ISRU DM
Delivery Service Executive Summary

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1. INTRODUCTION

1.1. SCOPE AND PURPOSE

The study and exploitation of In-Situ Resource Utilization (ISRU) technologies (with an initial focus on the Moon) are stimulating an increasing interest in the international community, both at Agencies and industry levels, in view and preparation of future manned exploration missions and in terms of scientific and societal long term benefits.

This document is part of the deliverables to be provided in scope with the Lunar ISRU Demonstration Mission Definition Study issued by the European Space Agency. In particular the information and data herein included are specifically relevant to the so called Segment 2, in charge for the Payload Delivery Service definition and in response to the tasks identified in the Statement Of Work (AD1).

1.2. APPLICABLE DOCUMENTS

Acronym	Reference	Issue	Title
AD1	-	1	Statement of Work Lunar ISRU Demonstration Mission Definition Study

1.3. REFERENCE DOCUMENTS

N/A

1.4. DEFINITIONS AND ACRONYMS

ASW	Application Software
CDMU	Command & Data Management Unit
C&DH	Command & Data Handling
DoD	Depth of Discharge
DOI	Descent Orbit Ignition
DS	Delivery Service
DTE	Direct To Earth
EPS	Electrical Power System
ESA	European Space Agency
GNC	Guidance, Navigation & Control
GS	Ground Station

GTO	Geosynchronous Transfer Orbit
HGA	High Gain Antenna
HK	House Keeping
IMU	Inertial Measurement Unit
ISRU	*In Situ* Resource Utilization
LGA	Low Gain Antenna
LLO	Low Lunar Orbit
LOI	Lunar Orbit Insertion
LTO	Lunar Transfer Orbit
MCC	Mission Control Centre
NRHO	Near Rectilinear Halo Orbit
NTO	Nitrogen Tetra Oxide
OBDH	On Board Data Handling
PCDU	Power Conditioning & Distribution Unit
PHS&T	Packaging, Handling, Storage & Transport
P/L	Payload
RCS	Reaction Control System
RF	Radio Frequency
TBP	To Be Prepared
TC	Tele Command
TGO	Trace Gas Orbiter
TLC	TeLeCommunication
TM	TeleMetry
TT&C	Telemetry, Tracking & Control
UDMH	Unsymmetrical DiMethyl Hydrazine
UPS	Unified Propulsion System
VAPS	Video Acquisition and Processing System

2. DELIVERY SERVICE MAIN CHARACTERISTICS

The Delivery Service is intended as a commercial type of service in charge to provide the required end-to-end support to a generic P/L for the execution of its mission on the Moon surface (from integration on the lander to the mission operations support and execution).

LANDER PROVISION

- P/L + lander analytical integration, which means the execution of all of the analysis and engineering assessments required to define the integrated system behavior. The covered activities are:
  - Thermo-Mechanical analysis
  - Structural Analysis
  - ICD preparation
  - Verification of compatibility with launcher
  - Safety Assessment as required by launcher
  - PHS&T requirements and constraints identification
- P/L + lander physical integration and testing
  - Preparation of the mechanical installation procedures
  - Preparation of the test specifications and procedures

    The test purpose and boundaries are refined during the P/L development phase, but are anyhow to be settled on the basis of some standard requirements defined by the lander (driven by the lander interfaces and capabilities, as defined *a priori*)
  - Execution of the integrated tests to confirm that all of the P/L to lander interfaces are properly working. The integration and test is to be performed at TAS in Italy premises (PHS&T definition from the Customer premises to TAS in Italy premises is considered under the Customer responsibility. Support by TAS can be provided as an optional activity).

LAUNCH PROVISION

- Commercial Launch Vehicle procurement
- The coordination and implementation of the logistics aspects relevant to the transportation from the lander-P/L integration facilities to the launch site (PHS&T requirements and constraints)
- The organization of the launch: this set of activities includes the support and coordination of the activities performed at launch site during the integrated stack integration with the launcher, in accordance and in agreement with the launch service provider.

