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SEI Rover Solar-Electrochemical Power System Options

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E-6224

ABSTRACT

This was a trade study of power system technology options for proposed lunar vehicles and servicers. A variety of solar-based power systems were selected and analyzed for each. The analysis determined the power system mass, volume, and deployed area. A comparison was made between periodic refueling/recharging and on-board power systems to determine the most practical system.

The trade study concluded that the power system significantly impacts the physical characteristics of the vehicle. The refueling/recharging systems were lighter and more compact, but dependent on availability of established lunar base infrastructure. On-board power systems pay a mass penalty for being fully independent systems.

BACKGROUND

One of the main objectives of the Space Exploration Initiative (SEI) is the permanent human operation of a lunar base. Various types of vehicles are required to perform a wide range of tasks ranging from personnel transportation to construction to scientific exploration.

A collection of four vehicles and one portable servicer have been compiled to complete the majority of the tasks necessary for successful operation of the base. The characteristics of each were derived from the NASA "Report of the 90 Day Study of the Human Exploration of the Moon and Mars".[1] These vehicles are the regolith hauler, mining excavator, lunar excursion vehicle payload unloader (LEVPU), and pressurized rover, with the lunar excursion vehicle (LEV) servicer as the portable servicer.

POWER SYSTEM CHOICES

There are two major criteria used to select power system technologies. First, the power technology must meet the known mission power requirements. Second, each technology must be mature enough for early hardware availability.

Given these selection criteria for the power system, there are five power system technologies options judged as available. The options are primary hydrogen-oxygen fuel cells (PFC), regenerative hydrogen-oxygen fuel cells (RFC), nickel hydrogen (NiH_2) batteries, and sodium sulfur (NaS) batteries. The fuel cells in a PFC or RFC configurations can use cryogenic (cs), low pressure (lps), or high pressure gas (hps) reactant storage. Photovoltaic arrays can be used to charge the power system for RFCs and batteries. For the five power system technology options, there are twelve different combinations that are studied. They are as follows:

1. PFC with cryo storage (PFC/cs)
2. PFC with low pressure gas storage (PFC/lps)
3. PFC with high pressure gas storage (PFC/hps)
4. RFC with cryo storage (RFC/cs)
5. RFC with low pressure gas storage - no array (RFC/lps)
6. RFC with high pressure gas storage - no array (RFC/hps)
7. IPV nickel hydrogen battery - no array (IPV NiH_2)
8. sodium sulfur batteries - no array (NaS)
9. RFC with low pressure gas storage - array (RFC/lps/Array)
10. RFC with high pressure gas storage - array (RFC/hps/Array)
11. IPV nickel hydrogen battery - array (IPV NiH_2/Array)
12. sodium sulfur batteries - array (NaS/Array)

The twelve power system options are divided into two categories, periodic refueling/recharging systems and on-board power generation systems. The periodic refueling/recharging system are dependent on an established lunar base infrastructure. They are the first eight listed above. The remaining four are on-board power generation systems which are completely independent of the base infrastructure. These can travel greater distances or longer periods without needing to return to the base.

The analysis resulted in the calculations of mass, volumes and deployed areas for the power systems chosen. The volumes presented herein are a sum total of the volumes of the individual components, and assume a 100% packaging efficiency. The deployed area refers to the photovoltaic array and radiator areas.

POWER SYSTEM CHARACTERISTICS

The primary fuel cells use three types of storage: low pressure gas, high pressure gas, and cryogenics. The primary fuel cell block diagram is within the dotted lines of figure 1. The low pressure gas storage is at 315 psia. The system components are the fuel cell stack, reactants, tankage for the O_2, H_2, and H_2O, radiator, and power management and distribution (PMAD). High pressure gas storage is at 3000 psi and has the same system components. The PFC with cryogenic storage requires a heat transfer loop to vaporize and heat the cryogens prior to entering the fuel cell.

The regenerative fuel cells also use low pressure, high pressure, and cryogenic storage. The block diagram is shown in figure 1. The RFC system components consist of a fuel cell, electrolyzer, reactants and tankage, radiator, and PMAD. The RFCs that are on-board also have a gallium arsenide germanium tracking array used to power the electrolyzer. The cryogenic storage option also requires a liquefaction plant to convert the electrolysis product gases to cryogens (figure 2). However, given the additional radiator and array areas associated with the liquefaction subsystems, this option is judged to be too cumbersome to be practical for an on-board application. Table I shows the system characteristics for both PFCs and RFCs.[2,3]

Two representative batteries were chosen for this study, nickel hydrogen and sodium sulfur. IPV nickel hydrogen batteries are state-of-the-art batteries. Sodium sulfur batteries are representative of an emerging technology. Both types of batteries can utilize a PV array to recharge or can return to the base to recharge. The battery system components are the battery, radiator, PMAD, and structure, with the option for a photovoltaic array. Table I shows the system characteristics for both battery types.

REGOLITH HAULER

The regolith hauler is used to transport large quantities of lunar material for in-situ processing or construction. The primary use for this vehicle is to transport regolith to an oxygen production facility. The vehicle is only scheduled to operate during the day. The specifications and requirements for the regolith hauler are in table II, with figure 3 showing the power profile. The fuel cell and battery power systems for the hauler are sized for daytime operation only.[1,4,5]

The twenty-four hour power profile for the regolith hauler has a nominal power of 3 kW for 8 hours and one hour of 5 minute peaks at 15 kW. There is 1.4 hours of standby power at 1.5 kW. In each twenty-four hour period, there are 13.6 hours of potential recharge time.

Since the hauler may remain near the base, re-supply of fuel cell reactant tanks and/or recharging of the power system at the base may be possible. Therefore, both on-board and periodic refueling/recharge systems are considered. The power system options selected for the regolith hauler are PFC's with low and high pressure gas storage and cryogenic storage, RFCs with low and high pressure gas storage, and both IPV NiH_2 battery systems. Figures 4a, b, and c, show the resulting masses, volumes, and deployed areas, respectively, for the selected options.

The nickel hydrogen battery with and without the photovoltaic array is not shown because its mass is four times as large as the sodium sulfur battery. The volume of the nickel hydrogen battery without the array is twenty seven times larger and the area is 18 times larger. The last three power systems on the chart are on-board systems; the remaining systems are all periodic refueling/recharging systems.

In the category of periodic refueling/recharging, the PFC with cryogenic storage and the PFC with high pressure gas storage have similar mass, volume, and area estimates (approximately 380 kg, 1.9 m^3, and 19.8 m^2). Sodium sulfur batteries have the heaviest mass of the periodic refueling/recharging systems at 674 kg (excluding NiH_2 batteries), but it is also the smallest volume (0.4 m^3) and area (1.2 m^2). Both the PFC and RFC with low pressure gas storage have large volumes around 3.9 m^3. The high pressure gas storage has a definite advantage over low pressure storage by reducing the tank volume by 90 percent.

