Lockheed Martin Space Mission Systems & Services
Science, Engineering, Analysis, and Test
2400 NASA Road 1, P.O. Box 58561, Houston, TX 77258-8561
Telephone (281) 333-5411

LOCKHEED MARTIN

Feb. 19, 2001
Subtask Order: 1HECECAYS
Contract: NAS9-19100
MSAD-01-0221

TO:	M.K. Ewert	/NASA/EC2	
VIA:	J.L. Cox	/LM/C70	*J.F. Keener for Jack Cox in absentia*
	J.F. Keener	/LM/C70	*signed by J.F. Keener*
	K.E. Lange	/LM/C70	*signed by K.E. Lange*
FROM:	B.E. Duffield	/LM/C70	

Advanced Life Support (ALS) Technologies List Version 4

SUMMARY: This list of potential ALS technologies is intended to be as comprehensive as possible so that it can be used to guide trade off studies that search for the best possible combination(s) of technologies for future missions. Here 'ALS technologies' is very broad, meaning any technology that has a significant interaction with the traditional life support functions of providing fresh air and water. ALS functions such as biomass production, food processing, solid waste processing and thermal control are also included.

The mass, power and volume values listed are based on a crew of 6 and a mission duration of 400 days with the exception of the food processing area. The mass, power and volume values for the food processing area were derived for the Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) project. Some estimates of mass, power and volume values were made using the Advanced Life Support Sizing Analysis Tool (ALSSAT), which is a preliminary version of a spreadsheet tool being developed at Johnson Space Center (JSC) for Environmental Control and Life Support Systems (ECLSS) sizing analysis. The technologies on this list are as specific as possible and, in general, represent development efforts, which are currently ongoing. The list will be updated as additional information becomes available. Any missing values are yet to be determined (TBD) at this time. Please report any suggested additions or corrections to the author (281) 333-7384 or e-mail at bruce.duffield@lmco.com.

The definitions of TRL are as follows:

TRL 1 – Basic principles observed and reported
TRL 2 – Technology concept formulated
TRL 3 – Critical function proof-of-concept
TRL 4 – Component or breadboard validated in a laboratory
TRL 5 – Components validated in a relevant environment
TRL 6 – Prototype demonstrated in a relevant environment
TRL 7 – Prototype demonstrated in a space environment
TRL 8 – Design flight qualified
TRL 9 – System flight proven in mission operations

LIFE SUPPORT SUBSYSTEMS:

AIR

CO_2 Removal

- LiOH - Lithium hydroxide for CO2 removal without regeneration; high resupply rate[1].

$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
9	0	623	1.9
comment: ALSSAT v 2.0			

- LiOH Paper – Being developed by Goretex for the shuttle program[2o].

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

- Molecular Sieve (4BMS) - In the 4BMS, two synthetic zeolites beds are used alternately for absorption and desorption of CO_2 from the atmosphere in conjunction with two moisture removal beds[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
8	1000	255	1.55
comment: BVAD			

- Molecular Sieve (2BMS) - The 2BMS uses a functional carbon molecular sieve and moisture removal beds are not needed[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Solid Amine Water Desorption (SAWD) - A steam heated solid amine (WA-21) is used. Solid amine degrades with time requiring bed changeouts and moisture is released adding load to the Condensing Heat Exchanger. The SAWD doesn't require vacuum conditions like the 4BMS and 2BMS[1]. The amine is no longer available[2a].

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	570	55	0.04
comment: ALSSAT v 2.0			

- Solid Amine Vacuum Desorption (SAVD) (Water save CO_2 (WSCR)) (new amine). Like the SAWD except uses vacuum to pull CO_2 and H_2O from the solid amine beds. Includes a hydrophilic membrane stack prior to the amine bed, for moisture removal[13]. If not venting to space vacuum, compressor development is required and TRL is lowered to the level of compressor development[2a].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	122	80	0.15
comment: ALSSAT v 2.0			

- Solid Amine Vacuum Desorption (SAVD) (RCRS amine with no water saver) (old amine). Like the SAWD except uses vacuum to pull CO_2 and H_2O from the solid amine beds[2a].