MISSION OPERATIONS

- Preparation and validation of the flight procedures involving the interactions of the P/L with the lander
- Definition of the contingency scenarios and preparation of the relevant recovery procedures to allow the completion of the P/L mission
- The Mission Control Centre operations include the tasks relevant to:
  - the transfer to the Moon, from release by the launcher in the targeted transfer orbit down to the Moon landing
  - the Moon lander surface operations: as needed to keep functional and operational the lander to allow P/L mission execution. The actual P/L operations are nominally considered under the Customer responsibility. Anyhow support can be provided as an optional activity.
- The Engineering support in case of anomalies that should occur either during the cruise phase or during the Moon operations when deriving from lander malfunctions or involving the lander-to-P/L interactions and interfaces

2.1. LAUNCHER SELECTION

The Falcon 9, provided by Space X, has been selected as the baseline launcher.

The Ariane 6.4 could be selected as the European option, considering also the LTO launch capability. Details on launches performed with this vector are provided in the following pages as well.

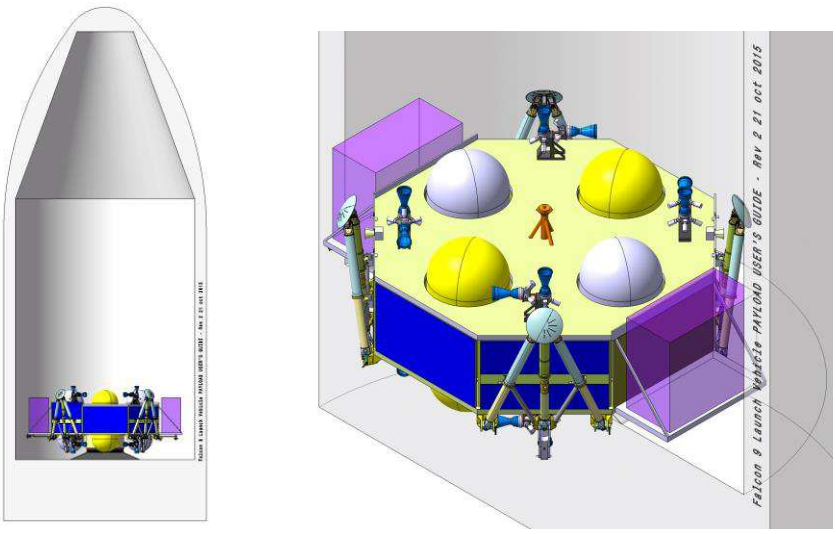


Figure 2-1 View Of Lander Installed in Falcon 9 Fairing

2.2. EARTH TO MOON TRANSPORTATION

As far as it regards the in-orbit delivery strategy, two different options have been considered:

- a direct release in the Transfer Lunar Orbit (TLO) by the launcher (F9 can release up to 3550 kg in this orbit)
- a release in GTO by the launcher and the subsequent spacecraft independent insertion in the LTO (F9 can release up to 5500 kg in this orbit).

Then, for both the release strategies, two different arrival approaches have been evaluated:

- a direct soft landing to the target site
- a Low Lunar Orbit (LLO) insertion from which the soft landing descent phase starts after an appropriate wait time to synchronize with the landing location.

	Ariane 6.4, GTO + LLO	Falcon 9, GTO + LLO	Falcon 9, Direct + LLO
Start Epoch (TLI)	21 Apr 2025 03:01:19.096	21 Apr 2025 22:16:00.538	19 May 2025 18:35:01.170
Arrival Epoch	25 Apr 2025 03:04:19.011	24 Apr 2025 17:38:08.938	24 May 2025 08:19:43.044
Sunlight Window Start Time	24 Apr 2025 17:47:21.034	24 Apr 2025 17:47:21.034	24 May 2025 08:53:02.863
Total DV [m/s]	3486.2	3677.8	2833.0
Fuel Mass [kg]	2000	2200	1450
Consumed Fuel Mass [kg]	1961.8	2157.5	1410.7
Residual Fuel Mass [kg]	38.2	42.5	39.3
	Ariane 6.4, GTO + Direct	Falcon 9, GTO + Direct	Falcon 9, Direct + Direct
Start Epoch (TLI)	20 Apr 2025 13:05:44.515	20 Apr 2025 02:14:22.485	20 May 2025 19:00:30.683
Arrival Epoch	25 Apr 2025 03:12:20.164	25 Apr 2025 01:59:25.156	24 May 2025 04:25:35:164
Sunlight Window Start Time	24 Apr 2025 17:47:21.034	24 Apr 2025 17:47:21.034	24 May 2025 08:53:02.863
Total DV [m/s]	3237.0	3235.0	2592.0
Fuel Mass [kg]	1770	1770	1250
Consumed Fuel Mass [kg]	1733.7	1733.1	1221.0
Residual Fuel Mass [kg]	36.3	36.9	29.0

