Contents

Pre	face.	ix							
Ab	About the author								
Lis	List of figures								
Lis									
Lis	t of ab	obreviations and acronyms							
1	The v	value of ISRU 1							
	1.1	NASA human mission studies and ISRU							
	1.2	IMLEO with and without ISRU							
	1.3	Cost-benefit analysis of lunar ISRU							
		1.3.1 Lunar ascent propellants							
		1.3.2 Lunar life support							
	1.4	Cost-benefit analysis of Mars ISRU							
		1.4.1 Mars ISRU products							
		1.4.2 Mars ascent propellants							
		1.4.3 Life support on the surface of Mars							
		1.4.4 Value of Mars ISRU 23							
	1.5	Lunar resources to provide propellants in LEO 23							
	1.6	Lunar Ferry for descent propellants							
	1.7	The NASA viewpoint							
2	Mars	SISRU technology							
	2.1	Mars resources							
		2.1.1 The atmosphere							
		2.1.2 Near-surface H ₂ O							

	~
V1	Contents

	2.2	Processes utilizing mainly CO_2 from the atmosphere	39
		2.2.1 The reverse water–gas shift reaction	39
		2.2.2 Solid state electrolysis	46
	2.3	The Sabatier/Electrolysis process	58
		2.3.1 The Sabatier/Electrolysis reaction	58
		2.3.2 S/E demonstration	60
		2.3.3 Reducing the requirement for hydrogen in the S/E process	64
	2.4	Obtaining water from the atmosphere	75
	2.5	Compressing and purifying CO ₂	79
		2.5.1 Sorption compressor	80
	2.6	NASA plans	84
		2.6.1 DRM-5: The latest Design Reference Mission	84
		2.6.2 Recent updates by NASA	88
3	Luna	ar ISRU technology	91
Ü	3.1	Lunar resources	91
	5.1	3.1.1 Silicates in regolith	93
		3.1.2 FeO in regolith	93
		3.1.3 Imbedded atoms in regolith from solar wind	94
		3.1.4 Water ice in regolith pores in permanently shadowed	
		craters near the Poles	94
	3.2	Lunar ISRU processes	95
		3.2.1 Oxygen from FeO in regolith	95
		3.2.2 Oxygen production from silicates in regolith	99
		3.2.3 Volatiles from imbedded atoms in regolith from solar	
		wind	101
		3.2.4 Water extraction from regolith pores in permanently	
		shadowed craters near the Poles	104
	3.3	NASA accomplishments and plans	110
4	Sum	mary and conclusions	113
•	~		
A D	DENID	I/EC	
AP	PEND	r ratios and transfer masses	125
В		lications of nuclear thermal propulsion for Earth departure	131
C	•	of aero-assist for Mars orbit insertion	135
D		support consumables on Mars	141
	D.1	Consumable requirements (without recycling)	141
	D.2	Use of recycling systems	143
	D.3	Life support summary	146

E	Refue	ling spacecraft in LEO using propellants derived from the Moon 14	19
	E .1	Introduction	19
	E.2	Value of lunar water in LEO	51
	E.3	Percentage of water mined on the Moon transferred to LEO 15	52
		E.3.1 Transfer via LL1	52
		E.3.2 Transfer via lunar orbit	50
F	Trans	porting hydrogen to the Moon or Mars and storing it there 16	53
	F.1	Storage as high-pressure gas at about room temperature 16	53
	F.2	Storage as a cryogenic liquid	54
		F.2.1 Mass factors	54
		F.2.2 Rate of boil-off from hydrogen tanks in the vacuum of	
		space	54
		F.2.3 Rate of boil-off from hydrogen tanks on Mars 16	58
		F.2.4 Effect of boil-off in a closed system 16	59
		F.2.5 Zero boil-off concepts	70
	F.3	Storage as a dense gas at reduced temperature	
	F.4	Storage as solid hydrogen	72
	F.5	Storage as solid-liquid slush	
	F.6	Storage as hydrogen at its triple point	75
	F .7	Storage as adsorbed hydrogen on a sorbent	75
	F.8	Storage on metal hydrides	76
Ref	erence	and bibliography	77
Ind	ex		33