TRL	POWER, W	MASS, kg	VOLUME, m^3
9	122	80	0.15
comment: ALSSAT v 2.0			

- Electrochemical Depolarization Concentrator (EDC) - Combines CO_2 with H_2 & O_2 (fire or explosion risk). EDC is a net power generator[1].

$$CO_2 + \tfrac{1}{2}O_2 + H_2 \longrightarrow CO_2 + H_2O + Elec.energy + Q_{heat}$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	44	42	0.06
comment: ALSSAT v 2.0			

- Liquid Amine Gravity Dependent CO_2 Removal Sys.

TRL	MASS, kg	POWER, W	VOLUME, m^3
3			

- Air Polarized Concentrator (APC) - Like the EDC but doesn't require H_2, *i.e.* safer but is a net power consumer[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	285	42	0.06
comment: ALSSAT v 2.0			

- Electroactive carriers within membranes - Fixed within membranes capable of binding CO_2 in the reduced state and releasing CO_2 in the oxidized state. Low TRL[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Membrane Removal - To date has shown inadequate selectivity for CO_2[1].
- Green Plants - Photosynthetic conversion of CO_2 to O_2. See BPS technologies for more details[1,2,4].

TRL for gas conversion (wheat in JSC Phase III test)
5

- Algal Systems - Photosynthetic conversion of CO_2 to O_2[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: TRL given for US or Japanese technology; Russian technology TRL 5			

- Enzyme facilitated Transport Reactors for CO_2 Capture – Thin polymer film separating a liquid membrane containing an enzyme (carbonic anhydrase(CA)), which catalyzes CO_2 capture. Dr. Michael Tractenberg is the PI.[6]

$$CO_2 + H_2O \xleftrightarrow{CA} H_2CO_3$$

TRL	MASS, kg	POWER, W	VOLUME, m^3
3			

- CO_2 compressor[2d].
  - Adsorption Pump – Being developed by John Finn Ph.D. at the Astrobiology Technology Branch Space Science Division of the NASA Ames Research Center (ARC).

TRL	MASS, kg	POWER, W	VOLUME, m^3
3			

  - SWR (Southwest Research)

TRL	MASS, kg	POWER, W	VOLUME, m^3
3			

  - Creare

TRL	MASS, kg	POWER, W	VOLUME, m^3
1			

CO_2 Reduction

- Sabatier - produces water and methane. Uses high temp. (450 - 800 K)[1]

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
6	130	31	0.01
comment: Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98./ Vol. - ALSSAT v 2.0			

- Bosch - produces Carbon and water. Uses high temp. (700 - 1000 K)[1]

$$CO_2 + H_2 \longrightarrow C + 2H_2O + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	242	68	0.09
comment: ALSSAT v 2.0			

- Advanced Carbon Formation Reactor System (ACRS) - a Sabatier, gas/liquid separator and Carbon Formation Reactor (CFR), CFR packs carbon better than Bosch but uses operating temp of 1100 K[1].
  Sabatier Rx with methane conversion to carbon.

$$CH_4 \longrightarrow C + 2H_2$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	400	180	0.30
comment: NASA/ARC In House Life Support Review Databook.			

- CO_2 Electrolysis (zirconia system)- Under development for ISRU. Reduces CO_2 & produces O_2 but operates at high temp (1100 K)[1].

$$CO_2 + H_2O \longrightarrow CO + O_2 + H_2$$

$$2CO \longrightarrow C + CO_2$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Green Plants - Photosynthetic conversion of CO_2 to O_2. See BPS technologies for more details[1,2,4].

TRL for gas conversion (wheat in JSC Phase III test)
5

- Algal Systems - Photosynthetic conversion of CO_2 to O_2[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: TRL given for US or Japanese technology; Russian technology TRL 5			

- Microchannel CO2 Reduction[2b].

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

- Liquid amine gravity dependent (LAGD) CO2 Removal - Bend report
- Membrane CO2 controller (alkanolamine sorbent) – Umpqa
- CO2 Electrolysis w/ perovskite or fluorites – Eltron Research Inc.

O_2 Generation & Delivery

- Solid Polymer Water Electrolysis (SPWE) - Uses solid polymer electrolyte to produce O_2 from water[1].