The on-board power systems are heavier. The sodium sulfur batteries are the heaviest (752 kg), but also the smallest volume (0.6 m^3) and deployed area (21 m^2). The RFC with high pressure storage and solar array is the lightest (605 kg) and in mid-range for volume (4.2 m^3). Table III summarizes the most attractive choices from the analyzed on-board and off-board options.

MINING EXCAVATOR

The mining excavator will be used to remove lunar regolith for either construction or mining purposes. It consists of a bulldozer configuration at one end and a backhoe at the other. Like the regolith hauler it is only scheduled for daytime operation. Figure 5 shows the power profile for the excavator. The profile shows that the excavator requires 22 kWe for 9.6 hours with twelve five minute peaks of 40 kWe and 10 kWe of standby power for 1.4 hours. The potential recharge time allocated to the system is 13.6 hours. Table II shows the specifications and requirements of the mining excavator.[1,4]

The results from the power system characterization for the mining excavator are similar to those of the regolith hauler, except on a larger scale. The same power systems were selected for the excavator as for the hauler. Figures 6a, b, and c show the results. Again, the nickel hydrogen batteries are not shown due to their large mass.

The PFC with cryogenic storage and the PFC with high pressure gas storage are similar in mass and volume (approx. 1050 kg and 5 m^3). The electrolyzer makes the RFC with high pressure gas storage 357 kg heavier than the PFC with high pressure storage. Again, the sodium sulfur batteries have the greatest mass (3448 kg), but also the smallest volume and mass (1.7 m^3 and 3.3 m^2).

For the on-board power systems, the sodium sulfur battery with the array is the heaviest (3910 kg) and the smallest in volume (2.9 m^3) and area (119 m^2). The RFC with high pressure gas storage and array has the lowest mass (2116 kg) and falls in the middle of the range of volumes (7.4 m^3). Table III shows a summary of these results.

LUNAR EXCURSION VEHICLE PAYLOAD UNLOADER

The lunar excursion vehicle payload unloader (LEVPU) is a large movable gantry crane that will be teleoperated. It will be used for local construction, site excavation, and equipment movement. The LEVPU has three telescoping legs which can raise, lower, and adjust the upper platform and cargo. The crane moves about by the use of a large diameter powered wheel at the base of each leg. Table II shows the specifications and requirements for the LEVPU and figure 7 shows the power profile. The power profile shows one hour of peak operation at 10 kWE, 11 hours of nominal power operation at 3 kWe, and a 12 hour potential recharge period with no night operation required.[1,4]

The power systems selected for the LEVPU are the same as for the mining excavator and the regolith hauler. Figure 8a, b, and c, show the results from the power system mass, volume and area characterizations. Again, due to the large mass of the NiH_2 battery it is not shown.

For the periodic refueling/recharging systems the results are similar to the excavator and hauler. The NaS batteries have the lowest volume and deployed area (0.3 m^3 and 0.8 m^2), but also the heighest mass (640 kg). The PFC with cryogenic storage and the PFC with high pressure gas storage have the lowest mass (approx. 280 kg). The PFC with cryo storage, the PFC high pressure storage, and the RFC with high pressure storage have similar volumes and areas (approx. 1.4 m^3 and 13 m^2).

The on-board power systems for the LEVPU are also similar to the excavator and hauler. The RFC with high pressure gas storage is lighter than the NaS batteries (541 kg vs. 733 kg). The NaS batteries are smaller in volume and area compared to the RFC high pressure gas storage (0.6 m^3 and 38 m^2 vs. 1.8 m^3 and 46 m^2).

Table III shows a summary of the mass, volume, and area for the periodic refueling/recharging system and the on-board power systems respectively. The table only shows the high pressure systems for the primary fuel cells and regenerative fuel cells, primary fuel cells with cryogenic storage, and sodium sulfur batteries.

SHORT AND LONG RANGE PRESSURIZED ROVER

There is one type of pressurized rover vehicle, but it is capable of being configured to accomplish two distinct missions, long and short range. Both configurations have a minimum 2 person crew and a maximum crew of 4 people. They are similar in size and shape and are required to function as an emergency habitation module. Table II contains the specifications and requirements for both the short and long range pressurized rovers.[4,5]

The short range vehicle is designed as a personnel transport to move about the base complex and surrounding area. It can be used for construction support, as a portable habitat chamber, and to support EVA tasks. Figure 9 contains the power profile for the short range vehicle. There were seven power systems selected as candidates for this vehicle. They were the PFC with cryogenic, low pressure gas, and high pressure gas storage, RFC with low and high pressure gas storage, nickel hydrogen batteries, and sodium sulfur batteries. Since the vehicle operates only in the vicinity of the base, on-board power systems were not considered. Figures 10a, b, and c contain the mass, volume, and area estimates for these power systems. The nickel hydorgen batteries are not shown in the graphs because it has a mass four times heavier than the NaS batteries. The volume of the nickel hydorgen batteries is 32 times more and the area is 18 times greater than the sodium sulfur batteries.

The PFC with cryogenic storage and the PFCs with high pressure gas storage are similar in mass and volume (298 kg and 1.3 m^3). The NaS batteries have the lowest volume and area (0.4 m^3 and 0.6 m^2), but is also the heaviest (955 kg). All PFCs and RFCs have the same area, 9.3 m^2.

The long range vehicle is designed for extended missions to remote areas of the lunar surface. It will be used for science, exploration, and reconnaissance missions. Figure 11 shows the power profile for this long range configuration. Seven power systems were selected to be characterized for this rover. They were PFCs with cryogenic, low, and high pressure gas storage, RFCs with low and high pressure gas storage, and RFCs with low and high pressure gas storage with arrays. Figure 12a, b, and c show the results of the characterization.

Of the periodic refuel/recharge systems considered, the PFC with cryogenic storage has the lowest mass and volume for the long range pressurized rover (992 kg and 4.4 m^3). The PFC with high pressure gas storage is the second lowest mass and volume (1811 kg and 7.6 m^3). For the on-board power systems the RFC with high pressure gas storage with an array is smaller in volume compared to the RFC with low pressure gas storage with an array (10 m^3 vs 68 m^3), but has a lighter mass (3060 kg vs 3460 kg). Both on-board power systems have an area of 225 m^2, and all periodic refueling/recharging systems have an area of 16 m^2.

LUNAR EXCURSION VEHICLE SERVICER

The lunar excursion vehicle servicer (LEV servicer) is a non-mobile but portable platform which can provide various services to reusable excursion vehicles. These services include supplying power, providing thermal control protection, active limitation of cryogenic fuel boil-off, and monitoring of vehicle subsystems. The LEV servicer can be moved by the LEVPU or by permanently mounting it on a rover cart. Table II shows the power requirements for the LEV servicer and figure 13 show the power profile, which is for day and night operation.[1,4]

Photovoltaic arrays will provide power to the servicer during the lunar day while RFCs with cryogenic storage were selected as the energy storage technology to provide power during the night. Figure 14 shows the mass, volume, and area estimates. The total mass of the power system is 3050 kg. It has a volume of 13 m^3 and an area of 159 m^2.

