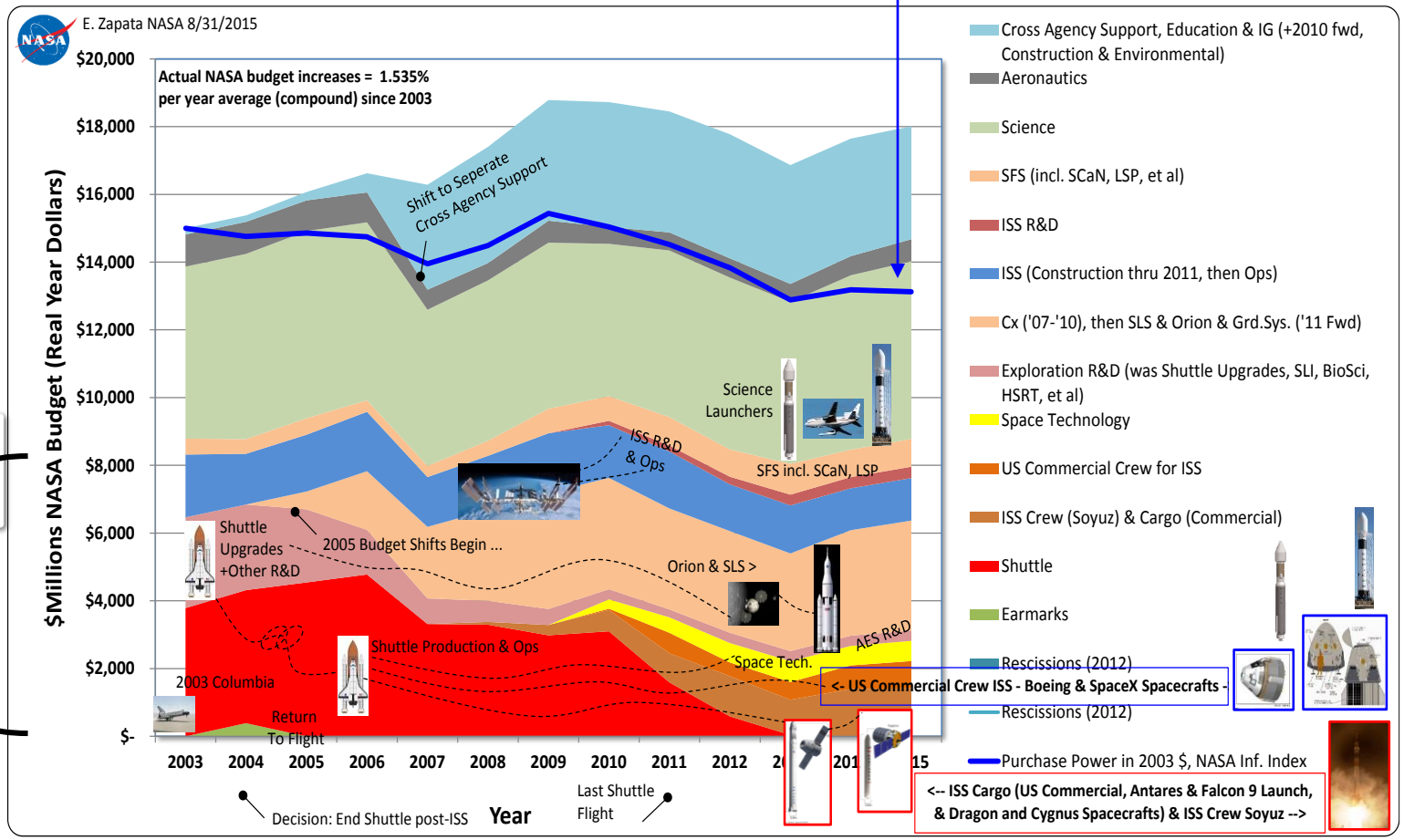
Purpose

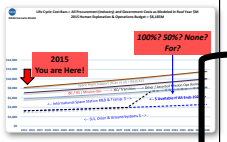
- Provide an overview of emerging US space launch and space systems trends that are critical to the future of new space business cases – like space solar power

- But first…some background, some visions, and some needs.

