Comment to the Committee's Option 4 as presented at the August 5th meeting

The Committee has presented seven options during the August 5th meeting in Washington D.C. The key drivers for the options presented are decisions made on the length of the Space Shuttle Program, the International Space Station Program, the choice of a heavy lift launch vehicle, whether refueling and depot technology should be part of the Exploration architecture and the destination(s) beyond-LEO NASA's Constellation program should include during the next 15 to 20 years.

This comment relates to Option 4 as presented by Committee member Dr. Edward Crawley. Option 4 which was specified as "Use Shuttle Systems" during the August 5th meeting includes the following main characteristics:

- Shuttle retirement in 2015
- ISS life until 2020
- Crew to LEO provided by Shuttle, International Partners and thereafter US commercial providers
- Heavy Lift Vehicle to be directly shuttle derived
- A refueling option being "enhancing" the architecture's capabilities
- First Beyond-LEO mission scenario to be "lunar sortie/outpost"
- Commercial engagement for both crew and cargo
- Above FY2010 budget guidance

Politically, this option accomplishes varies goals that other options cannot. It has the ability to close the human space flight gap by extending the Shuttle Program to 2015 while developing commercial crew to LEO access and an HLV with the potential capability for crewed launches with IOC shortly after 2015. Option 4 also includes the politically favored decision to extend the ISS program as requested by international partners as well as many members of Congress and the scientific community. It further provides the possibility for NASA to go beyond LEO within a reasonable time scale.

Despite Option 4 to be appealing as is, this comment would like to provide a modified approach to the scenario presented during the August 5th meeting. The current baseline's "lunar sortie/outpost" architecture for Option 4 could be replaced by the "Flexible Path" approach (Option 5) of flying deep-space missions (circum-lunar, NEOs, EML-1/2, SEL-1/2, Mars flyby, Venus flyby, Mars orbital, Venus orbital, Deimos/Phobos mission). Human lunar sorties could be kept as an option of the overall beyond-LEO program with a potential first lunar surface mission towards the middle of the 2020s.

The shift to "Flexible Path" with optional lunar sorties provide a clear strategy to use in-orbit propellant transfer and fuel depots in an incremental approach. Fuel depots are a technology that are not yet available. In contrast, in-orbit propellant transfer is a technology which is nearly 40 years old. Committee members have stressed that there is no fundamental technical reason why fuel depots could not be part of the architecture. Considerable research and development in this technology however would be required to be a viable part of any beyond-LEO

architecture (storage of hypergolics vs. cryogenics).

This comment argues for the inclusion of fuel depots as part of the critical path of Phase 2 long-duration beyond-LEO missions (SEL-1/2, Mars flyby, Venus flyby, Mars orbital missions) and for the combination of fuel depots and a small, potentially only temporarily occupied successor space station to the ISS at EML-1 or EML-2. The modified Option 4's milestones, taking into consideration the Committee's July 30th presentation's time-line overview for “Flexible Path” could thus be:

- Shuttle Program's last mission: Q4 2014 or Q1 2015
- ISS Program extended to 2020, deorbiting ISS in 2021
- Commercial crew to ISS IOC 2014/2015
- HLV (directly shuttle derived) IOC 2016
- Precursor beyond-LEO mission: circum-lunar, EML-1 and EML-2 as well as a NEO mission in 2017-2021 time-frame without use of depot technology but potentially using propellant transfer technology
- First deep space mission in ~2020 to SEL-1 or SEL-2, thereafter NEO mission(s) and a Mars or Venus flyby
- Mars orbital mission to Deimos or Phobos ~2024/2025, potentially using advanced propulsion technology (VASIMR)
- EML-1/2 space station IOC in 2022
- Chemical fuel depot module at EML-1/2 space station IOC in 2023/2024, potentially argon fuel depot module thereafter
- Optional within architecture: Lunar sortie missions, potentially medium length extended stays at certain locations (International Partner engagement possible)
- Human Mars surface mission preparation to start in 2015 with the goal of the first Mars surface mission in 2035-2040 time-frame, reusing technology used in previous Mars orbital mission(s)