ADVANTAGES/ DISADVANTAGES

Each power system technology discussed has advantages and disadvantages. In selecting which power systems technologies are more appropriate, all advantages and disadvantages must be weighed including system concerns and safety, in addition to the physical parameters of mass, volume, and area estimates.

The fuel cells discussed have three types of storage: cryogenic, low pressure gas, and high pressure gas. Cryogenic storage has the advantage over low and high pressure storage because the tank sizes are smaller and lighter. One disadvantage of cryogenic storage is the potential problems associated with transferring cryogenics in low vacuum or space. There is also the added complexity of the liquefaction plant. High pressure storage has potentially greater safety problems than low pressure storage, but has much smaller tanks.

The main advantage of primary fuel cells over regenerative fuel cells is that an on-board electrolyzer is not needed for recharging the fuel cells. This reduces the mass and volume that the rover must accommodate. This can also be a disadvantage because the rover must return to the base for recharge, thus limiting its range. Another disadvantage of the primary fuel cell is the problem of recharging the tanks by making gas connections in a low pressure environment.

Regenerative fuel cells are all self contained, so they do not need fluid connections to recharge. The RFC can have an on-board photovoltaic array for recharge or without the array it must rely on the lunar base infrastructure. With the on-board photovoltaic array a vehicle could travel long distances from the base without the need to return to the base for recharge. An RFC with an on-board cryogenic system is usually not practical because of the array and radiator areas and the added complexity associated with the liquefaction units.

In the category of batteries, IPV nickel hydrogen battery estimates resulted in sizes that where much larger than sodium sulfur batteries, in mass, volume, and area. Nickel hydrogen batteries also have the safety issue of the battery being under high pressure. However, the sodium sulfur batteries also have safety concerns. These batteries contain quantities of hot liquid sodium which could be dangerous if the cells were to breech their containers.

CONCLUSIONS

There were a total of four vehicles and one portable servicer analyzed herein. For each there were twelve different power systems selected for evaluation. The regolith hauler, mining excavator, and lunar excursion vehicle payload unloader all had the same eleven power systems selected for characterization. The short and long range pressurized rover each had seven power system options, but not the same options. The lunar excursion vehicle servicer had only one.

The regenerative fuel cell with cryogenic storage was analyzed for only the LEV servicer due to the size and complexity of the system. The IPV nickel hydrogen battery, both with and without the array, was analyzed for most. Its short coming was the large mass, volume, and area compared to other options analyzed.

Under the operational category of periodic refueling/recharging systems, the primary fuel cell emerged as the most attractive option. It was applicable to the largest number of missions. Of the three types of primary fuel cells, the cryogenic storage of the reactants had the largest mass savings. The sodium sulfur batteries were also a favorable option. They had the lowest volume and area, although heavier than the fuel cells.

The on-board power systems had the regenerative fuel cells with photovoltaic arrays having the lowest mass. The sodium sulfur batteries with photovoltaic arrays were competitive in mass, but lowest in both volume and area.

There is a penalty for a fully independent power systems versus periodic refueling/recharging systems. These penalties may be judged minor should a mission be enabled by a totally on-board power systems.

The mass, volume, and area for the power system options presented herein can influence the vehicle configuration. As the mission requirements mature, the power system technology options will be reduced or may even influence mission requirements.

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TABLE I: FUEL CELL AND BATTERY SYSTEM CHARACTERISTICS

	FUEL CELLS		BATTERIES	
	PFC	RFC	NiH2	NaS
FUEL CELL				
CURRENT DENSITY	215 - 1075 mA/sq.cm.	215 - 1075 mA/sq.cm.		
CELL ACTIVE AREA	0.092 sq.m.	0.092 sq.m.		
OPERATING PRESSURE	0.4 MPa (60 psi)	0.4 MPa (60 psi)		
OPERATING TEMPERATURE	355 K	355 K		
ELECTROLYZER				
CURRENT DENSITY		215 mA/sq.cm.		
CELL ACTIVE AREA		0.092 sq.m.		
OPERATING PRESSURE		2.2 MPa (315 psi)		
OPERATING TEMPERATURE		355 K		
RADIATOR				
EMISSIVITY (EFFECTIVE)	0.595	0.595	0.595	RADIATES
SPECIFIC MASS	5 kg/sq.m.	5 kg/sq.m.	5 kg/sq.m.	DIRECTLY
REJECTION TEMPERATURE	355 K	355 K	293 K	TO
SINK TEMPERATURE	220 K day / 20 K night	220 K day / 20 K night	220 K day / 20 K night	SPACE
GaAs/Ge ARRAY				
SPECIFIC POWER		94 W/kg	94 W/kg	94 W/kg
SPECIFIC MASS		2.05 kg/sq.m.	2.05 kg/sq.m.	2.05 kg/sq.m.
EFFICIENCY		18.30%	18.30%	18.30%
BATTERY				
CELL CAPACITY (@ 100% DOD)			81 AH	54.7 ah
OPERATIONAL DOD			50%	80%
OPERATIONAL TEMPERATURE			293 K	623 K
PMAD				
SPECIFIC POWER	10 kg/kw	10 kg/kw	10 kg/kw	10 kg/kw

TABLE II: MISSION SPECIFICATIONS

	REGOLITH HAULER	MINING EXCAVATOR	LEVPU	SHORT RANGE	LONG RANGE	LEV SERVICER
VEHICLE CHARACTERISTICS						
VEHICLE MASS	1000 kg	3000 kg	15000 kg	4500 kg	6000 kg	-
HAULING / LIFTING CAPACITY	750 kg	1000 kg	10000 kg	-	-	-
AVERAGE VELOCITY	2 m/s	1 m/s	1 m/s	2.8 m/s	2.8 m/s	-
MAX. SLOPE ANGLE FOR FULL FUNCTION OPERATION	6 deg	6 deg	6 deg	20 deg	20 deg	-
CREW - MIN/MAX	-	-	-	2 OR 4	2 OR 4	-
POWER REQUIREMENTS						
PEAK POWER	15 kWe	40 kWe	10 kWe	-	-	-
NOMINAL POWER	3.0 kWe	22 kWe	3 kWe	7.0 kw	12.0 kw	10 kw
STANDBY POWER	1.5 kWe	10 kWe	-	-	-	-
OPERATION PARAMETERS PER CYCLE						
PEAK OPERATION TIME	1.0 hrs	1.0 hrs	1.0 hrs	-	-	-
NOMINAL OPERATION TIME	8.0 hrs	8.6 hrs	11.0 hrs	10 hrs	96 hrs	30 days - 1 yr
STANDBY OPERATION TIME	1.4 hrs	1.4 hrs	-	-	-	-
INACTIVE TIME	13.6 hrs	13.6 hrs	12.0 hrs	14 hrs	48 hrs	-