Electrolysis Rx.

$$2H_2O + Energy \longrightarrow 2H_2 + O_2 + heat$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
7	1021	64	0.05
comment: ALSSAT v 2.0			

- Static Feed Water Electrolysis (SFWE) - Uses aqueous electrolyte to produce O_2 from water[1].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	959	54	0.03
comment:			

- ISS OGA with "Removal of H_2 Dome".

- CO_2 Electrolysis - Reduces CO_2 & produces O_2 but operates at high temp (1100 K). (See above in CO_2 reduction) [1]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Green Plants - Photosynthetic conversion of CO_2 to O_2. (see above in CO_2 reduction)[1,2,4]

- Algal Systems - Photosynthetic conversion of CO_2 to O_2. (see above in CO_2 reduction)[1]

- Artificial Gill - Binds O_2 from low concentration streams by combining O_2 with organometallic compounds like hemoglobin. Could be used to recover O_2 from plant chambers or the Martian atmosphere[1,2h].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- O_2 Concentrator (Commercial off the shelf item (COTS))[2e]

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

Diluent Gas Supply

- Gas storage - high pressure liquid or gaseous N_2[1]

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment: ALSSAT v 2.0			

- Thermal Catalytic Dissociation of hydrazine or ammonia to N_2[1,2h]

$$3N_2H_4 \longrightarrow N_2 + 4NH_3 + heat$$

$$4NH_3 + heat \longrightarrow 2N_2 + 6H_2$$

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Argon Recovery Bed

Trace Contaminant Control System (TCCS)

- Activated Charcoal Adsorption[1]

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Photo catalytic oxidation[2a]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- ISS Baseline TCCS[2a]

TRL	POWER, W	MASS, kg	VOLUME, m^3
6	244	83	0.25
comment: ALSSAT v 2.0			

- Improved TCCS - features a regenerable sorbent bed that is regenerated using space vacuum[2o].

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	128	77	0.13
comment: BVAD			

- Regenerable Air Purification System (RAPS) - (NASA (ARC) & Vanderbilt U. joint effort) use of a humidity-swing desorption cycle, which uses less power than a thermal desorption cycle and requires no venting of air and water to space vacuum[2b].

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Biological Air Filter - Contains a liquid phase, which has microbes, separated from the gas phase (air) by membranes[1, 2h].

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Soil Reactor Beds (SRB) - Air movement through living soil that supports a population of plants[2h].

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Air Quality Monitoring[2o]
  - Rice Sniffer- Rice University
  - E-nose- JPL
  - Bioluminescent Reporter Circuit - Oakridge
  - Mini GC/MS – JPL
  - Trace Organics Characterization:
    - Surface Acoustical Wave Hygrometer (SAW Hygrometer)- JPL
    - Tunable Diode Laser – JPL

- Regenerative Trace Contaminant Control.
  - TDA Silicalite Regenerative Sys. – TDA
  - Capillary Electrode Non-thermal Plasma – Stevens Institute

BIOMASS

- Lighting[2e,2m]
  - Direct Lighting
    1. High Pressure Sodium
    2. Light Emitting Diodes (LED)
    3. Fluorescent – there's an issue with scaling up
    4. Microwaves - potential power saver vs. high pressure sodium
    5. Solar Space Greenhouse

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	6			
2	7			
3	4			
4	5			
5	2			
comment:				

  - Indirect Lighting
    1. Fiber Optic
    2. Light Pipe

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	4			
2	4			
comment:				

- Heat Removal Systems for Lighting
    1. Water Jacketed High Pressure Sodium Lamps
    2. Cold Plate
    3. Air Heat Exchangers
    4. Barriers
        a. Teflon
        b. Tempered glass
        c. Lexan
        d. Water

	TRL
1	4
2	6
3	6
4a	4
4b	5
4c	4
4d	4

- Nutrient/Water Delivery[2e,2m]
    1. Solid Media
    2. Hydroponics
    3. Aeroponics

	TRL
1	4
2	5
3	4

- Nutrient Composition Management[2e,2m]
    1. On demand
        a. Conductivity
        b. Ion Specific
    2. Model Based

	TRL
1a	5
1b	3
2	4

- Nutrient Sources[2e,2m]
    1. Pure chemicals
    2. Resource recovery
        a. Breadboard Scale Aerobic Bioreactor (BSAB) / Compost
        b. Incineration
        c. Waste water recovery