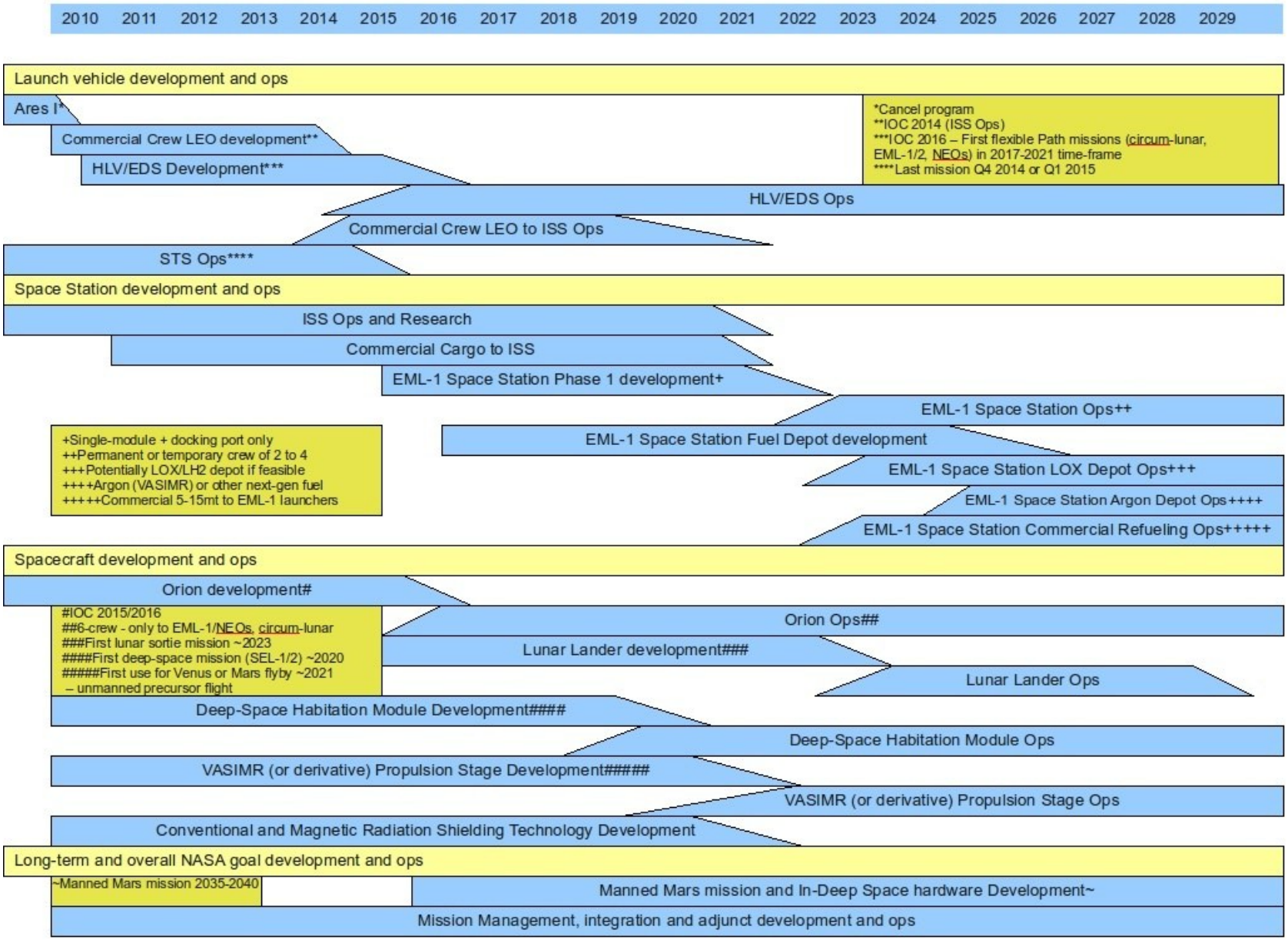
The modified Option 4 presented in this comment recognizes that the scenario envisioned is not in line with FY2010 budget guidance. However, a key element of the “Flexible Path” approach is its ability to be scaled and its time-line to be stretched without running the risk to lose sight of the ultimate goal of the program or risking it becoming technically unfeasible with a more limited budget. The annexed time-line chart and budget estimate chart present a high-end and fast paced approach which cannot be achieved in the FY2010 budget guidance. It also assumes that optional parts of the scenario (lunar sortie hardware) will not be developed in partnership with International Partners. It further does not assume that cheaper commercial alternatives to a single-module space station at L1/2 may exist in the future.

This document may be used publicly.