TABLE III: MOST ATTRACTIVE POWER SYSTEM OPTIONS

		MASS (kg)	VOLUME (m^3)	DEPLOYED AREA (m^2)		MASS (kg)	VOLUME (m^3)	DEPLOYED AREA (m^2)
	PERIODIC REFUELING / RECHARGING				**ON BOARD POWER SYSTEMS**			
REGOLITH HAULER	*PFC w/ Cryo*	369	1.9	RAD: 20	*RFC w/ HPS & Array*	605	2.2	RAD: 20 PV: 27
	PFC w/ HPS	379	1.8	RAD: 20				
	RFC w/ HPS	499	1.9	RAD: 20	*NaS Batteries & Array*	752	0.6	RAD: 1.2 PV: 20
	NaS Batteries	674	0.4	RAD: 1.2				
MINING EXCAVATOR	*PFC w/ Cryo*	993	4.5	RAD: 53	*RFC w/ HPS & Array*	2116	7.4	RAD: 53 PV: 156
	PFC w/ HPS	1138	5.4	RAD: 53				
	RFC w/ HPS	1495	5.8	RAD: 53	*NaS Batteries & Array*	3910	2.9	RAD: 3.3 PV: 116
	NaS Batteries	3448	1.7	RAD: 3.3				
LEVPU	*PFC w/ Cryo*	272	1.4	RAD: 13	*RFC w/ HPS & Array*	541	1.8	RAD: 13 PV: 33
	PFC w/ HPS	284	1.3	RAD: 13				
	RFC w/ HPS	411	1.5	RAD: 13	*NaS Batteries & Array*	733	0.6	RAD: 15 PV: 23
	NaS Batteries	640	0.3	RAD: 0.8				