Background – The (Slightly) Bigger Picture

- The Entire NASA Budget since 2003 – *and Purchasing Power*

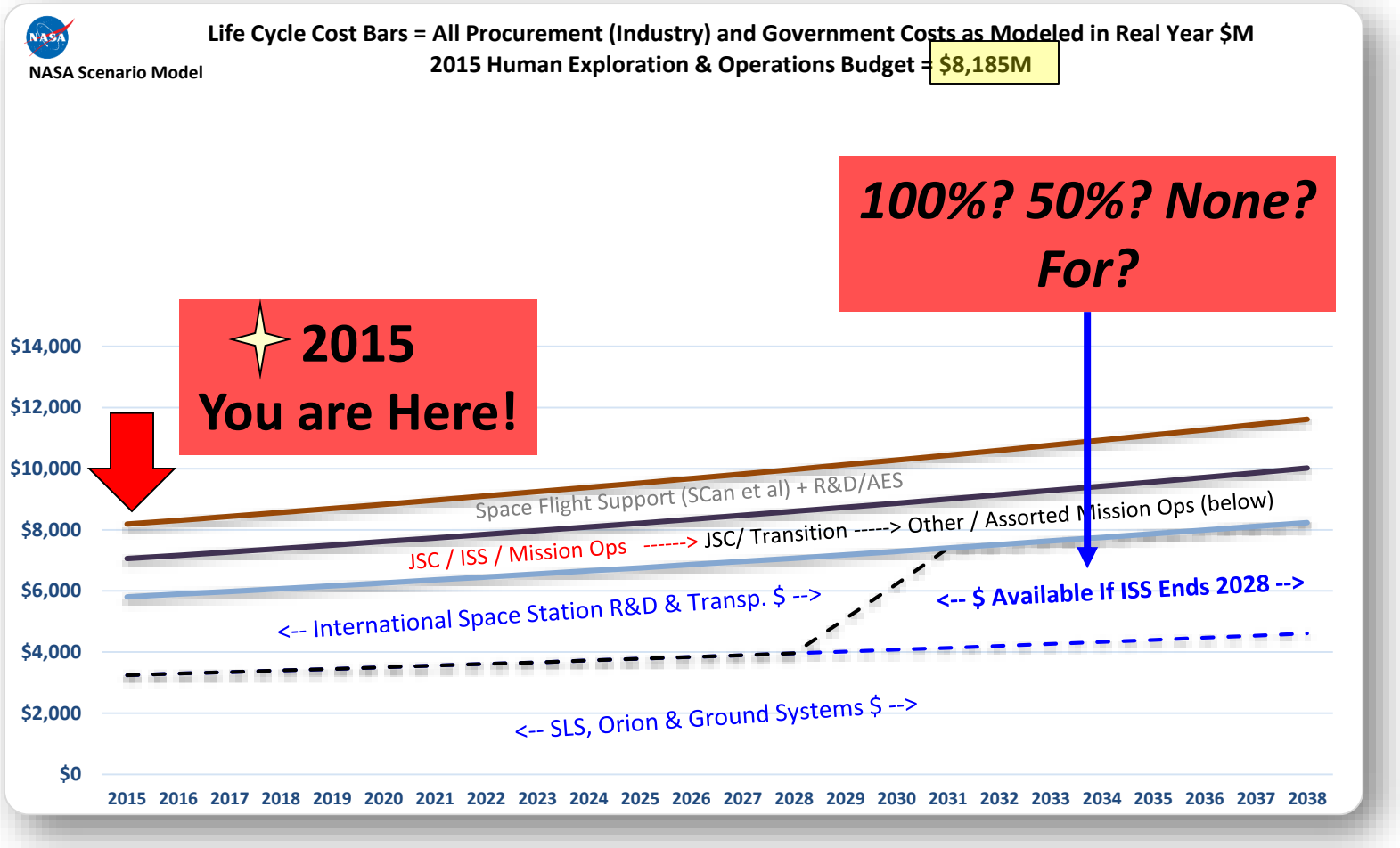




HEO

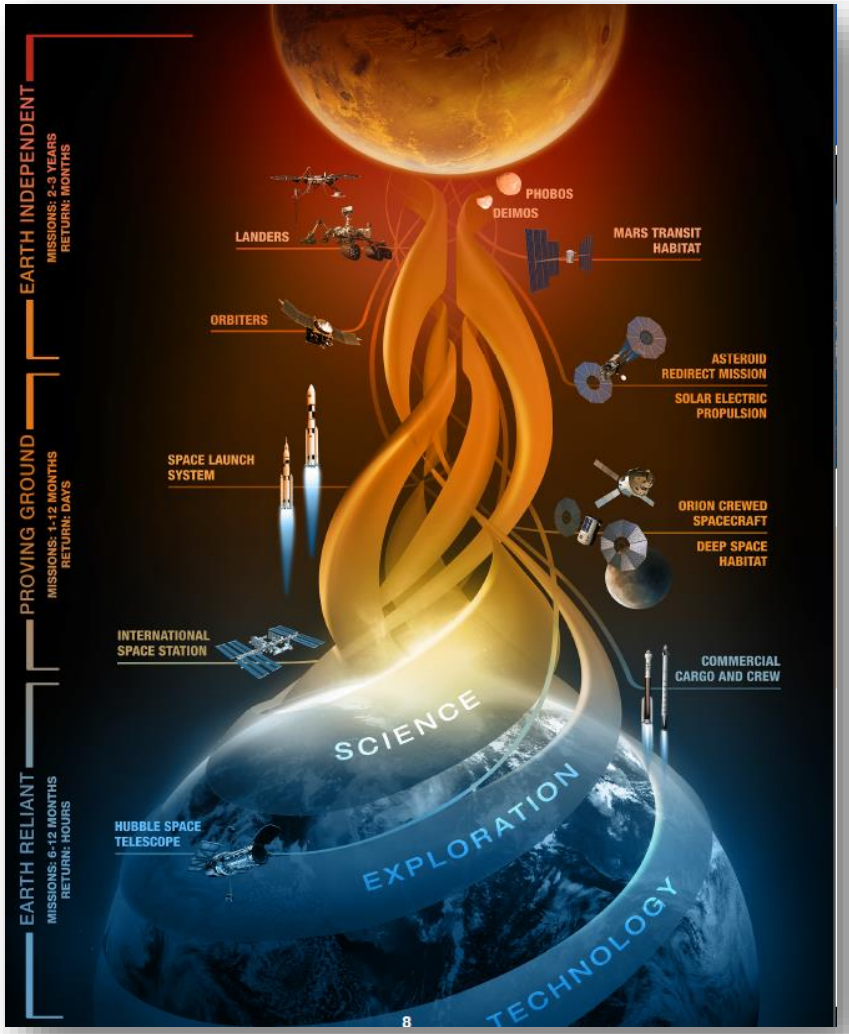
Background – The HEO Picture

- The Human Exploration & Operations (only) part of the NASA Budget



Visions of Mars

- ISS, SLS, Orion
- Then Deep Space Habitat
- Then Transit Habitat (& Propulsion/Power)
- Then – not shown:
  - In-Space Stage(s), Assorted
  - Mars Landers
    - Descent
    - Ascent/Return
    - Cargo/Crew
  - Mars (Surface) Habitats
  - Taxis
  - Rovers
  - Power Plants
  - In-situ Resource Plants
  - Equipment
    - :



http://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf *(NASA)*

Visions of Mars – or not?

- National Research Council 2014

"Human Spaceflight Budget Projections. With current flat or even inflation-adjusted budget projections for human spaceflight, there are no viable pathways to Mars.

Potential Cost Reductions. The decadal timescales reflected above are based on traditional NASA acquisition. Acceleration might be possible with substantial cost reductions resulting from

a. More extensive use of broadly applicable commercial products and practices

b. Robust international cost sharing (that is, cost sharing that greatly exceeds the level of cost sharing with the ISS)

c. Unforeseen significant technological advances in the high-priority capabilities."

Visions of Mars – or maybe?

- Jet Propulsion Laboratory 2015 – Price, Baker, Naderi

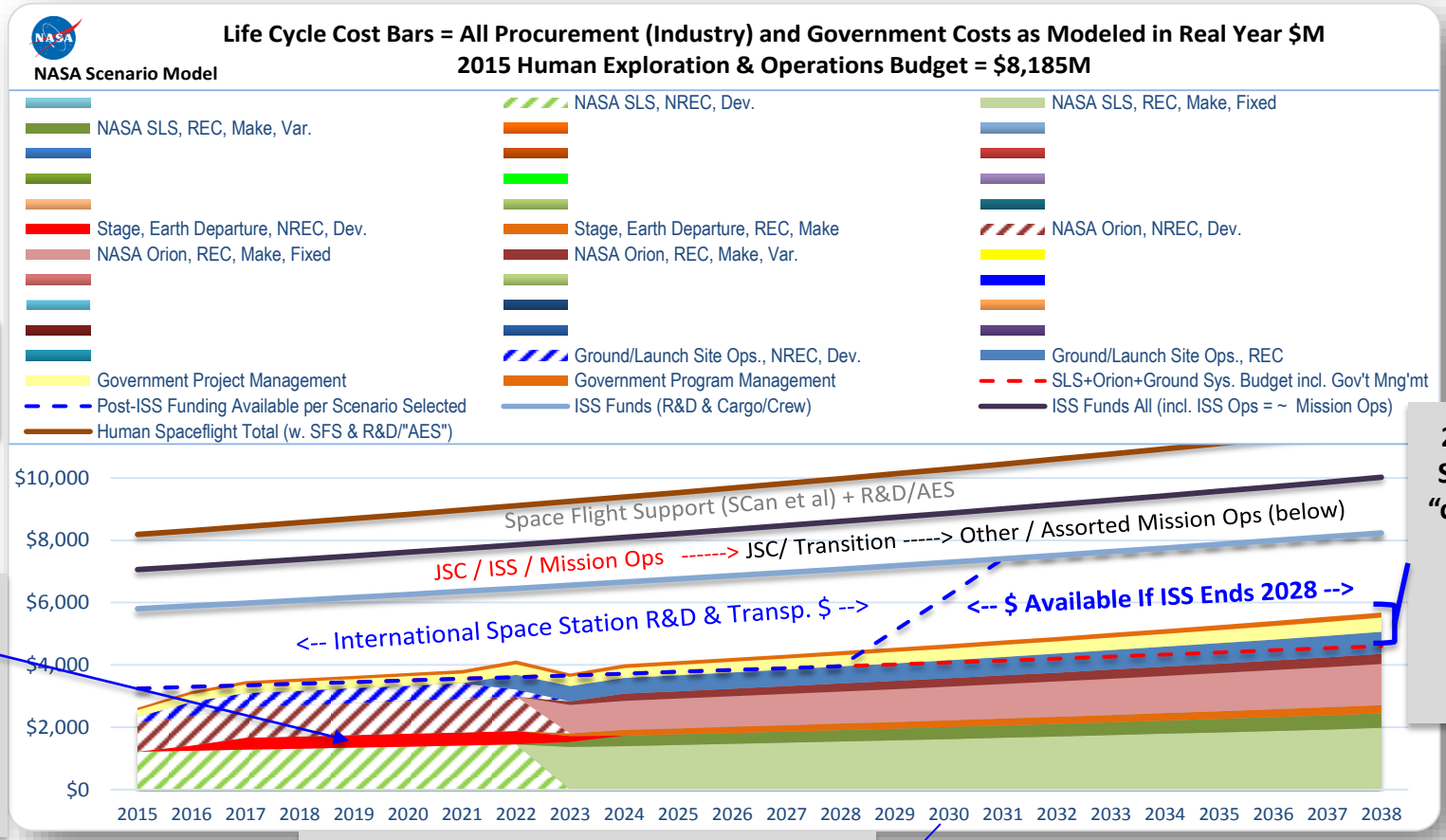
"This was the motivation for this study of a ''minimal architecture'' based on a high technology readiness level and the concept of staggered mission campaigns, in order to stay close to the current HSF annual budget adjusted for inflation.