2.3. MISSION INTEGRATION

The entire mission integration and launch service are developed along a period of about 24 months (on average), starting with the contract signature with the launch service provider up to the launch itself. Along this period, different preliminary and conclusive analysis are performed by the launch service provider. The schedule for the execution of those analysis may vary from launch service provider to launch service provider. This implies that at least 24 to 30 months need to be accounted for when defining the ISRU P/L mission timeframe and the launch date.

3. LANDER CHARACTERISTICS & CAPABILITIES DESCRIPTION

First important thing to notice is that the lander that is presented hereafter is the result of a preliminary high level conceptual development, not yet detailed in deep and whose design and manufacturing is not started yet. The basic idea is to have a lander capable to autonomously reach the Moon orbit and land on it. Its design should be such to allow flexibility to accommodate different P/Ls with different target missions, in different target locations on the Moon (equatorial areas or poles).

The lander proposed configuration consists of a main body, accommodating all subsystems equipment units, four deployable landing legs attached to the shorter sides of the body, a main central engine in charge to provide the thrust during the different mission maneuvers (Earth to Moon transfer and Moon landing) and two distinct platforms on the lander sides devoted to the accommodation of the P/L (identified with the purple volumes in Figure 3-1). Each one capable of supporting 100 kg.

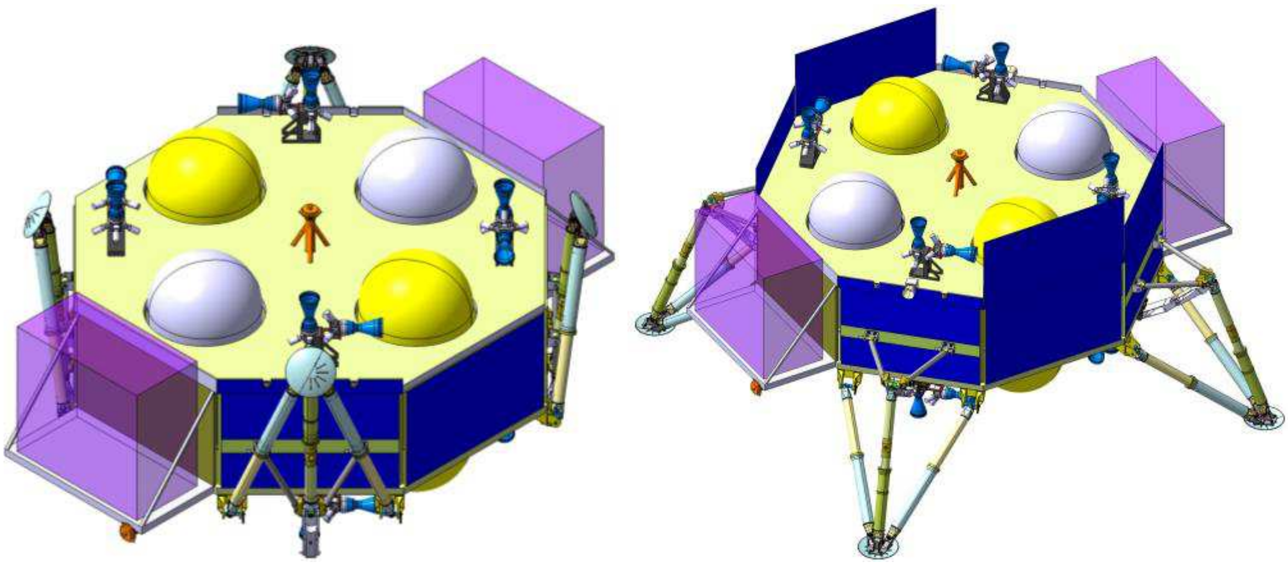


Figure 3-1 Lander Configurations: Launch (Left), Moon Ops (Right)