	TRL
1	5
2a	4
2b	3
2c	2

- Specialized Harvest & Planting Equipment[2e,2m]
    1. Tray Lid Conveyor
    2. Tray Lift
    3. Processing Conveyor
    4. Tray Lid
        a. Support Frame
        b. Rooting Matrix
    5. Automated Seeder
    6. Harvester
    7. Germination cabinet
    8. Crop dryer

	TRL
1	4
2	4
3	4
4a	4
4b	4
5	2
6	2
7	3
8	2

- Plant Health Monitors[2e,2m] TRL(4)
- Higher productivity crops[2e,2m]. TRL(2)
- Shorter crops[2e,2m]. TRL(2)
- Mechanical stimulation of tomato plants

FOOD[2x, 2y, 2q]

- STOW (Soy milk, Tofu, Okara, Whey)

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment: First prototype completed. Should be available for the 1st BIO-Plex test as a demonstration. Currently no data on power, mass, etc. Should have some data within 6 months[2x].			

- Tempeh Maker

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment: First prototype almost complete. Will not be used for 1st BIO-Plex test but may be available for 2nd BIO-Plex test[2x].			

- Starch/Gluten Separator

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment: First prototype completed. Should be available for 1st BIO-Plex test as a demonstration. Currently no data on power, mass, etc. Should have some data within 6 months[2x].			

- Extruder - uses shear force, high temperature and high pressure to convert plant material into edible food ingredients. Increases available food texture and variety.

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: Will not be available for 1st BIO-Plex test. It has not been demonstrated that we can find a low mass, low power, easily cleanable, with low usage of start up material extruder[2x].			

- Grain/Flour Mill - convert various food crops to flour.

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: FPS is planning on using a commercial off the shelf (COTS) product for BIO-Plex. May use for the 1st BIO-Plex test, if identified. Mill identified fits functional characteristics, however is large and heavy[2x].			

- Food processor

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	373 peak	11	0.023
comment: FPS is planning on using a commercial off the shelf product for BIO-Plex. The current item identified is very heavy and another one may be identified[2x].			

- Bread machine

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	600 peak	6.8	0.026
comment: Commercial off the shelf product item. Will be used for the 1st BIO-Plex test[2x].			

- Dishwasher

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: Part of BIO-Plex infrastructure.			

- Refrigerator

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: Part of BIO-Plex infrastructure.			

- Freezer

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment: Part of BIO-Plex infrastructure.			

- Dehydrator

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	600 peak	10	0.066
comment: FPS is planning on using a commercial off the shelf product. No plan to use it for the 1st BIO-Plex test. It may need some modification prior to use[2x].			

- Press (oil extraction hydraulic)

TRL	POWER, W	MASS, kg	VOLUME, m^3
2	100 peak	9.1	0.024
comment: This item is not a priority since there will not be peanuts or soybeans for the 1st BIO-Plex test. It is expected that item will need re-engineering prior to use[2x].			

- Pasta maker

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: FPS is planning on using a commercial off the shelf product though not identified yet. Plan to use it for 1st BIO-Plex test[2x]			

- Galley[2q]
  - Specialty faucet
  - Triple compartment sink

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	None		
comment: Part of BIO-Plex infrastructure.			

- Stovetop

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	6300, peak	29	0.2
comment: Part of BIO-Plex infrastructure.			

- Toaster oven

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	1600		0.03
comment: If this item is placed into a BIO-Plex test, it would be a COTS item (Proctor Silex).			

- Mixer

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	373	10.9	0.03

- Convection Oven/Microwave

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	900, microwave, 1450, conv. oven		0.124
comment: Part of BIO-Plex infrastructure.			

- Bagel Maker

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	1300, max 850, when baking	2.3	0.021
comment: If this item is placed into a BIO-Plex test, it would be a COTS item. Do not plan to use it for the 1st BIO-Plex test.			

- Blender

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	350 W	5.7	0.007
comment: If this item is placed into a BIO-Plex test, it would be a COTS item. We do not plan to use it for the 1st BIO-Plex test. Not needed if food processor present.			