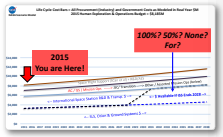
This work was aimed at showing an example (an existence proof) that journeys to Mars could be doable using technologies that NASA is currently pursuing and on a time horizon of interest to stakeholders -- without large spikes in NASA budget."

http://spirit.as.utexas.edu/%7Efiso/telecon/Price_5-20-15/Price_5-20-15.pdf

Visions of Mars – the Scope of the Challenge

- SLS with Larger Upper Stage (~100+t>LEO)
- 2 SLS/Year, 1 w. Orion as Payload. Other Payload TBD (No $ available)





HEO

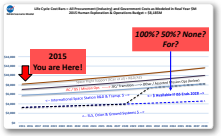
Upper Stage "challenge"
No $ - Exceeds Usual Budget Growth

2 X ~100t SLS a year "challenge"
No $ - Exceeds Usual Budget Growth

Replace SRB/SRM, "Advanced Booster" by 2030 for SLS ~130t>LEO
No $ - at Current Budget Growth/Inflation

Visions of Mars – the Scope of the Challenge

- Or alternate futures? Other stakeholders.



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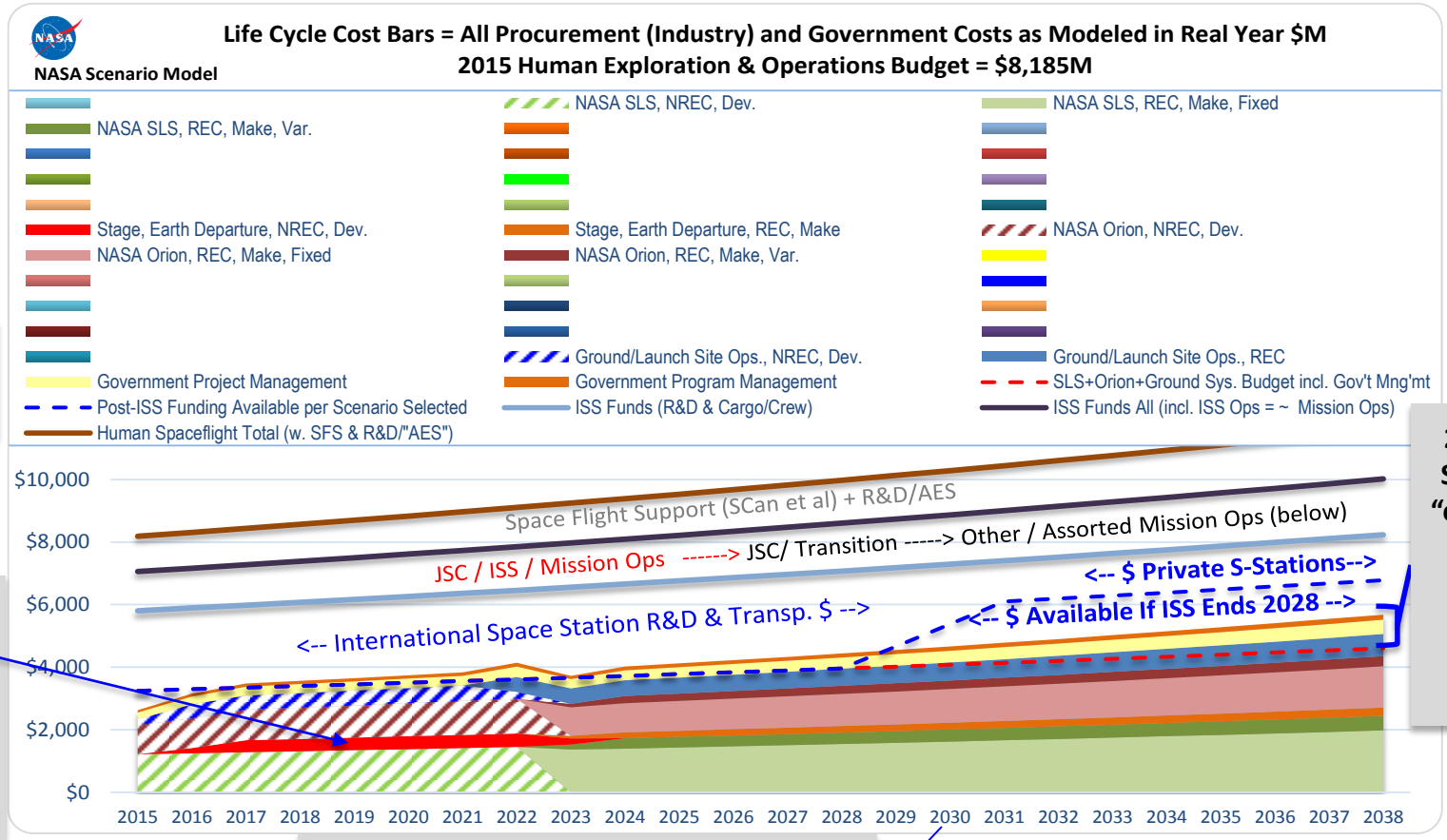


2 X ~100t SLS a year "challenge"
No $ - Exceeds Usual Budget Growth

Replace SRB/SRM, "Advanced Booster" by 2030 for SLS ~130t>LEO
No $ - at Current Budget Growth/Inflation

Needs

- Option 1: Getting More Money?

  "Meaningful human exploration is possible under a less-constrained budget, ramping up to approximately $3 billion per year in real purchasing power above the FY 2010 guidance in total resources."

  -Seeking a Human Spaceflight Program Worthy of a Great Nation, by The Review of US Human Spaceflight Plans Committee

  - Also NRC 2014, et al

- Option 2: Getting More Time? (& Money, & Doing Less)

  - JPL 2015 et al
  - Mars landing by 2039
  - Assumption of infinite patience – if neglecting certain stakeholders