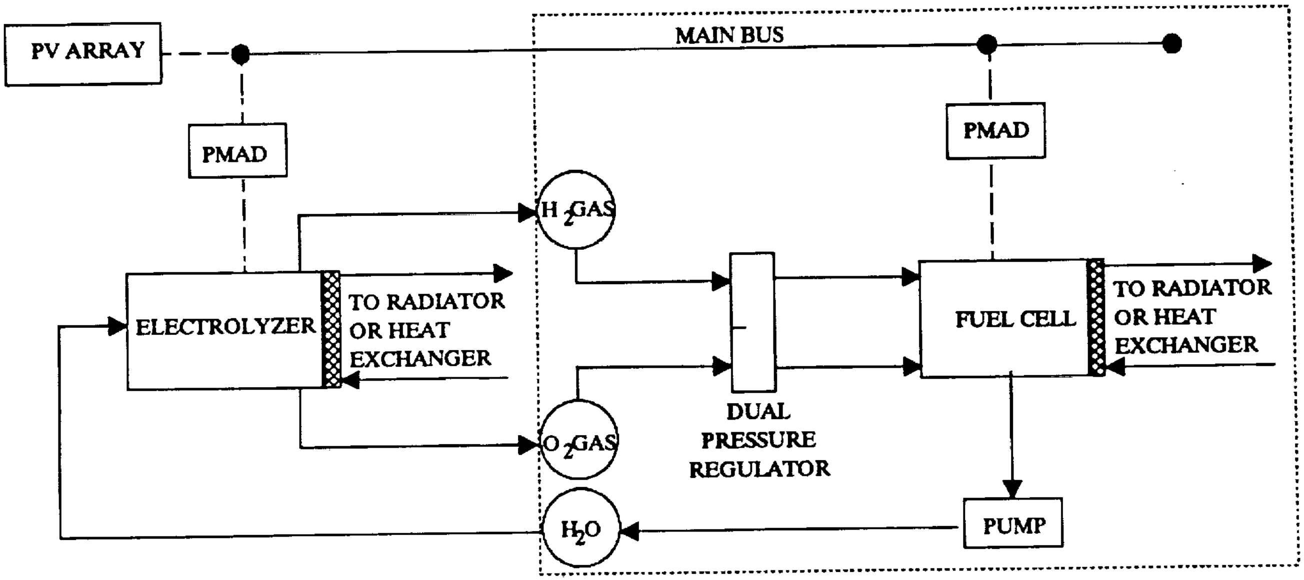

FIGURE 1: BLOCK DIAGRAM OF REGENERATIVE FUEL CELL WITH GASEOUS STORAGE

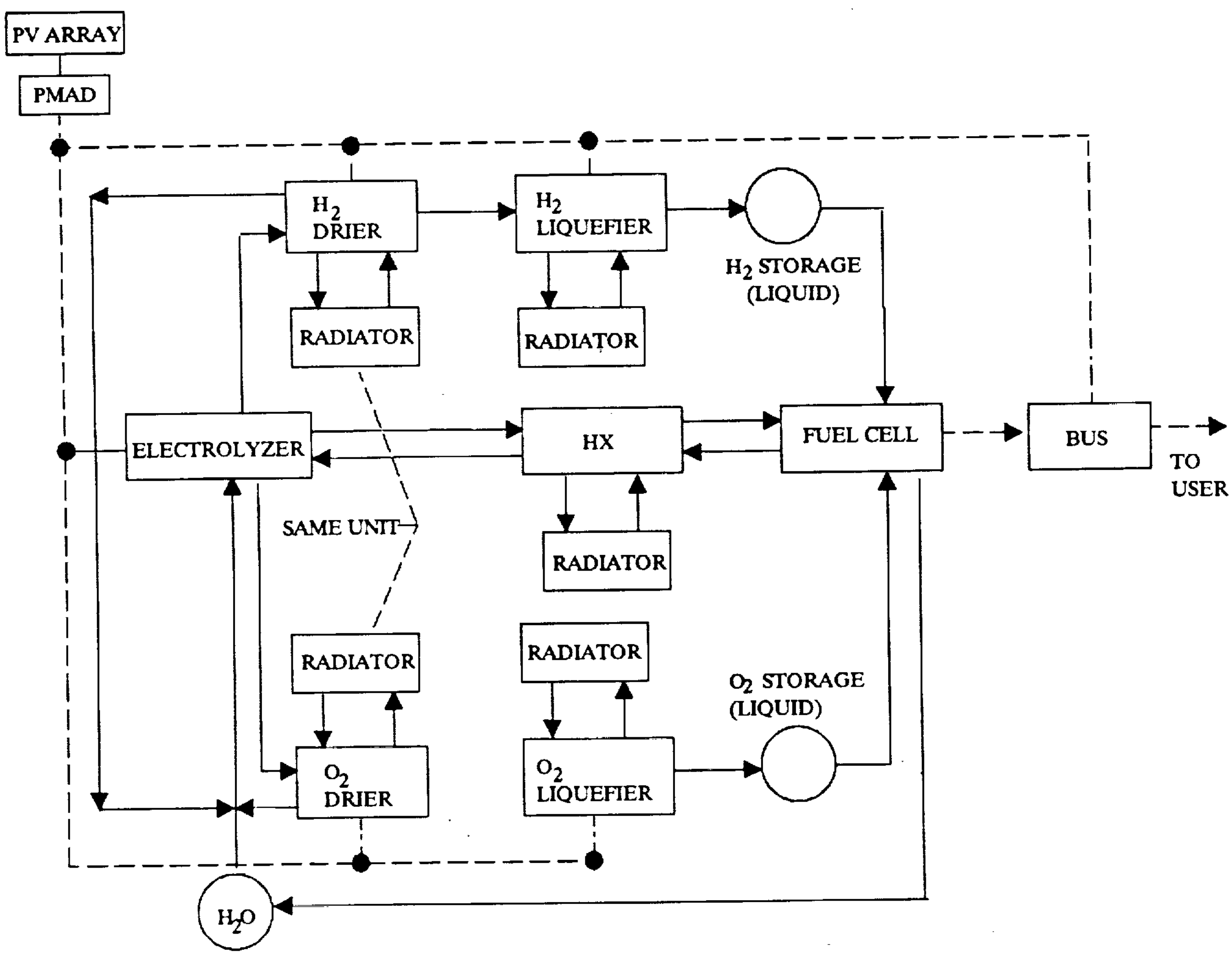

FIGURE 2: BLOCK DIAGRAM OF REGENERATIVE FUEL CELL WITH CRYO STORAGE

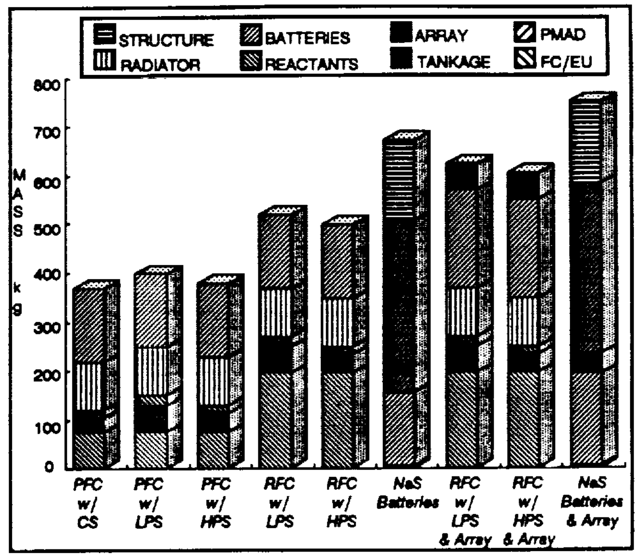

FIGURE 4a: REGOLITH HAULER SYSTEM MASS ESTIMATES

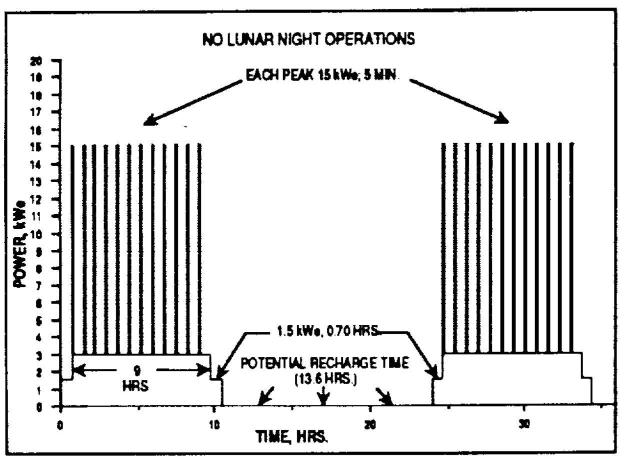

FIGURE 3: REGOLITH HAULER POWER PROFILE

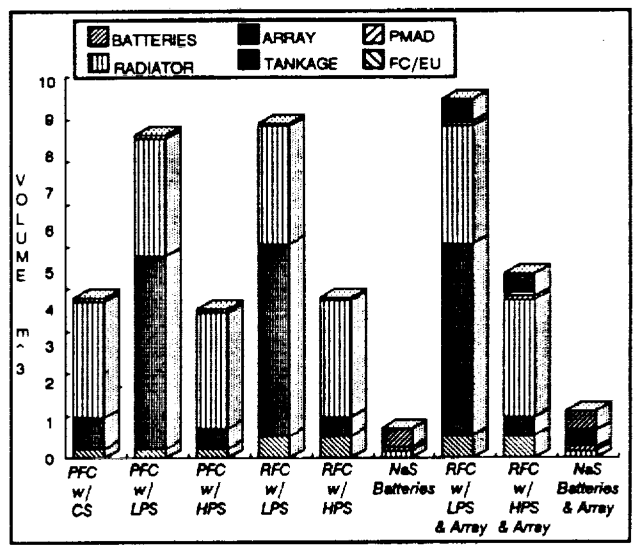

FIGURE 4b: REGOLITH HAULER SYSTEM VOLUME ESTIMATES

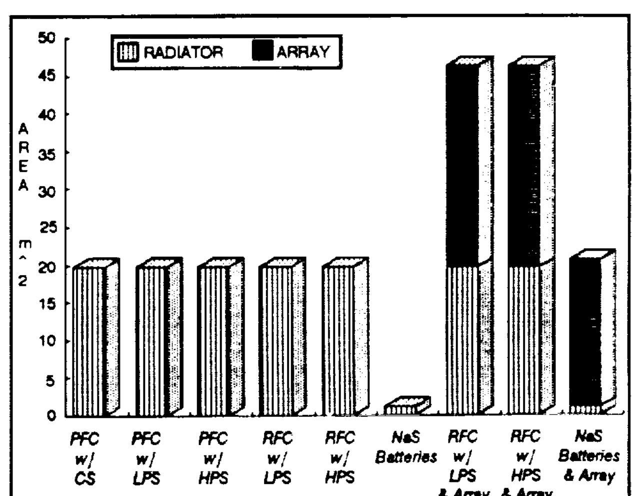

FIGURE 4c: REGOLITH HAULER SYSTEM AREA ESTIMATES

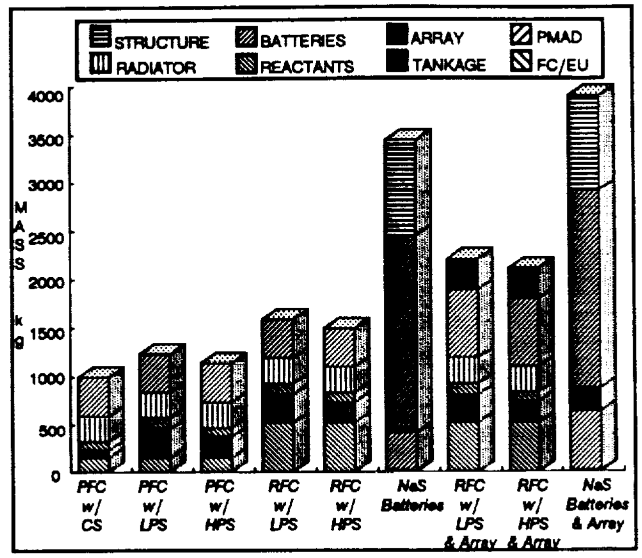

FIGURE 6a: MINING EXCAVATOR SYSTEM MASS ESTIMATES

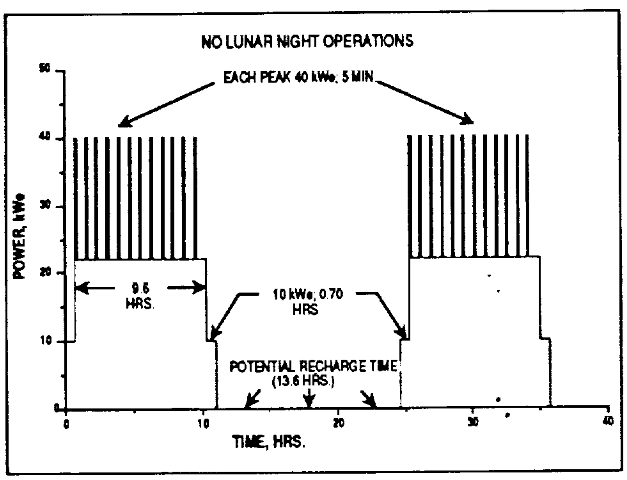

FIGURE 5: MINING EXCAVATOR POWER PROFILE