- Individual Packaging

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: Will probably use similar packaging to the ISS thermally stabilized packaging.			

- Bulk Packaging

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: Not available or developed to date.			

- Dehydrated Food

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: Available through Shuttle food system.			

- Electronic scale

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			0.014
Comment: 22.7 kg capacity, 0.0045 kg resolution, measuring/weighing out ingredients			

- Protease protein cleaner

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment: Enzyme breaks down protein with little water use			

- Ultrasonic nozzle

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment: Uses ultrasound to break away particles and minimize water use			

- Steamer/sanitizer

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	1700	13.6	0.11
Comment: Steam under pressure sanitizes surfaces			

- Bulk storage bins (may be provided by BPS for BIO-Plex)

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	0	1.8	0.057
Comment: Plastic Bins with top loading and dispensing from below, allow for precise dispenses without extra utensils, and a “First In First Out” standard			

- Dryer

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
Comment: May need a dryer to aid extruded products in expansion, drying, etc.			

- Juicer (could be used for carrots and other vegetables)

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment:			

- Rice cooker steamer

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment:			

- Yogurt maker

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment:			

THERMAL

Heat Acquisition

- Aluminum Coldplates

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Condensing HX's

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Avionics air HX's

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Adsorbent/desiccant H_2O removal
  1. solid
  2. liquid

	TRL
1	6
2	4

- Cold plate shelf - integrate with structures, metal or composite, possible incorporation of heat pipes

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Carbon velvet heat exchanger

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Fault tolerant heat exchangers

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Thermal storage – note: The technologies list will be expanded, in future versions, to include specific technologies

- Cooling jacket

TRL	POWER, W	MASS, kg	VOLUME, m^3
2-3			
comment:			

Heat Transport

- Single-phase pumped loop

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Low-power two-phase pumped loop

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Vapor compression heat pump
  1. Solar powered
  2. Conventional

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	3			
2	6			
comment:				

- Internal heat pump - for low temperature loads

TRL	POWER, W	MASS, kg	VOLUME, m^3
6			
comment:			

- Thermal-powered heat pump

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Fluids that can be used inside and outside the spacecraft (single phase)
  1. Water
  2. Freon

	TRL	POWER, W	MASS, kg	VOLUME, m^3
1	9			
2	3			
comment:				

Heat Rejection

- Aluminum radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment:			

- Flexible fabric radiators - metal or carbon

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Laminate radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Laminate loop heat pipe

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Composite radiators

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Mars convection device

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Parabolic radiator shade

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Radiator surface cleaning and refreshing

TRL	POWER, W	MASS, kg	VOLUME, m^3
1			
comment:			

- Water membrane evaporator (WME)

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- New Sublimator

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Refrigerator/Freezer: 1. Stirling 2. Vapor Compression

WASTE[1, 2f,, 2h, 2p, 8, 9]

- Pre-Processing
  - Collection, Transport, Vacuum Waste Collection
    - Vacuum Toilet

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	200	31	0.2
comment:			

    - Trash compactor
    - Garbage disposal
  - Compaction (bulk compactor)[8]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	110	15.1	0.355
comment:			

  - Drying or Dehydration
    - Forced Air Thermal Convection. Example: Crop dryers or oven configuration.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	290	1.1	0.033
comment:			

    - Thermal Vacuum - lowering the boiling point by lowering pressure.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	220	31	0.18
comment:			

  - Sterilize & Stabilize - This is one method that does not require O_2 and might be appropriate for partly open food systems.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

  - Storage

TRL	POWER, W	MASS, kg	VOLUME, m^3
9			
comment: TRL given is for relatively short terms. TRL for long term storage has not been demonstrated.			

    - Containers for long term storage
    - Trash containers for temporary storage & transport
    - Hazardous storage containers

- Transport
  - Pneumatic Transport[8]

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	200	25	0.3
comment:			

  - Screw Conveyor[8]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	200	25	0.3
comment:			

  - Slurry Pumping[8]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	200	25	0.5
comment:			

- Blending
  - Solid/Liquid; Slurrying (50-95% water[8], practical limits may be 90-95%[2p])

TRL	POWER, W	MASS, kg	VOLUME, m^3
2-3			
comment:			

  - Solid/Solid Blending

- Dry Size Reduction & Particle Size Control[8]

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	200	100	3.5
comment:			

- Wet Size Reduction & Particle Size Control – Mechanical plus chemical size reduction[8].