3.1. ELECTRICAL POWER SYSTEM

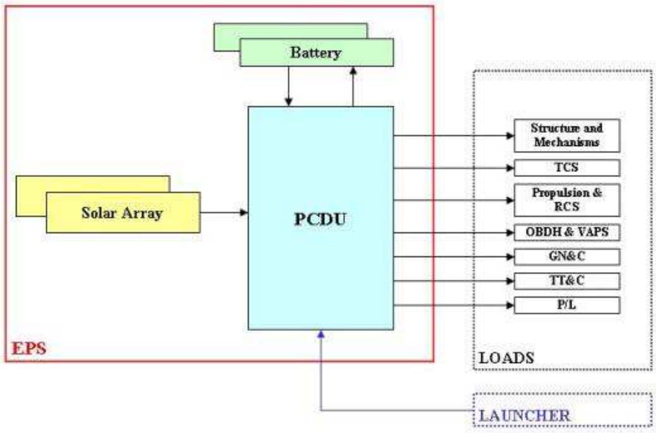


Figure 3-2 Lander EPS Schematic

The **PCDU** is in charge to provide:

- The solar array power conditioning
- The batteries and bus management
- The power supply to loads
- The power lines protection

The two **battery** packages are made of Li-Ion battery cells manufactured by SAFT, assembled in the configuration 8s7p.

Battery Type	Cell Weight (Kg)	Cell Energy Density (Wh/Kg)	Cell Voltage (V)	Cell Energy (Wh)	Battery Package Mass (Kg)	Battery Package Total Energy (Wh)
SAFT MP 176065 xlr	0.15	165	3.65	24.8	9	1388

Table 3-1 Battery Characteristic

The **Solar Arrays** that have been selected are the GaAs 4 Junctions cell (type 4G32) from Azur Space and include panels mounted all around the lander lateral side and 4 deployable panels (thus to increase the total available surface once on the Moon up to about 6 m^2), with cells on both sides.

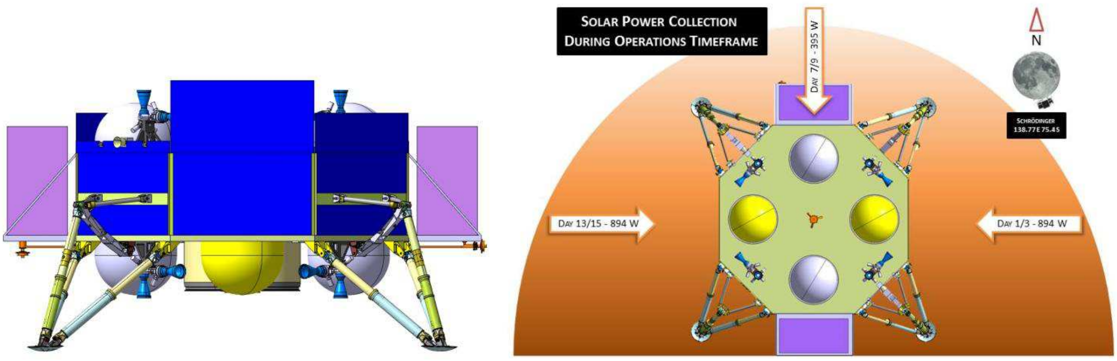


Figure 3-3 Deployed Solar Arrays & Power Generation Capability Profile

3.2. THERMAL CONTROL SYSTEM

The TCS S/S is conceived to be a passive system, with thermistors and heaters; internal and external walls of lander covered with MLI, capable of providing about 100 W of thermal power, for both the lander and ALCHEMIST (70 W – 30 W).