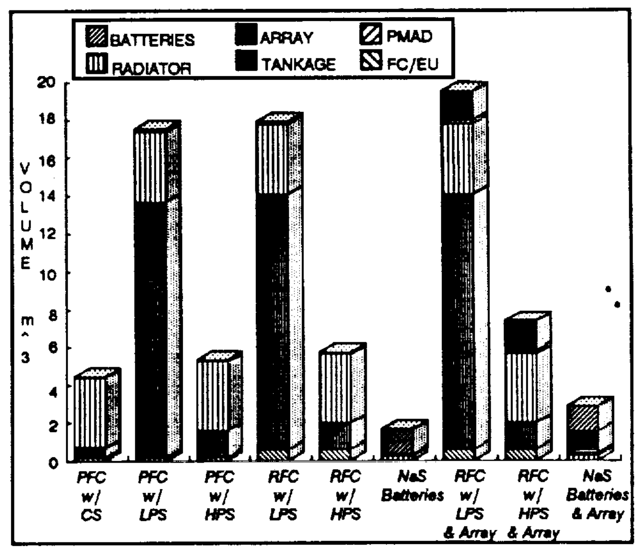

FIGURE 6b: MINING EXCAVATOR SYSTEM VOLUME ESTIMATES

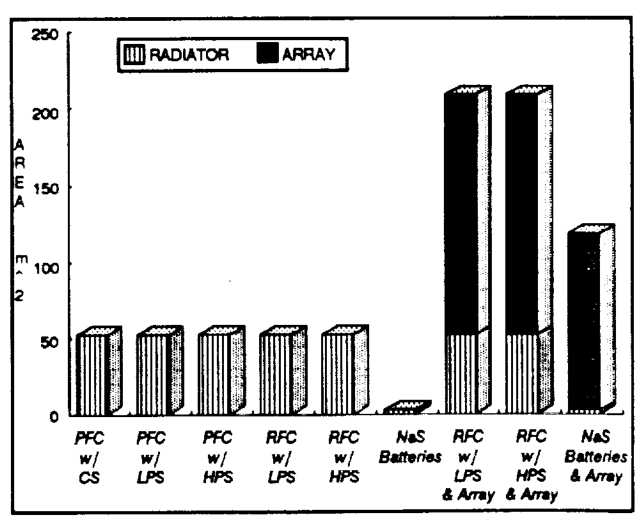

FIGURE 6c: MINING EXCAVATOR SYSTEM AREA ESTIMATES

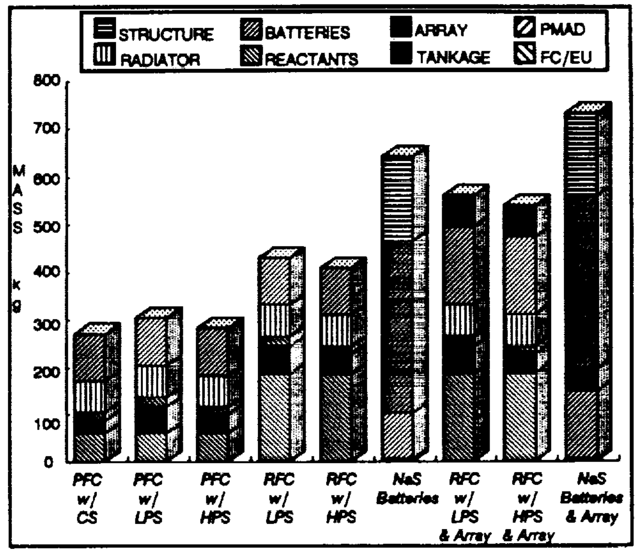

FIGURE 8a: LEVPU SYSTEM MASS ESTIMATES

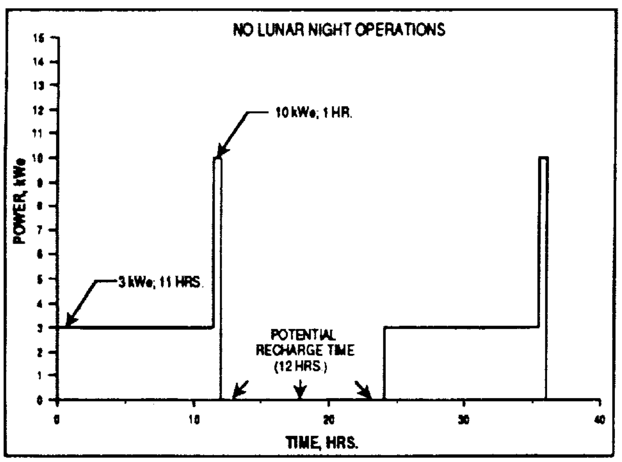

FIGURE 7: LEVPU POWER PROFILE

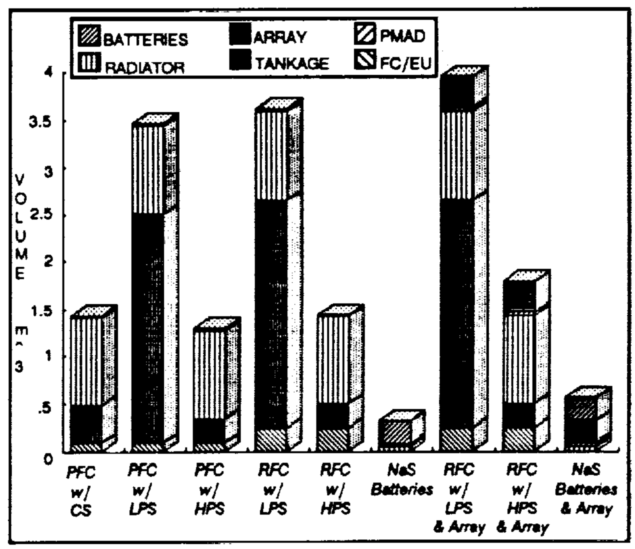

FIGURE 8b: LEVPU SYSTEM VOLUME ESTIMATES

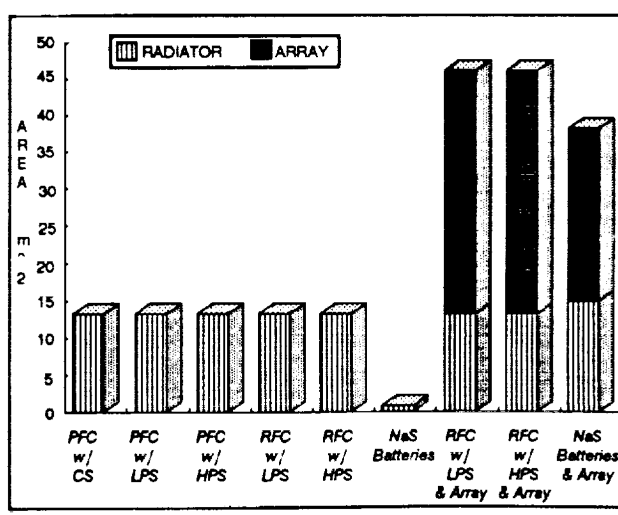

FIGURE 8c: LEVPU SYSTEM AREA ESTIMATES

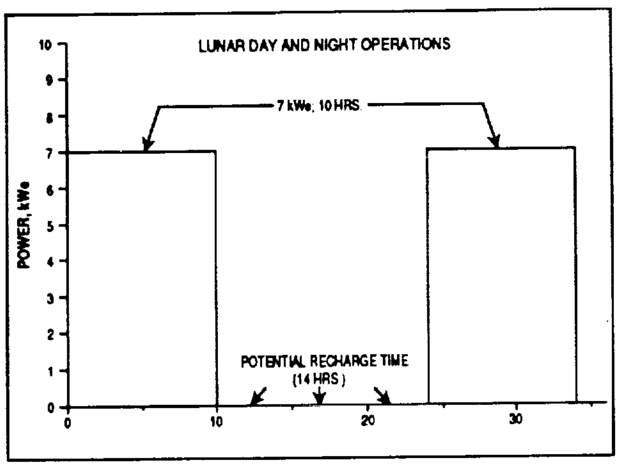

FIGURE 9: SHORT RANGE PRESSURIZED ROVER POWER PROFILE

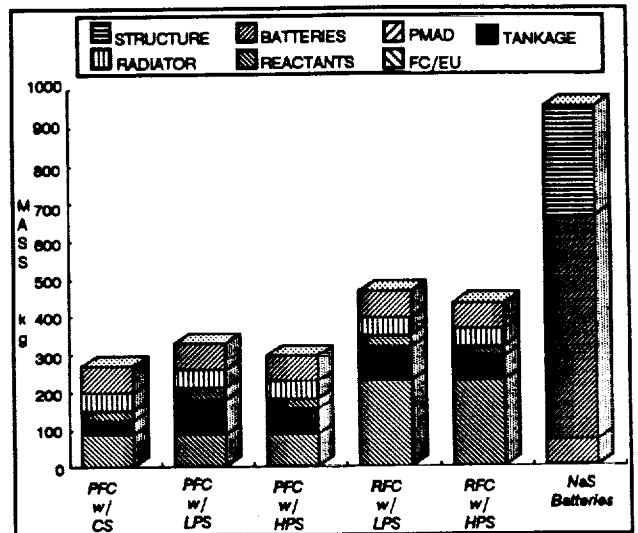

FIGURE 10a: SHORT RANGE PRESSURIZED ROVER SYSTEM MASS ESTIMATES

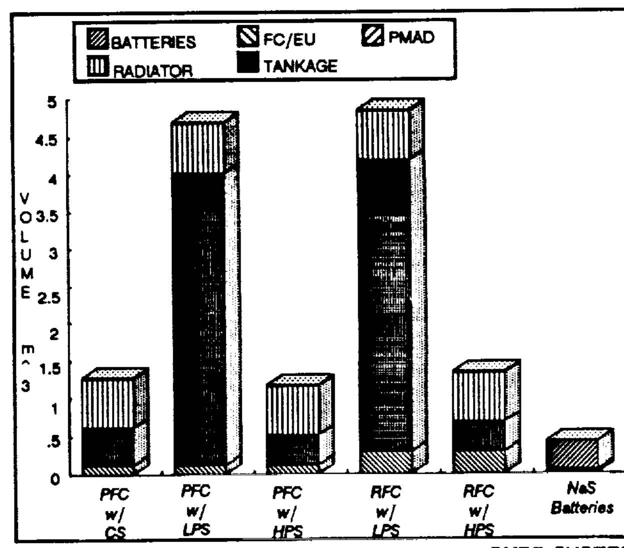

FIGURE 10b: SHORT RANGE PRESSURIZED ROVER SYSTEM VOLUME ESTIMATES