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Physical/Chemical (P/C) fullup[1,8]
  - Super Critical Water Oxidation (SCWO) - No catalyst needed. Can reuse most of the heat generated. Produces potable water from all input wastewaters. Operates 647 K & 2.21 x 10^7 Pa. Exothermic reaction.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	1440	694	2.12
comment:			

- Wet Oxidation - High temperature and pressure oxidation of wet slurries. Output depends on the temperature and pressure used. Particularly attractive in conjunction with plants as CO_2 is produced. Exothermic reaction.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Combustion/Incineration - Requires evaporation prior to combustion. Highly oxidized waste products. Exothermic reaction.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	388	72.6	0.57
comment:			

- Electrochemical Oxidation - Non- thermal (oxidizes with catalytic electrodes) and doesn't use atmospheric O_2. Lower power requirements than SCWO, Wet Oxidation or Combustion/Incineration.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Peroxide oxidation.

TRL	POWER, W	MASS, kg	VOLUME, m^3
1			
comment:			

- Partial P/C
  - High Temperature Gasification - Temperature 1,300 – 1,700K, Pressure ambient. Partial combustion of a carbonaceous fuel to generate a combustible fuel. Basically an incinerator operating under reducing conditions. Heat to sustain the process is obtained from exothermic reactions while the combustible components of the low energy gas are generated by endothermic reactions.

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

  - Magnetically Assisted Gasification.

TRL	POWER, W	MASS, kg	VOLUME, m^3
1			
comment:			

  - Plasma Arc Thermal Destruction.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	800	50	0.2
comment:			

- Carbonization[8] (Pyrolysis) - Heat to 250 °C and 10342 kPa (1500 psi) then cool – Liquid phase process; Recover water with a second process; Can be used for deactivation after biological processes. Upon heating in an O_2 free atmosphere, most organics are split into gas, solid and liquid fractions. Endothermic reaction.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Pyrolysis in subcritical water - Temperature 523 – 573K; pressure 10000 kPa

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

- Acid Hydrolysis[8] - The acid breakdown of cellulose and hemicelluloses to more easily fermentable sugars. Useful for pretreatment of inedible biomass.

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Lyophilization[8] (Freeze Drying) - Temperature 230-290K; pressure 0.01-101.3kPa. Freezing of waste, sublimation of water vapor, condensation of water vapor, melting of frozen condensate.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Steam reforming

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

- Partial Biological Digestion / Composting

  - Continuous Stirred Tank Reactor (CSTR) - could be used to recover nutrients for plants.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	100	TBD	2
comment:			

- Composting
  - Aerobic composting
    - 7 day residence time

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	6	48	1.25
comment:			

    - 21 day residence time

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment:			

  - Anaerobic composting

TRL	POWER, W	MASS, kg	VOLUME, m^3
Comment:			

- Fixed film Bioreactor

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
Comment:			

- Fermentation of Paper and Biomass to useful products.

TRL	POWER, W	MASS, kg	VOLUME, m^3
2-3			
Comment:			

- Single celled protein production plus crop nutrient recovery.

TRL	POWER, W	MASS, kg	VOLUME, m^3
3	0	80	1.4
Comment:			

WATER

ISS Baseline Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
6	990 VCD only: 65	1269 + 2108(expendable) VCD only: 48	VCD only: 0.08
comment: All three technologies included; Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98; VCD only ALSSAT v 2.0			

- Vapor Compression Distillation (VCD) - 96% recovery of water from urine with low energy use. Rotating parts may cause high failure rate. Potential problems with recondensing of volatile organics and ammonia.

TRL
6

- Multifiltration (MF) – Removes contaminants using mixed adsorbents; high expendables

TRL
6

- Volatile Removal Assembly (VRA) - removes low molecular weight organics using catalytic oxidation and ion exchange.