There's a reason stakeholders are called "stake" holders

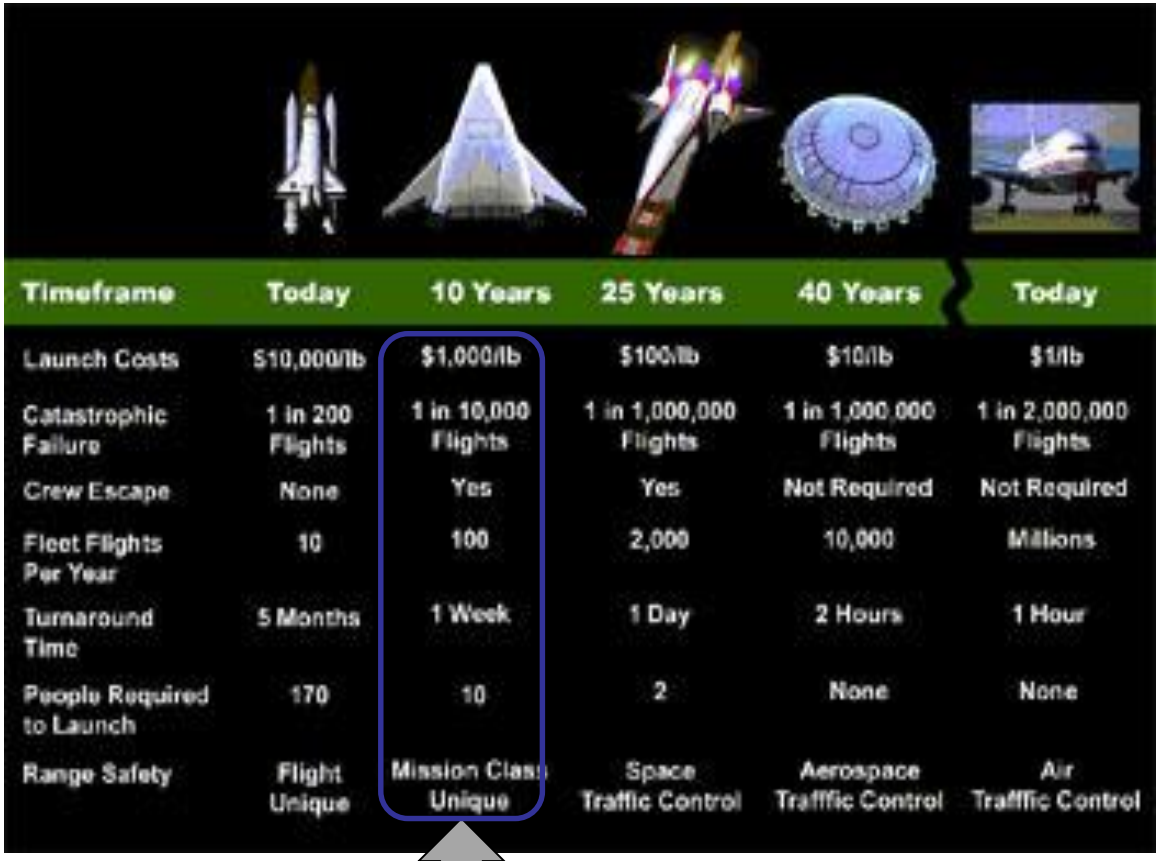
Needs

- Option 3: Adapting? – like Smith Corona?
  - For a time, saw threat as typewriters manufactured abroad
    - Response: Plants moved abroad
  - For a time, created “personal word processors” –advanced for their time
    - Why use someone else’s software?
    - Why use someone else’s electronics?
    - Why use someone else’s floppies?
    - Numerous advantages over those “PCs”
  - Bankruptcy 1995

Adapting - right to the end

Visions of Launch Affordability

…Once upon a time…the Reusable Launch Vehicle program, NASA, late 1990's

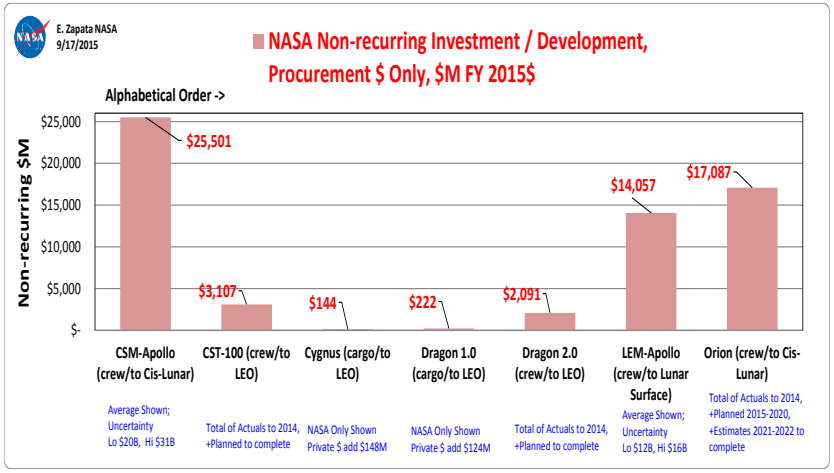


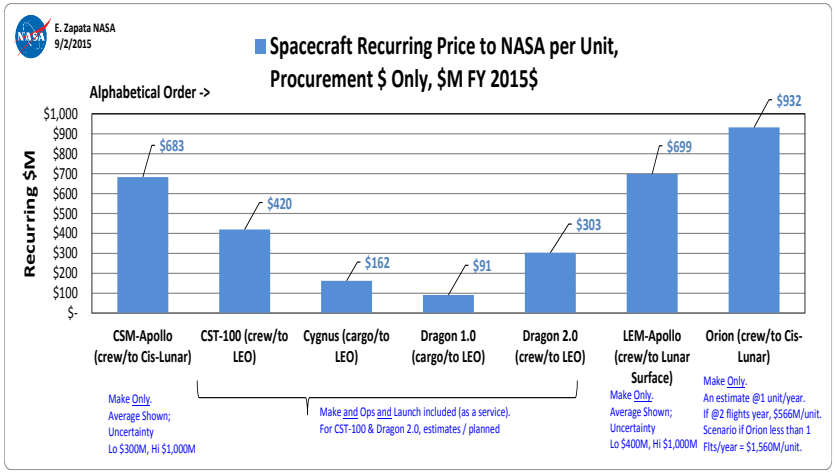
Timeframe	Today	10 Years	25 Years	40 Years	Today
Launch Costs	$10,000/lb	$1,000/lb	$100/lb	$10/lb	$1/lb
Catastrophic Failure	1 in 200 Flights	1 in 10,000 Flights	1 in 1,000,000 Flights	1 in 1,000,000 Flights	1 in 2,000,000 Flights
Crew Escape	None	Yes	Yes	Not Required	Not Required
Fleet Flights Per Year	10	100	2,000	10,000	Millions
Turnaround Time	5 Months	1 Week	1 Day	2 Hours	1 Hour
People Required to Launch	170	10	2	None	None
Range Safety	Flight Unique	Mission Class Unique	Space Traffic Control	Aerospace Traffic Control	Air Traffic Control

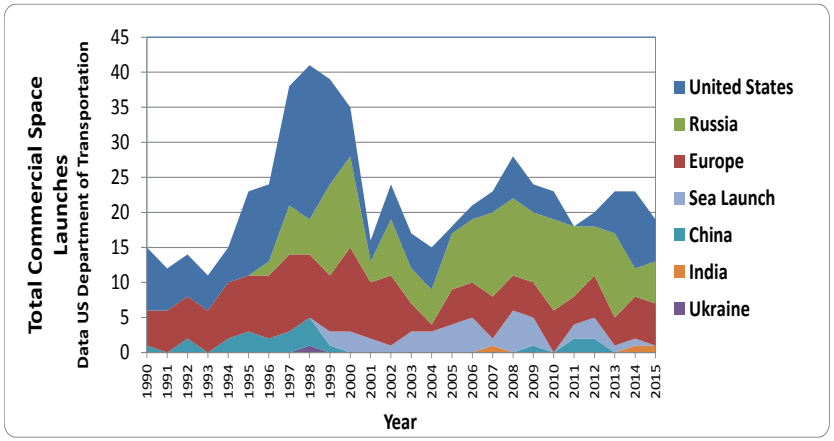
$1000/lb = $2,222/kg

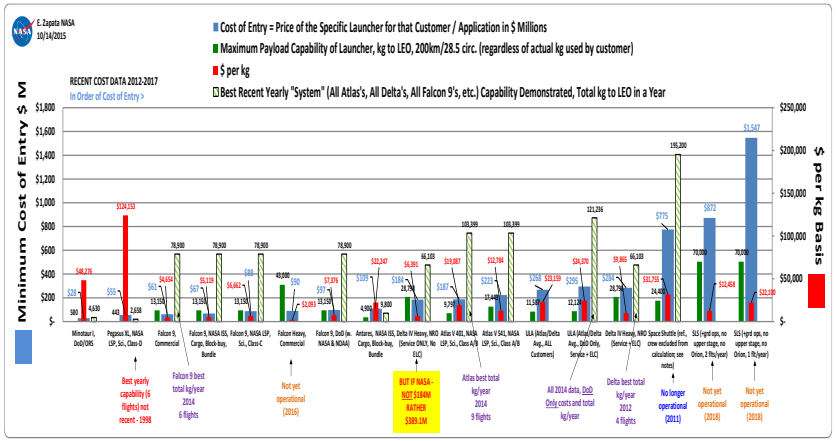
Affordability – How are we doing?