3.3. GUIDANCE, NAVIGATION & CONTROL SYSTEM

Following main units and sensors compose the GN&C:

- Sun sensors
- Star Tracker
- Radar altimeter
- IMU

3.4. ON BOARD DATA HANDLING SYSTEM

The OBDH architecture includes:

- 1 Command & Data Management Unit (CDMU)
- 1 Vision Based Navigation System
- A Spacewire data bus for high rate data (e.g. P/L near real time video)
- A MIL-STD-1553B bus for TC/TM.

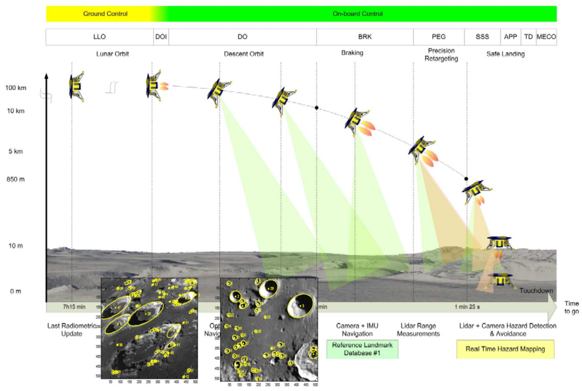


Figure 3-4 Simulated VisNav Operational Sequence

3.5. TELECOMMUNICATIONS SYSTEM

Following main units compose the TLC:

- K-Band Transceiver, which includes a Solid State Power Amplifier, currently being developed by Thales Alenia Space.
- RF switches (RFDN)
- LGA (3)

During all flight phases subsequent to separation from launcher, the TT&C subsystem is used for low-data-rate communications until in Moon proximity, when an higher data rate will allow communications with the relay orbiter in support to LOI insertion and landing, this permitting a deeper insight of the landing operations by the Mission Control Centre.
During surface operations the lander will mainly interface with the data relay orbiter, transmitting TM (Video, system HK and P/L scientific data) and receiving TCs. The telecommunications will happen in K-Band. The expected TM volumes per phase is reported in following table

Phase	Data Volume (kbps)
Launch	0
Cruise	10 – 100
Landing	10 – 100
Moon Ops	100 (L) + 500 (ALC)

The field of view of the LGAs is depicted in Figure 3-5. Each antenna grants an hemispherical FoV of ±80°.

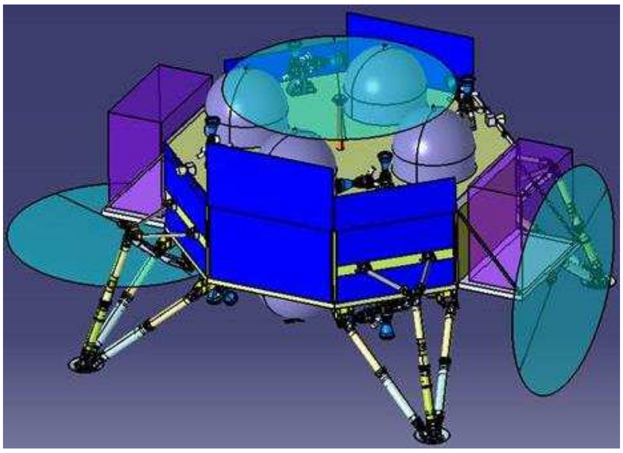
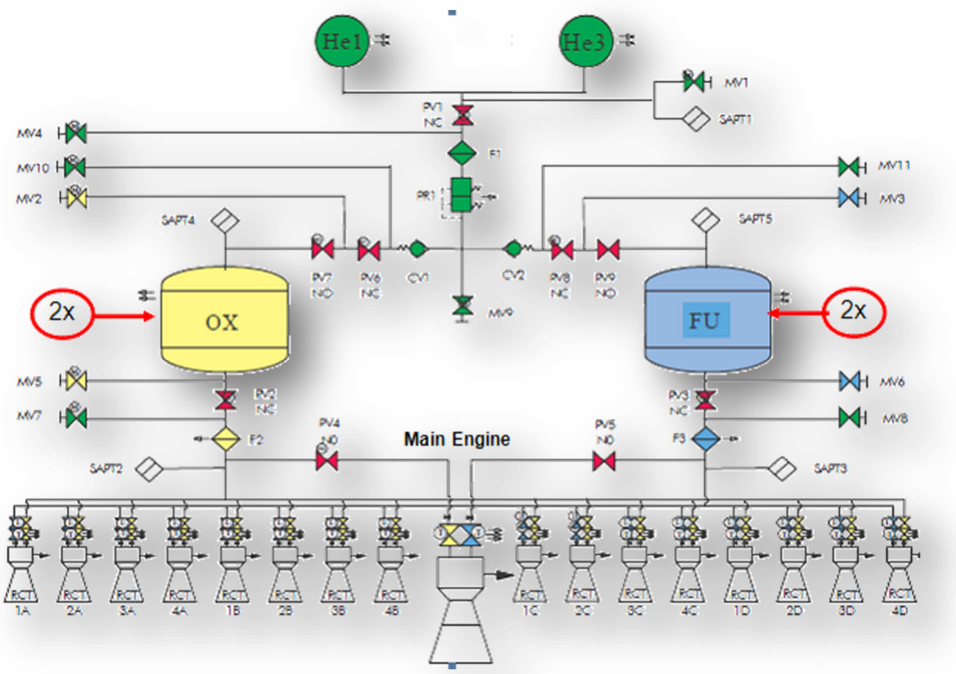