TRL
7

Alternate ISS Baseline Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	TIMES only: 183	TIMES only: 56	TIMES only: 0.11
comment: TIMES only; ALSSAT v 2.0			

- Thermoelectric Integrated Membrane Evaporation System (TIMES) - Uses hollow fiber membrane technology. 95% water recovery. Potential problems with recondensing of volatile organics and ammonia.

TRL
4

- Multifiltration (MF) – see above

TRL
6

- Improved Post Processor - pre-oxidizer plus adsorbent.

TRL
4

Advanced Node 3 Architecture

TRL	POWER, W	MASS, kg	VOLUME, m^3
5	1270	211 + 145(expendable)	
comment: Mars Transit Habitat Environmental Control & Life Support System., Chin H. Lin, 1/15/98			

- Bioreactor - TOC and Nitrogen oxidation using cultures of mixed microbes.
    - Packed Bed Biological Water Processor (PBWP) - anerobic packed bed reactor with single phase liquid flow.

TRL
5

    - Nitrification Biological Water Processor (NBWP) - aerobic membrane reactor - O_2 delivery via membrane for nitrification

TRL
4

    - Tubular Nitrification Water Processor – Aerobic reactor with gas/liquid slug flow through narrow tubes.

TRL
4

    - Membrane Biological Water Processor (MBWP) - aerobic membrane reactor - O_2 delivery via membrane for TOC reduction.

TRL
4

    - Biological Water Processor: (trickling filter bioreactor) – aerobic reactor with two-phase gas/liquid flow.

TRL
4

    - Biological Water Processor: (immobilized cell bioreactor) - packed bed aerobic reactor with two-phase gas/liquid flow.

TRL
5

    - Magnetically separated Biological Water Processor

TRL
3

    - Membrane / Continuously Stirred Tank Reactor combination

TRL
2

- Microfiltration or Ultrafiltration

TRL
5

- Reverse Osmosis (RO) – Potential low energy use and low expendables, Produce s brine requiring additional treatment.

TRL
5

- Air Evaporation System (AES) - Used in Advanced Node 3 Architecture as a RO brine processor but could also be used as a urine processor. Uses evaporation via a wick + condensation.

TRL
5

- Advanced Post Processor - TOC and ion polishing by adsorption and ion exchange beds in conjunction with photolysis or photocatalysis.

TRL
4

Alternative Technologies

- Vapor Phase Catalytic Ammonia Removal (VPCAR) – Wiped-film rotating disk evaporator for vaporization and condensation with catalytic oxidation of volatile impurities including ammonia *i.e.* doesn't need pretreatment or post treatment.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	2380	283	
comment: VPCAR and BWRS trade study. Yeh 1999			

- Super Critical Wet Oxidation (SCWO) - Waste treatment above 647 K and 2.21 x 10^7 Pa. Complete oxidation of organics and precipitation of most inorganics.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	1440	694	2.12
comment: NASA/ARC In House Life Support Review Databook.			

- Aqueous Phase Catalytic Oxidation Post-treatment System (APCOS) - Polishing apparatus that uses catalytic oxidation.

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Electrodialysis - Uses ion exchange resins and membranes to deionize water.

TRL	POWER, W	MASS, kg	VOLUME, m^3
4	460	759	0.261
comment: NASA/ARC In House Life Support Review Databook.			

- Green Plants - Photosynthetic conversion of CO_2 to O_2 (See BPS section for details)

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment: TRL for water recovery			

- Multistage Vacuum Rotary Distiller (MVRD) (TRL–4) – Russian built wastewater processor being evaluated by JSC.

- Water Recovery from Condensate - Recovered from transpiration of plants (includes gray water recovery from plants) or evaporated from breathing, skin surfaces or other sources.

TRL
5

- Many other kinds of bioreactor e.g. destruction of organics such as soap in the Nutrient Delivery System (NDS) of a hydroponics system by the microbes in the root mat, continuously stirred tank reactors, etc. Composter might be able to treat heavily contaminated water, e.g. urine, better than other types.