- **What do the numbers tell us?**







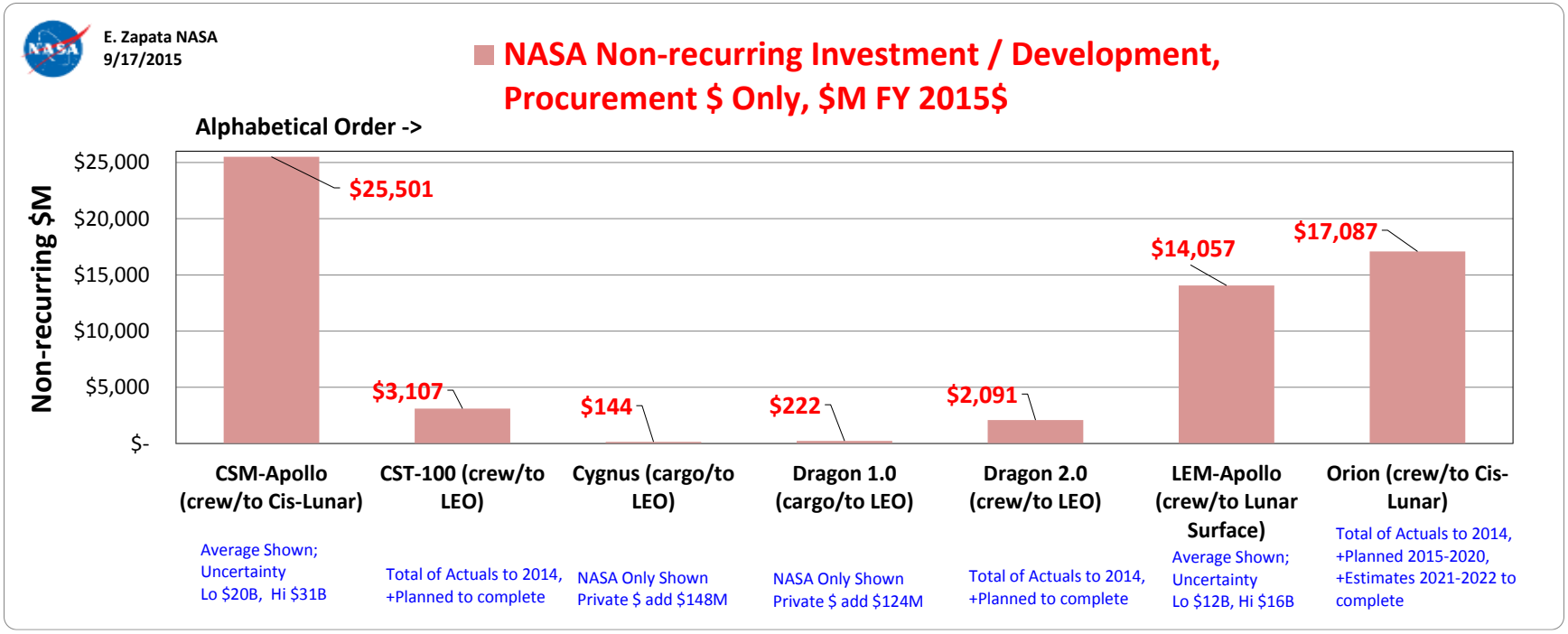


Emerging Space

Spacecraft Cost Data - Development

(Cost as Price to NASA)

- Holistic view, recent/old, cargo/crew, commercial/cost-plus

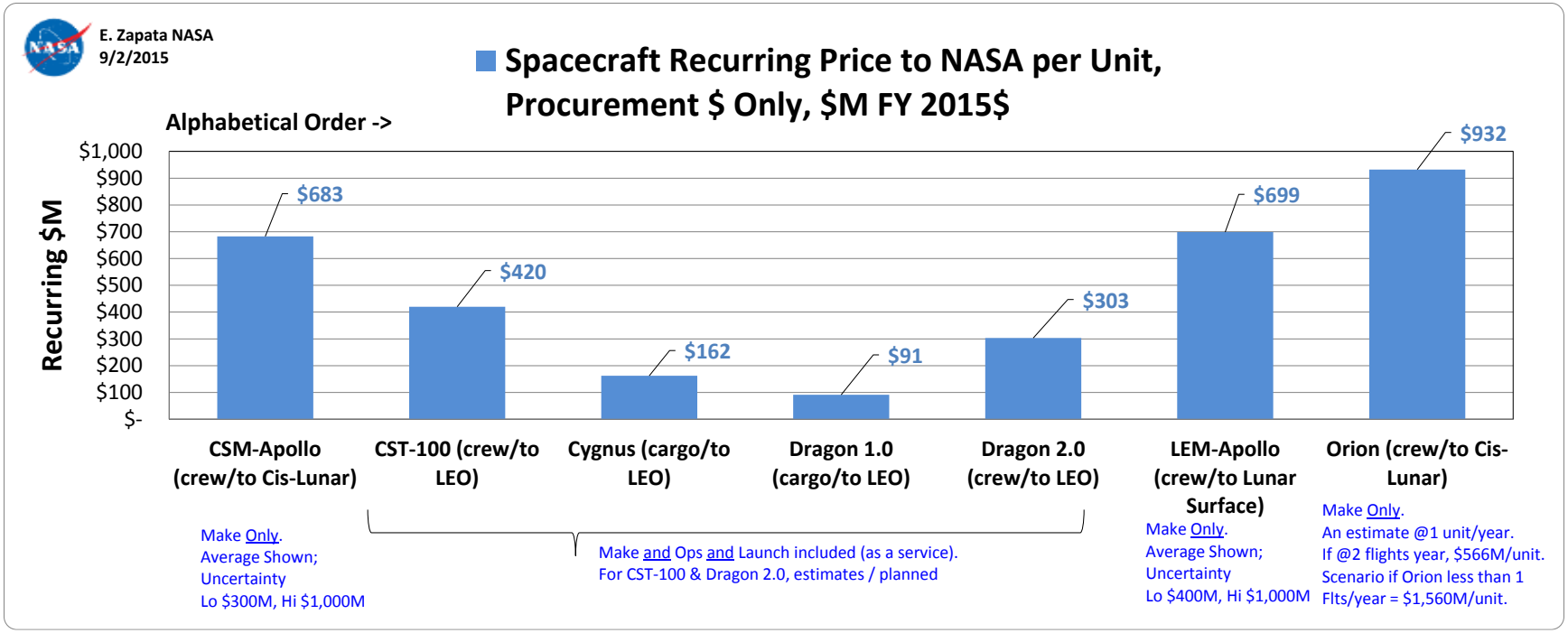


Emerging Space

Spacecraft Cost Data – Manufacturing - "Thru Delivery"