Figure 3-5 LGAs Field Of View

3.6. PROPULSION SYSTEM

A Unified Propulsion System (UPS) approach, in which the main propulsion system(1 main Engine) and the Reaction Control System (RCS, 16 thrusters) are merged together, is considered the proper solution for the lander design: this implies that common propellant tanks feed both the Main Engine and multiple thruster clusters.



3.7. MASS BUDGET

Item	Unit Mass [kg]	Q.ty	BEE Mass [kg]	Contingency [%]	Current Mass [kg]
Primary Structure			**120,04**	**15,0**	**138,05**
Primary Structure			114,54	15,0	131,72
LVA ring (Ø 937)	5,50	1	5,50	15,0	6,33
Secondary Structure			**8,00**	**15,0**	**9,20**
Mechanisms			**88,00**	**20,0**	**105,60**
Landing Legs	22,00	4	88,00	20,0	105,60
Solar Array Deployment System	0,50	4	2,00	20,0	2,40
Thermal Control System			**21,80**	**20,0**	**26,16**
Guidance Navigation & Control			**7,15**	**5,0**	**7,51**
Star Tracker	2,60	2	5,20	5,0	5,46
Sun Sensor	0,10	4	0,40	5,0	0,42
IMU	0,75	1	0,75	5,0	0,79
Radar Altimeter	0,40	2	0,80	5,0	0,84
On-Board Data Handling			**9,00**	**10,0**	**9,90**
CDMU	5,30	1	5,30	10,0	5,83
VMU	1,70	1	1,70	10,0	1,87
Cameras	0,50	4	2,00	10,0	2,20
Electrical Power System			**26,00**	**10,0**	**28,60**
PCDU	10,00	1	10,00	10,0	11,00
Battery	9,00	2	18,00	10,0	19,80
Solar Array	15,97	1	15,97	10,0	17,56
Telecommunication System			**17,00**	**5,0**	**17,85**
Low Gain Antennas	0,25	3	0,75	5,0	0,79
X-band Transceiver	3,60	2	7,20	5,0	7,56
Switches	0,20	1	0,20	5,0	0,21
RF interconnection	2,70	1	2,70	5,0	2,84
Propulsion System			**221,62**	**7,1**	**237,42**
Main Engine	27,50	1	27,50	20,0	33,00
Propellant Tanks	37,25	4	149,00	5,0	156,45
Pressurant Tanks	10,16	2	20,32	5,0	21,34
Valves			2,00	20,0	2,40
Piping			2,00	20,0	2,40
Thrusters	1,30	16	20,80	5,0	21,84
RHU	0,195	8	**1,56**	**5,0**	**1,64**
Nominal Dry Mass			**518,61**	**12,2**	**581,92**
Harness	4	%	**20,74**	**30,0**	**26,97**
Total Dry Mass			**539,35**		**608,89**
System Margin	**20,0**	**%**	**107,87**		**121,78**
Total Dry Mass with Margin			**647,22**		**730,67**