Dr. Axel Wittmann

Annex I: Timeline for modified Option 4

Annex II: Budget estimate for modified Option 4


2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
Launch vehicle development and ops
Ares I*
Commercial Crew LEO development**
HLV/EDS Development***
*Cancel program
**IOC 2014 (ISS Ops)
***IOC 2016 – First flexible Path missions (circum-lunar, EML-1/2, NEOs) in 2017-2021 time-frame
****Last mission Q4 2014 or Q1 2015
HLV/EDS Ops
Commercial Crew LEO to ISS Ops
STS Ops****
Space Station development and ops
ISS Ops and Research
Commercial Cargo to ISS
EML-1 Space Station Phase 1 development+
EML-1 Space Station Ops++
+Single-module + docking port only
++Permanent or temporary crew of 2 to 4
+++Potentially LOX/LH2 depot if feasible
++++Argon (VASIMR) or other next-gen fuel
+++++Commercial 5-15mt to EML-1 launchers
EML-1 Space Station Fuel Depot development
EML-1 Space Station LOX Depot Ops+++
EML-1 Space Station Argon Depot Ops++++
EML-1 Space Station Commercial Refueling Ops+++++
Spacecraft development and ops
Orion development#
#IOC 2015/2016
##6-crew - only to EML-1/NEOs, circum-lunar
###First lunar sortie mission ~2023
####First deep-space mission (SEL-1/2) ~2020
#####First use for Venus or Mars flyby ~2021
– unmanned precursor flight
Orion Ops##
Lunar Lander development###
Lunar Lander Ops
Deep-Space Habitation Module Development####
Deep-Space Habitation Module Ops
VASIMR (or derivative) Propulsion Stage Development#####
VASIMR (or derivative) Propulsion Stage Ops
Conventional and Magnetic Radiation Shielding Technology Development
Long-term and overall NASA goal development and ops
~Manned Mars mission 2035-2040
Manned Mars mission and In-Deep Space hardware Development~
Mission Management, integration and adjunct development and ops