(Cost as Price to NASA)

- Holistic view, recent/old, cargo/crew, commercial/cost-plus



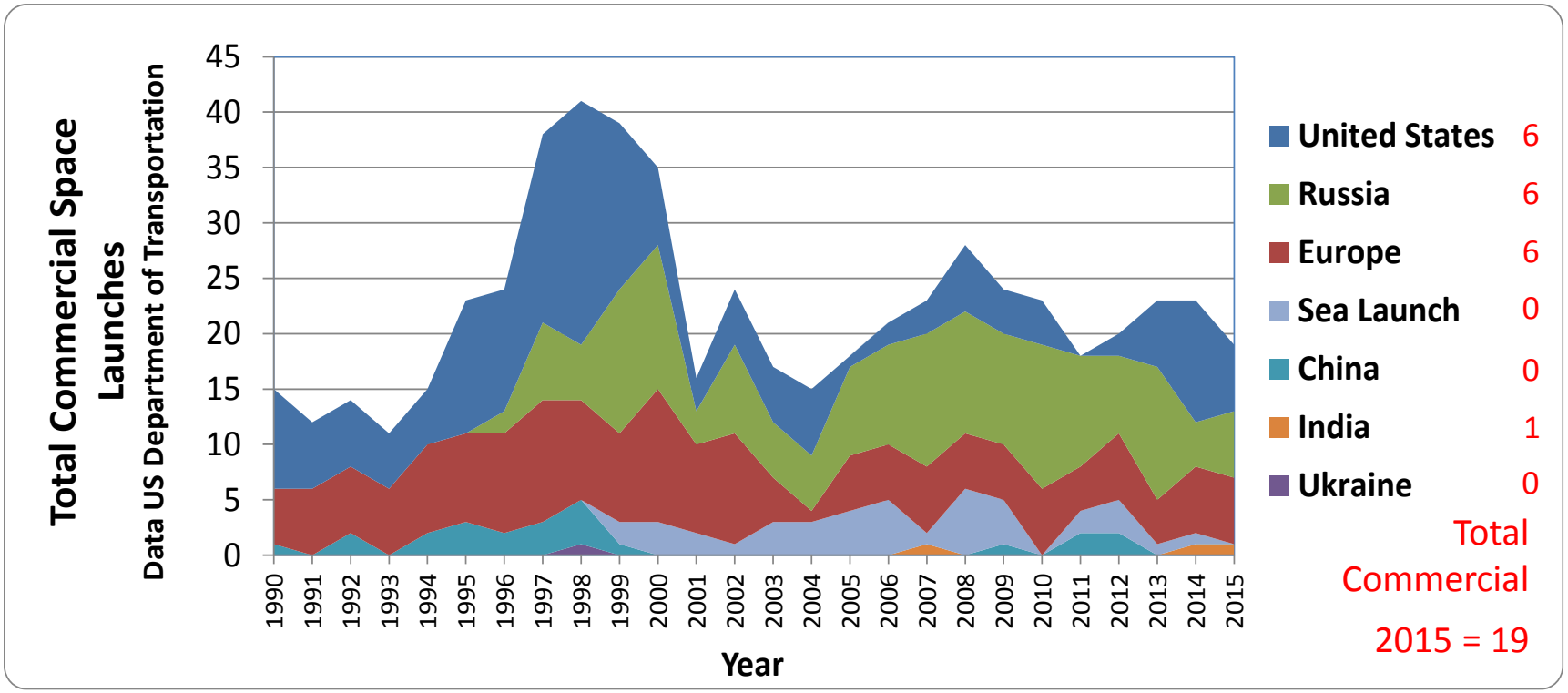
Crew Commercial | Cargo Commercial | Cargo Commercial | Crew Commercial | Crew Cost+/BAU

Manuf. $ Only ← Manuf. **and Ops/Launch $** → Manuf. $ Only | Manuf. $ Only

Emerging Space Competitiveness

2015 = 19 Commercial Launches out of 68 Total Global Major Launches

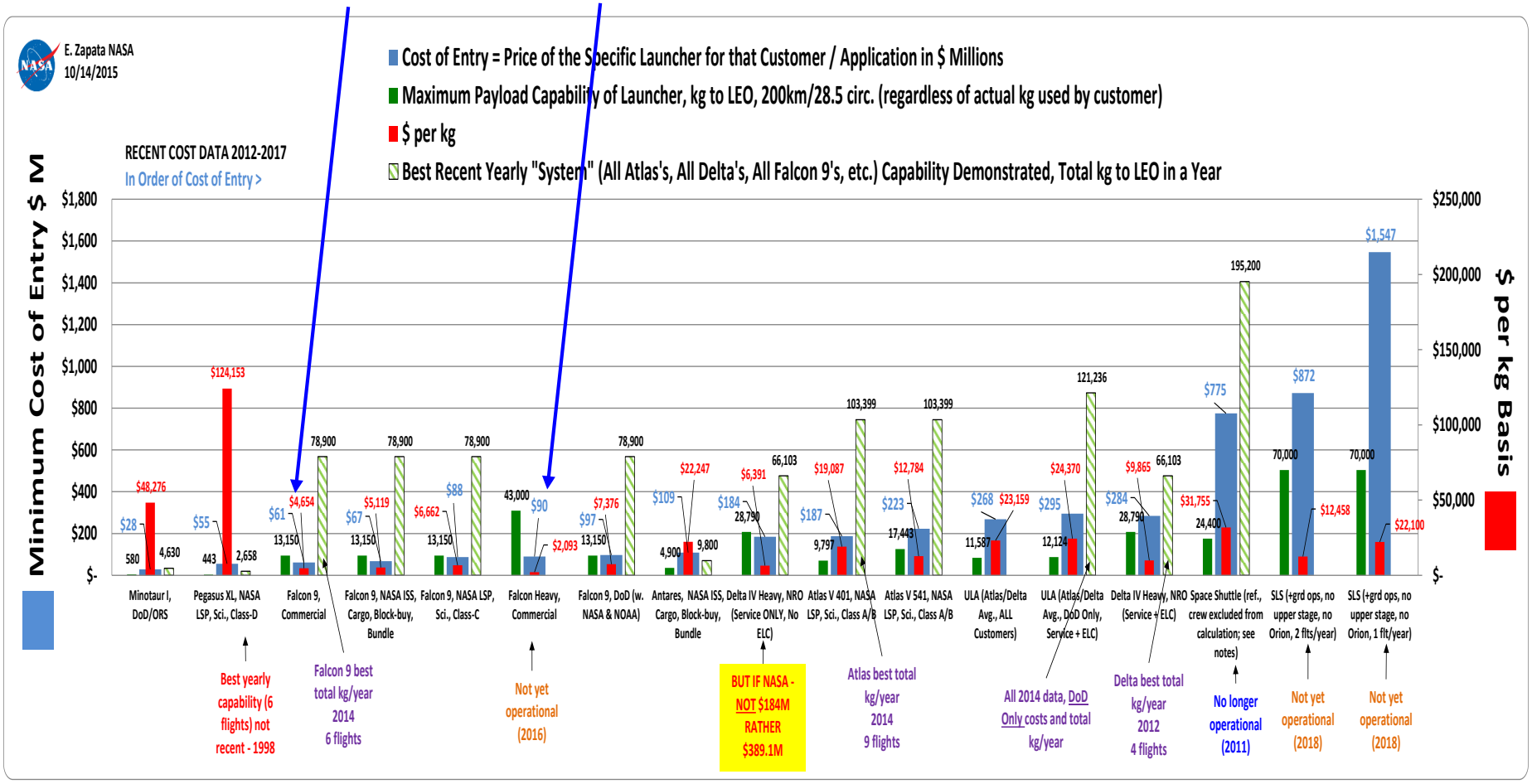
- The US is regaining commercial launch market share
- Customers appear glad to return – for the right price