- Photocatalysis – Although it uses O_2, it is potentially low consumable post-processing[2g]

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Freeze purification by lyopholization (lower latent heat than distillation processes) [2g]

TRL	POWER, W	MASS, kg	VOLUME, m^3
2			
comment:			

- Other types of still, e.g. using solar energy directly or thermopervaporation. (The latter may be related to TIMES.) [2g]

TRL
1

- Other electrochemical approaches involving ozone or hydroxyl ions generated in situ to destroy organics. [2g]

TRL
2-3

- Disinfection / Sterilization Technologies
    - Microbial check valve

TRL
9

- Filters

TRL
9

- Peroxide

TRL
2-3

- Phase Separation
  - Passive membranes

TRL
4-5

  - Vortex

TRL
6

  - Powered (centrifugal)

TRL
9

OTHER:

- Magnetic Air-Water Separation Technology – Magnetic separation of gas and liquids in zero G using permanent magnets and little or no electric power. Brian Tillotson PI.[6]

TRL	POWER, W	MASS, kg	VOLUME, m^3
3			
comment:			

EXTERNAL LIFE SUPPORT INTERFACES:

HUMAN ACCOMODATIONS

- Washer & dryer

TRL	POWER, W	MASS, kg	VOLUME, m^3
5			
comment:			

- Disposable & permanent clothing

TRL	POWER, W	MASS, kg	VOLUME, m^3
4			
comment:			

- Lyntech washer/dryer(using ozone as a detergent substitute)
- Low water use washer
- Clothes washing with liquid CO_2 as solvent – Process developed by Pacific Northwest National Laboratories[11] with DOE funding and licensed to MiCell Technologies Inc. [12]

TRL	POWER, W	MASS, kg	VOLUME, m^3
comment: Mars atmosphere, although less dense than earth's, is 95% CO_2.			

- Clothes dryer using waste heat
- Vacuum shower (TRL 9)
- Exercise equipment

References:

1. Eckart Peter, Spaceflight Life Support and Biospherics, Herbert Utz Publisher, Munich Germany '94.
2. Personal Communications: Chin Lin (2a), Mike Ewert (2b), Fred Smith (2c), Sandra Brasseaux (2d), Barta Daniel (2e), John Graf (2z), Yael Vodovotz (2y), Michele Perchonok (2x) - NASA JSC, John Fisher (2f) NASA ARC, John Sager (2g) NASA KSC, Alan Drysdale (2h) Boeing KSC, Frank Jeng (2i), Jannivine Yeh (2j), Kevin Lange (2k), Tony Hanford (2l), Juan M Castillo (2m), Karen Myers (2o), Mike Alazraki (2p), Laurie Peterson (2q) - Lockheed/Martin Houston.
3. Barta Daniel, Castillo Juan M, Fortson Russ E, The Biomass Production System for the Bioregenerative Planetary Life Support Systems Test Complex: Preliminary Designs and Considerations, SAE Technical Paper Series 1999-01-2188.
4. BIO-Plex TRL Evaluation Meeting, JSC, 1/25/2000
5. Advanced Life Support Subsystem Descriptions and Interfaces, Sytems Modeling and Analysis Project (SMAP) publication, Tony Hanford, 1/24/2000.
6. ALS poster session at the Center for Advanced Space Studies Houston TX, March 1999.
7. NASA/ARC In House Life Support Review Databook. / NASA/ARC In House Life Support Review Databook.
8. Waste Processing and Resource Recovery Workshop (WPRR) 2000 Appendix.
9. Perry's, Chemical Engineers' Handbook, 6th Edition.
10. Design of a Post-Processor for a Water Recovery System, Verostko, Charles E, *et al.*, SAE 2000-01-2519.
11. Lab-developed system uses carbon dioxide to clean up on dirt, U.S. Water News Online, June 1998.
12. Garment and Textile Care Program, Case Study: Liquid Carbon Dioxide Surfactant System for Garment Care, www.epa.gov/opptintr/dfe/garment/lcds/micell.htm
13. Lunar-Mars Life Support Test Project: Phase III Final Report, JSC-39144, Feb. 23, 2000.

DISTRIBUTION:

D.L. Henninger	/NASA/EC
T.O. Tri	/NASA/EC
C.H. Lin	/NASA/EC2
M.K. Ewert	/NASA/EC2
A.J. Hanford	/LM/C70
J.L. Cox	/LM/C70
J.F. Keener	/LM/C70
K.E. Lange	/LM/C70
B.E. Duffield	/LM/C70
Task Order File	