3.8. POWER BUDGET

S/S	Item	Power Budget [W]					
		Launch	Transfer		LLO	D&L	Surface Ops
			Burning	Coasting			
TCS	Heaters	0	80	80	80	80	80
EPS	PCDU	27	27	27	27	27	27
UPS	Main engine	0	56	0	0	56	0
	Attitude thrusters	0	64	64	64	64	0
OBDH	CDMU	37	37	37	37	37	37
	SSMM	0	0	0	0	12.5	12.5
	VisNav IPU	0	0	0	0	15	0
	Cameras	0	0	0	0	3.6	0
GN&C	Star tracker	0	8	8	8	8	0
	Sun Sensors	0	0	0	0	0	0
	IMU	12	12	12	12	12	0
	Radar Altimeter	0	0	0	0	3	0
TT&C	XPDR LGA #1	0	0	0	36	36	36
	XPDR LGA #2	0	36	36	0	0	0
	XPDR LGA #3	0	36	36	0	0	0
Subtotal Power Consumption [W]		*76.0*	*348.0*	*292.0*	*256.0*	*346.1*	*192.5*
System Margin (20%) [W]		15.2	69.6	58.4	51.2	69.2	38.5
Harness Loss (5%) [W]		3.8	17.4	14.6	12.8	17.3	9.6
Total Power Consumption [W]		**95.0**	**435.0**	**365.0**	**320.0**	**432.6**	**240.6**

Entry	Value
Max P/L power need (W)	544
Lander Power Need (W)	241
Duration Of P/L Max Power (h)	4.3
Total Power Need (W)	785
Total Energy Need (kWh)	3.38
Energy Provided by SA (kWh) ([1])	1.7
Corresponding Battery DoD	65%

(1) Worst case generation condition 395 W

Table 3-2 Max Power And Energy Need With ALCHEMIST

3.9. CONCLUSIONS

Different aspects need to be considered when setting up a commercial oriented delivery service. Along the study the main aspects relevant to each of the service building block have been identified and evaluated.
For some of the aspects there are no concerns when asked to define the mission feasibility by 2025:

- Capability of setting up the required contractual and technical agreements with the launch provider is considered exploitable within the required schedule and with the adequate margin
- Various launch opportunity windows are available along 2025: in addition to the ones studied in more detail during the study, some other windows are available.
- Different saving options for the launch and landing strategy in terms of propellant can be considered: the most promising in this sense are the Direct Insertion + LLO and Direct Insertion + Direct Landing options with Falcon 9.
- Opportunities to provide the P/L with the capability to exploit an almost complete Moon day window can be granted.
- The ISRU MCC setup and qualification, thanks to the heritage and previous experiences, is deemed feasible without any particular concern.

On the other hand, some aspects may arise concerns and should be thoroughly evaluated. It is not to be under-estimated that the availability of a lander as conceived by TAS In Italy and presented along the study could be at risk when considering the relevant design and development schedule (as highlighted, the presented solution is only conceptual and needs to undergo a complete design and qualification process), for which 6 to 7 years are deemed a credible figure.

Additionally it has to be considered that, since a thorough and conclusive analysis of the exploitable market of such a commercial service has not been completed yet, a credible number of possible customers along an appropriate timespan (e.g. over a 10 years period) cannot be identified. It can be then understood that the momentum for the Industry to put in place the steps required for the lander development might be relatively low at the moment. The market survey should be, then, one of the first steps to be performed in the very near future. The understanding of the possible market needs strongly constraints the lander design: a lander designed for mining is completely different from a lander designed for scientific purposes.

Previous concern can be enforced by the fact that, from a very preliminary survey of the other landers currently available, it is difficult to identify one fully exploitable in terms of accommodation, mass, power and data as required by ALCHEMIST.

END OF DOCUMENT