Data through 2014 from US DOT: http://www.rita.dot.gov/bts/node/490911
2015 data from assorted launch records

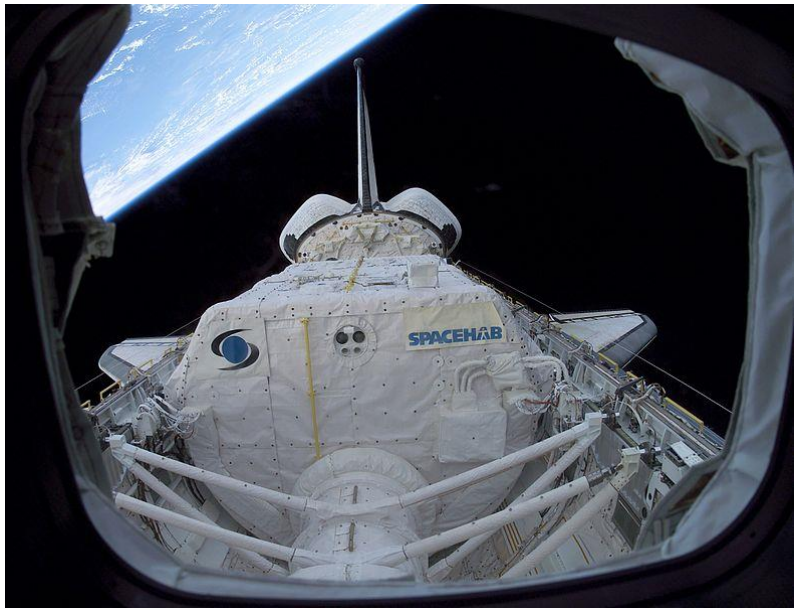
US Launch Prices (Costs to the Customers)

$4,600/kg $2,000/kg?



This is Not New – and it's not limited to launch systems

- SpaceHab Price-Water House Report 1991
- SpaceHab was 1/10th the cost as commercial (as defined then) versus business-as-usual
  - One of a handful of historical data points with a Business-as-Usual ~ analog (SpaceLab)
  - Dependent on Shuttle; very much an ECLSS system extension shielded within the Orbiter payload bay



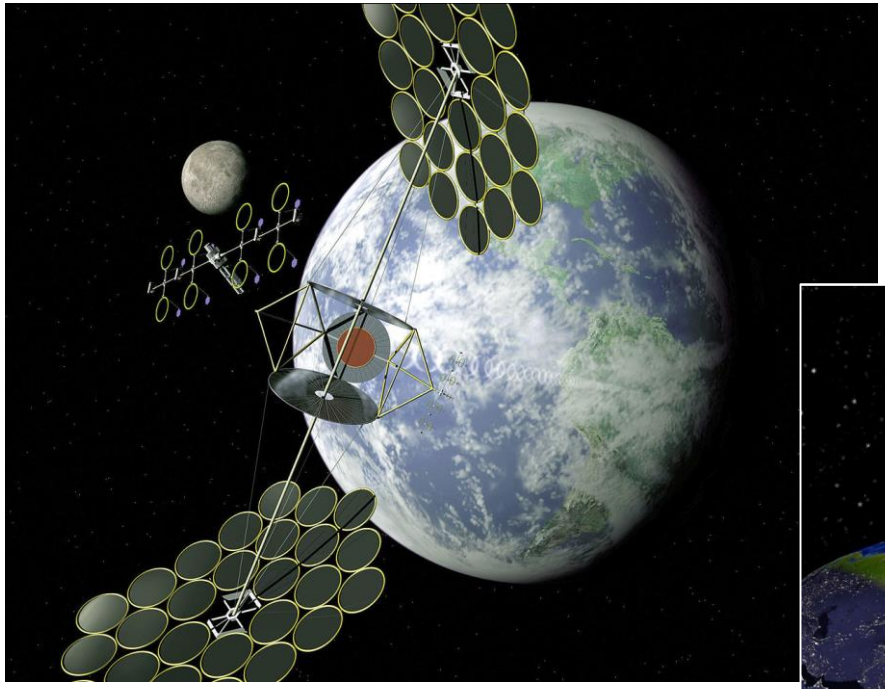
SpaceHab double-research module, STS-107 Columbia, NASA

In the Pipe

- Reusability – Falcon 1st Stage(s)?
- ULA Vulcan launcher – price drops?
- Constellations of Sat's – Round 2? OneWeb, Google/SpaceX, etc.
- Small Launch – business plans around the business plans of ever more Small Sat capabilities

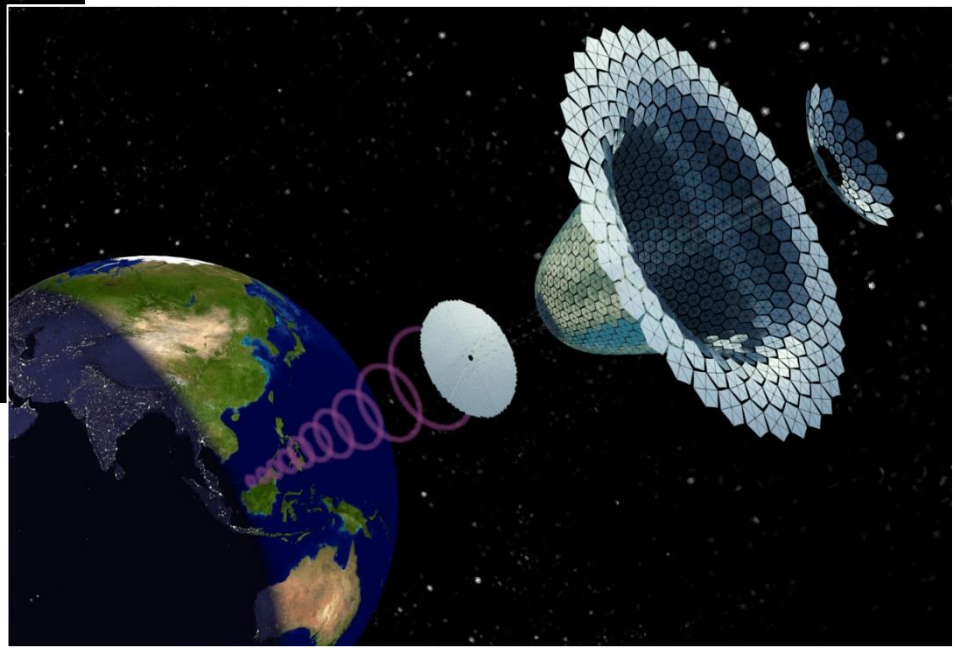
Visions of Space Solar Power

"Integrated Symmetrical Concentrator" (ISC) Solar Power Satellite, late 1990s, NASA



http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Images/solar_power_satellite_concept.jpg (Public Domain)

"SPS-ALPHA" (Solar Power Satellite by means of Arbitrarily Large Phased Array), 2013, Mankins Space Technology, Inc.



By permission, John C. Mankins

Relevance to Space Solar Power

Are the barriers to Mars and Space Solar Power the same?

- Both need more affordable space transportation
- Both need more affordable space systems
- Will both always be 20 years away?