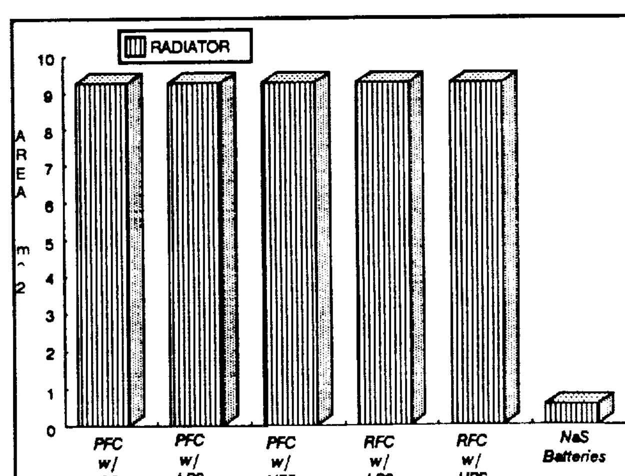

FIGURE 10c: SHORT RANGE PRESSURIZED ROVER SYSTEM AREA ESTIMATES

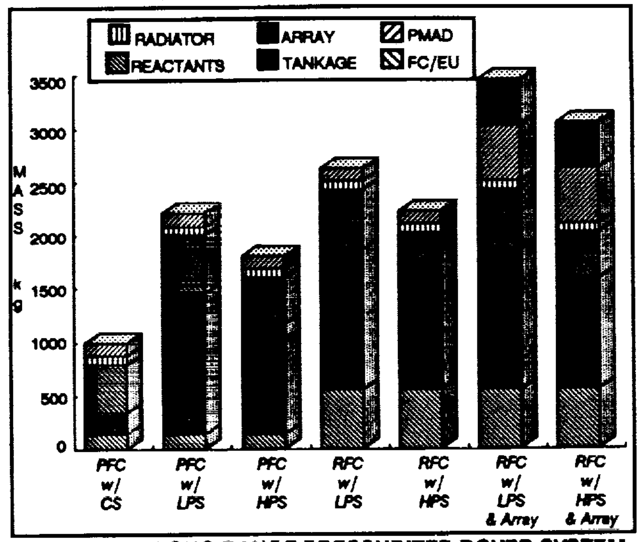

FIGURE 12a: LONG RANGE PRESSURIZED ROVER SYSTEM MASS ESTIMATES

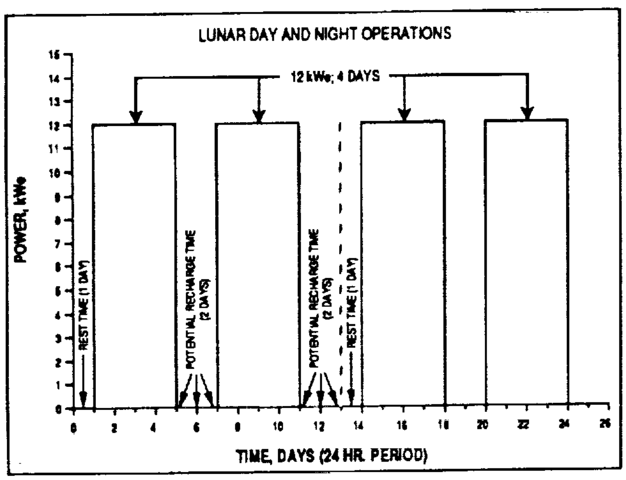

FIGURE 11: LONG RANGE PRESSURIZED ROVER POWER PROFILE

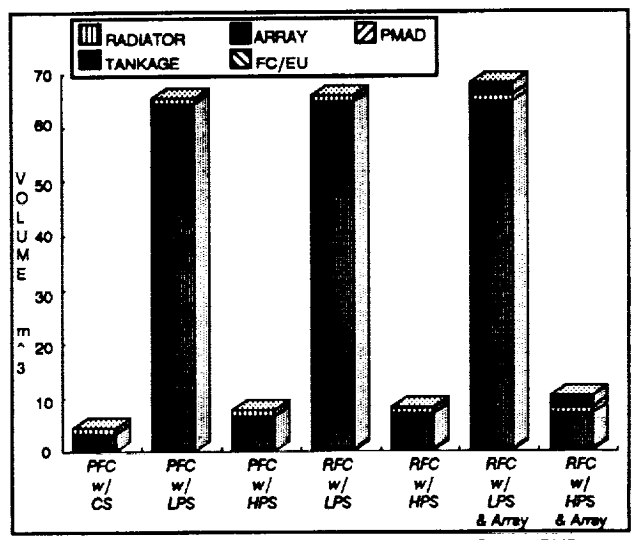

FIGURE 12b: LONG RANGE PRESSURIZED ROVER SYSTEM VOLUME ESTIMATES

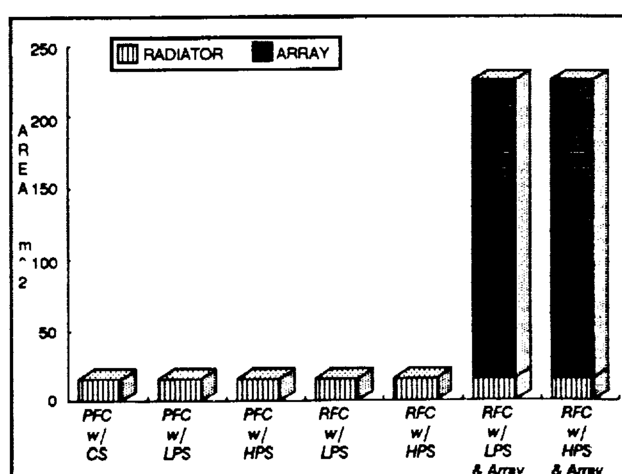

FIGURE 12c: LONG RANGE PRESSURIZED ROVER SYSTEM AREA ESTIMATES

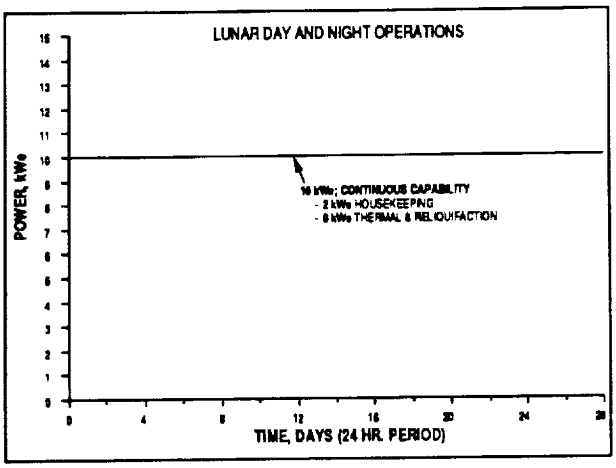

FIGURE 13: LEV SERVICER POWER PROFILE

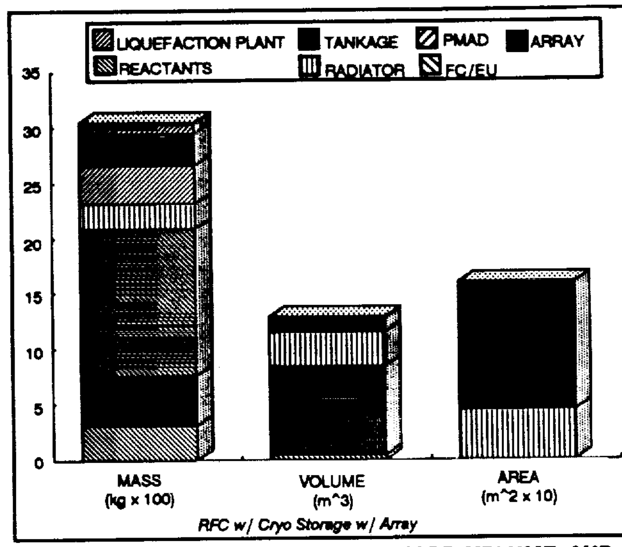

FIGURE 14: LEV SERVICER SYSTEM MASS, VOLUME, AND AREA ESTIMATES

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16. Abstract

This was a trade study of power system technology options for proposed lunar vehicles and servicers. A variety of solar-based power systems were selected and analyzed for each. The analysis determined the power system mass, volume, and deployed area. A comparison was made between periodic refueling/recharging and onboard power systems to determine the most practical system. The trade study concluded that the power system significantly impacts the physical characteristics of the vehicle. The refueling/recharging systems were lighter and more compact, but dependent on availability of established lunar base infrastructure. On-board power systems pay a mass penalty for being fully independent systems.

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