Modified Option 4 Budget Estimate to 2030

Option 4: modified for Flexible Path

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Science*	**4733.2**	**4903.0**	**4477.2**	**4747.4**	**4890.9**	**5069.0**	**5185.4**	**5289.1**	**5447.8**	**5611.2**	**5779.6**	**5952.9**	**6131.5**	**6315.5**	**6504.9**	**6700.1**	**6901.1**	**7108.1**	**7321.4**	**7541.0**	**7767.2**	**8000.3**
Aeronautics*	**511.4**	**650.0**	**507.0**	**514.0**	**521.0**	**529.0**	**536.0**	**546.7**	**563.1**	**580.0**	**597.4**	**615.3**	**633.8**	**652.8**	**672.4**	**692.6**	**713.3**	**734.7**	**756.8**	**779.5**	**802.9**	**827.0**
Human Space Flight*	**8726.5**	**9720.2**	**9717.7**	**9870.9**	**10398.9**	**11132.5**	**10676.6**	**10761.9**	**10602.1**	**12163.2**	**13220.5**	**13588.5**	**13161.6**	**12955.0**	**13097.6**	**13555.5**	**13916.7**	**14631.2**	**15183.2**	**16401.2**	**16822.7**	**17397.9**
Ares I***	1030.5	1067.4	800.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ares V	15.0	30.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
US Commercial Crew to LEO Development (COTS-D)	0.0	0.0	100.0	200.0	250.0	200.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
US Commercial Crew to ISS Operations	0.0	0.0	0.0	0.0	0.0	0.0	50.0	200.0	200.0	220.0	220.0	220.0	120.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HLV/EDS Development (side-mounted SDLV)****	0.0	0.0	50.0	690.0	1133.0	1914.0	1977.0	903.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HLV/EDS Ops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	500.0	1200.0	1500.0	1800.0	1800.0	1900.0	1900.0	2000.0	2000.0	2200.0	2200.0	2200.0	2300.0	2300.0	2300.0
Space Shuttle Program*****	3295.4	2981.7	3157.1	2500.0	2400.0	2400.0	2000.0	700.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
International Space Station Ops	1603.2	1755.4	1639.0	1717.3	1513.9	1437.8	1449.0	1478.0	1522.3	1568.0	1615.0	1663.5	1713.4	400.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Space and Flight Support (ISS first – EML-1 SP later)	441.2	722.8	751.5	732.7	745.9	749.7	748.9	763.9	786.8	810.4	834.7	859.8	885.5	912.1	939.5	967.7	996.7	1026.6	1057.4	1089.1	1121.8	1155.4
Commercial Cargo to ISS Development	130.5	303.0	39.1	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IP (Crew and Cargo) and Commercial Cargo to ISS Ops******	82.3	304.8	500.0	600.0	650.0	650.0	650.0	900.0	700.0	700.0	700.0	600.0	500.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EML-1 Space Station Pressurized Section Development (Phase 1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	400.0	600.0	700.0	700.0	600.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EML-1 Space Station Fuel Depot Development (Phase 2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	600.0	800.0	800.0	600.0	1200.0	1200.0	1350.0	400.0	200.0	0.0	0.0	0.0	0.0
EML-1 Space Station Ops (Total)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	600.0	700.0	800.0	1000.0	1000.0	1200.0	1200.0	1300.0
EML-1 Space Station Commercial Refueling Ops*******	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	600.0	1000.0	1000.0	1200.0	1400.0	1400.0	1600.0	1600.0
Orion Development	889.5	1387.2	1383.5	1938.9	2056.1	1931.0	1751.7	1500.0	400.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orion Hardware and Ops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0	600.0	600.0	612.0	630.4	649.3	668.7	688.8	709.5	730.8	752.7	775.3	798.5	822.5	847.2
Lunar Lander and Lunar Hardware Development********	0.0	0.0	0.0	0.0	0.0	0.0	0.0	400.0	1300.0	1500.0	1500.0	1600.0	1600.0	1800.0	1600.0	500.0	100.0	100.0	150.0	150.0	50.0	0.0
Lunar Lander and Lunar Hardware Ops********	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	800.0	1500.0	1500.0	1500.0	1700.0	1200.0	600.0
Deep-Space Habitation Module Development	0.0	0.0	30.0	80.0	200.0	250.0	300.0	700.0	800.0	1000.0	1000.0	1200.0	500.0	100.0	103.0	106.1	109.3	112.6	0.0	0.0	0.0	0.0
Deep-Space Mission Ops and Hardware	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	300.0	500.0	500.0	1000.0	1600.0	1800.0	2000.0	2500.0	2500.0	2500.0	2600.0	2800.0	2800.0
Advanced Capabilities (VASIMR; Radiation Protection etc.)	623.5	472.3	600.0	700.0	700.0	800.0	800.0	1500.0	1500.0	1545.0	1591.4	1639.1	1688.3	1738.9	800.0	824.0	848.7	874.2	900.4	927.4	955.2	983.9
Human Mars Mission Development, Management and Planing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	200.0	400.0	400.0	400.0	1000.0	1500.0	1500.0	1600.0	2000.0	2500.0	3000.0	3500.0	4500.0
Program Integration + Ops and Overall Management	610.4	645.5	642.5	700.0	750.0	800.0	850.0	867.0	893.0	919.8	947.4	975.8	1005.1	1035.2	1066.3	1098.3	1131.2	1165.2	1200.1	1236.1	1273.2	1311.4
Other (Administration, Support, Education, Inspector)*	**3430.8**	**3509.2**	**3615.1**	**3629.2**	**3687.3**	**3723.9**	**3814.0**	**3890.3**	**4007.0**	**4127.2**	**4251.0**	**4378.5**	**4509.9**	**4645.2**	**4784.6**	**4928.1**	**5075.9**	**5228.2**	**5385.1**	**5546.6**	**5713.0**	**5884.4**
Total Budget	**17401.9**	**18782.4**	**18317.0**	**18761.5**	**19498.1**	**20454.4**	**20212.0**	**20488.0**	**20620.0**	**22481.6**	**23848.5**	**24535.3**	**24436.8**	**24568.5**	**25059.5**	**25876.3**	**26607.0**	**27702.3**	**28646.4**	**30268.3**	**31105.8**	**32109.5**
Budget available (FY2010)**	**17401.9**	**18782.4**	**18686.0**	**18631.0**	**18613.0**	**18607.0**	**18858.0**	**19235.2**	**19812.2**	**20406.6**	**21018.8**	**21649.3**	**22298.8**	**22967.8**	**23656.8**	**24366.5**	**25097.5**	**25850.4**	**26626.0**	**27424.7**	**28247.5**	**29094.9**
Human Space Flight Budget available (FY2010)**	**8726.5**	**9720.2**	**10086.7**	**9740.4**	**9513.8**	**9285.1**	**9322.6**	**9509.1**	**9794.3**	**10088.2**	**10390.8**	**10702.5**	**11023.6**	**11354.3**	**11694.9**	**12045.8**	**12407.2**	**12779.4**	**13162.8**	**13557.6**	**13964.4**	**14383.3**
Difference FY 2010 and projected budget	**0.0**	**0.0**	**-369.0**	**130.5**	**885.1**	**1847.4**	**1354.0**	**1252.8**	**807.8**	**2075.0**	**2829.7**	**2886.0**	**2138.0**	**1600.7**	**1402.7**	**1509.7**	**1509.5**	**1851.8**	**2020.4**	**2843.5**	**2858.4**	**3014.6**
Cumulative budget shortfall	**0.0**	**0.0**	**-369.0**	**-238.5**	**646.6**	**2494.0**	**3848.0**	**5100.8**	**5908.6**	**7983.6**	**10813.3**	**13699.3**	**15837.3**	**17438.0**	**18840.6**	**20350.3**	**21859.9**	**23711.7**	**25732.1**	**28575.7**	**31434.0**	**34448.6**

*2015-2030 are projections assuming budget adjustment for 2% inflation
**FY2010 budget according to FY2010 budget request by NASA, 2015-2030 adjusted for 2% inflation
***Assumes program cancellation at beginning of FY2010 – J2-x contract extension
****As presented by John Shannon on June 17, 2009
*****Assumes a flight rate of 1-2 between 2011 and 2014; 5 additional flights added
******Reduction in budget projection due to STS extension to 2015 (cargo and crew rotation to ISS by Shuttle)
*******Assumes a commercial kg to EML-1 price of ~USD 10,000 or below for fuel due to high flight rate
********Potentially developed in conjunction with international partners