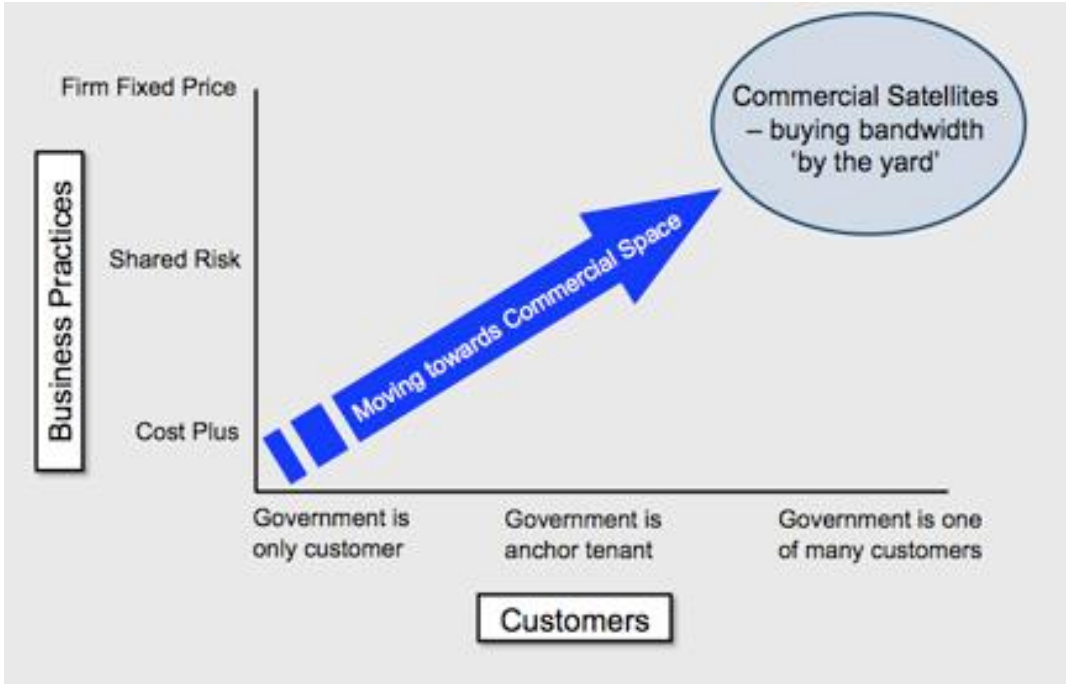
Relevance to Space Solar Power – A New Option

1. ~~Get Money~~
2. ~~Get Time~~
3. ~~Adapt~~
4. NASA as Investor – transforming to become "one of many customers"

Decreasing Prices,
Decreasing Costs

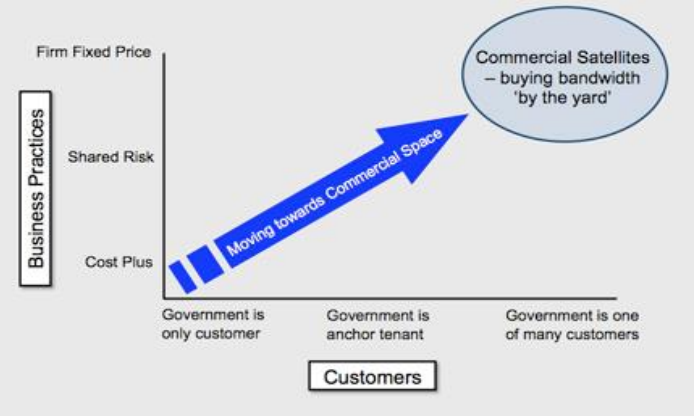
Space Systems
-Launch
-Spacecraft
-Habitation

Highest Price,
Unsustainable Costs



NASA, http://www.nasa.gov/offices/oct/partnership/comm_space/

Relevance to Space Solar Power – A New Option – ~~Make. Buy.~~ Partner



COTS/CRS - another existence proof of the potential for NASA to FIRST invest, to FIRST enable a healthier market, THEN to procure - at much less cost.

Example-$4.0B to $1.7B Falcon 9 investment predicted if traditional ways of doing business vs. ~$300M* actual

(*inclusive of private investment; excludes Dragon; less if considering actual cost to NASA – 2011 Commercial Market Assessment for Crew and Cargo Systems Pursuant to Section 403 of the NASA Authorization Act of 2010)

Major characteristics of a NASA COTS/CRS "like" partnership include:

- Significantly improved **alignment of incentives** – both short and long term - partnering decision considers potential non-government market / business cases (seen more in SpaceX getting commercial launches, but OSC not; not seen in either side yet for their spacecraft)
  - Private sector market pressures akin / aligned with the gov't "ops" long term POV
  - Other potential future work; e.g., cargo business can lead to crew business
- Investor mindset, government as "investor" (beyond "engineering management" or "contractor management" or "smart buyer")
- Early commitment to buy future services in block contracts; addresses / reduces long term business case (investment) risk
- OTA / SAA with fixed payments for achieving development milestones (not cost plus); more risk to the private sector partner, less risk to the government
- Small gov't office for acquisition & management (e.g., ~3% of total program cost)
- Maturation / risk buy down with numerous early partners; delay down-selecting prematurely
- Two providers selected, not just one (competition built in throughout, even in the operational phases)
- "Bundling" the acquisition; e.g., service requires a vehicle and a spacecraft

Relevance to Space Solar Power

- NASA as Investor / Partner
  - Smaller amounts of $ to justify
  - NASA (and partner contributions) $ leveraged into large effects
    - Business case maturation
    - Strategic technology maturation / demonstration
      - Modularity
      - Assembly
      - Transmission
    - Encourage non-government investors
      - "NASA on board" (credibility of NASA)
      - "Virtuous cycle" – more investors ease the case for more NASA partnering (credibility of the business)

"As was mentioned previously, a number of technology and systems level demonstrations can be accomplished without new space transportation"
-The Case for Space Solar Power, J. Mankins

Closing

- Space sector supply AND demand can, will and must grow together
- Large scale programs – like Space Solar Power – face similar challenges

~~Money~~
~~Time~~
~~Adapt~~
Transform

- An increased emphasis on public-private partnerships offers the most viable path forward

…when you have eliminated the impossible, whatever remains, however improbable, must be the truth? -Sherlock Holmes in The Sign of the Four

You can always count on Americans to do the right thing - after they've tried everything else. –Winston Churchill

Backup

Comparison of NASA Space Exploration Architecture Level Assessments

Study	NASA Human Spaceflight Budget? (and/or inflation)	CAS, Science, Aeronautics $? STMD $? HEO SFS, M/G Ops, & R&D $?	Mars Exploration Possible?	SLS, Orion?	ISS?	Budget Profile incl. NASA support for Private Space Stations post-ISS?	Budget for 70t SLS to 110t? To 130t?
2014 NRC Committee on Human Spaceflight	..increases faster than *inflation (pp.41)	†Unaddressed Unaddressed / **Frozen/Flat?	Yes – Phobos early 2040s, Mars surface 2050s	Yes	Ends 2028	~No?	Unaddressed
2015 JPL H2M Minimal Architecture	…increases at rate of *inflation	†Unaddressed Unaddressed / **Frozen/Flat?	Yes – surface by 2039	Yes	Ends 2028	~No?	Unaddressed
2015 Planetary Society Humans Orbiting Mars	Segues off of JPL H2M Minimal Architecture →						
Evolvable Lunar Architecture w. PPP	…increase at historical budget growth…	All NASA areas increase at same rate as HEO	Lunar 1st, Mars as follow-up study	**No	n/a->	Possible - Budget set aside –ample fund split possible	n/a
Evolvable Mars Campaign	TBD →						

* aerospace, space systems specific inflation per se ill-defined
** moves funds from X to Y
† if flat, this shifts the whole NASA portfolio split

What about the 1991 Space Exploration Initiative (SEI)? Budget growth by *multiples of then current*. Rest ~ n/a.