PAST, PRESENT AND FUTURE ADVANCED ECLS SYSTEMS FOR HUMAN EXPLORATION OF SPACE

Kenny Mitchell
MSFC Manager for Advanced ECLSS/New Space Exploration Initiative

This paper will review the historical record of NASA's regenerative life support systems flight hardware with emphasis on the complexity of spiral development of technology as related to the International Space Station program. A brief summary of what constitutes ECLSS designs for human habitation will be included and will provide illustrations of the complex system/system integration issues. The new technology areas which need to be addressed in our future Code T initiatives will be highlighted. The development status of the current regenerative ECLSS for Space Station will be provided for the Oxygen Generation System and the Water Recovery System. In addition, the NASA is planning to augment the existing ISS capability with a new technology development effort by Code U/Code T for CO2 reduction (Sabatier Reactor). This latest ISS spiral development activity will be highlighted in this paper.

NASA/CP—2004-213205/VOL1

Past, Present and Future Advanced ECLSS

(Strategic Planning for Participation in New Initiatives of NASA HQ/Code T and Code U)

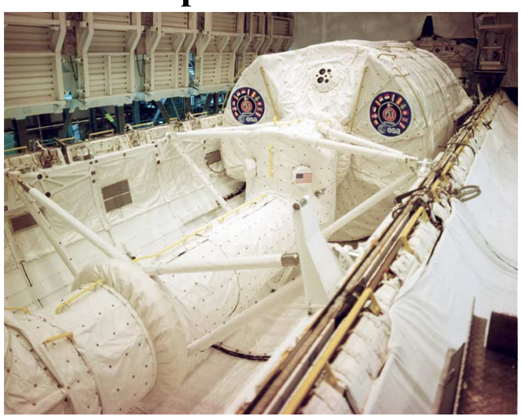
NASA has Vast Experience in Human Space Exploration Programs

Saturn/Apollo

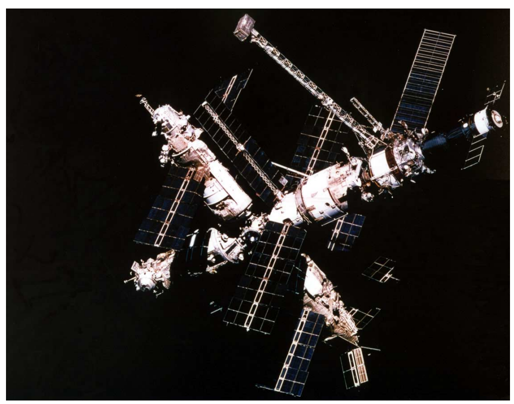
Skylab

Space Shuttle

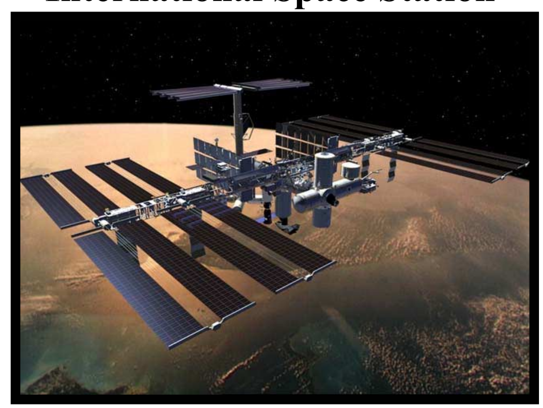
Spacelab



Shuttle/Mir



International Space Station



Historical Driving Mission Requirements for Human Exploration

	Mission Length	Crew Size	Habitat Atmosphere
Saturn/Apollo	< 14 days	3	5 Pisa (pure oxygen)
Skylab*	28 – 84 days	3	5 Pisa (N2/02, 70%/30%)
Space Shuttle	< 14 days	2 - 7	14.7 Pisa (N2/02, 79%, 21%)
Spacelab	< 14 days	3 - 4	14.7 Pisa (N2/02, 79%, 21%)
Mir*	~ 15 years	2 - 6	14.7 Pisa (N2/02, 79%, 21%)
International Space Station*	15 -20 years Planned	2 - 6	14.7 Pisa (N2/02, 79%, 21%)

*Regenerative life support systems on-board

Basic ECLSS Functions for Human Support

Atmosphere Revitalization

- CO2 Removal
- CO2 Reduction
- Oxygen Generation
- Trace Contaminant Control
- Trace Contaminant Monitoring
- Atmosphere Composition Monitoring

Atmosphere Control & Supply

- O2 Storage Systems
- N2 Storage Systems
- 02/N2 Atmosphere Pressure Control
- Negative & Positive Pressure Relief of Habitat
- Purge and pressurant supply gases
- EVA Support
- O2/N2 Distribution

Water Management Systems

- Potable H20 Storage
- Waste H20 Processing
- Urine Processing
- Water Distribution
- Hygiene H20 Supply
- Water Quality Monitoring
- Biocide and Sterilization

Fire Detection & Suppression

- Smoke Detection
- Fire Detection
- Fire Suppression
- Emergency Breathing Support

Temperature & Humidity Control

- Cabin Air Temperature Control
- Habitable Volume Air Ventilation
- Air Filtration
- Air Circulation
- Humidity Control
- Temperature & Humidity Monitoring

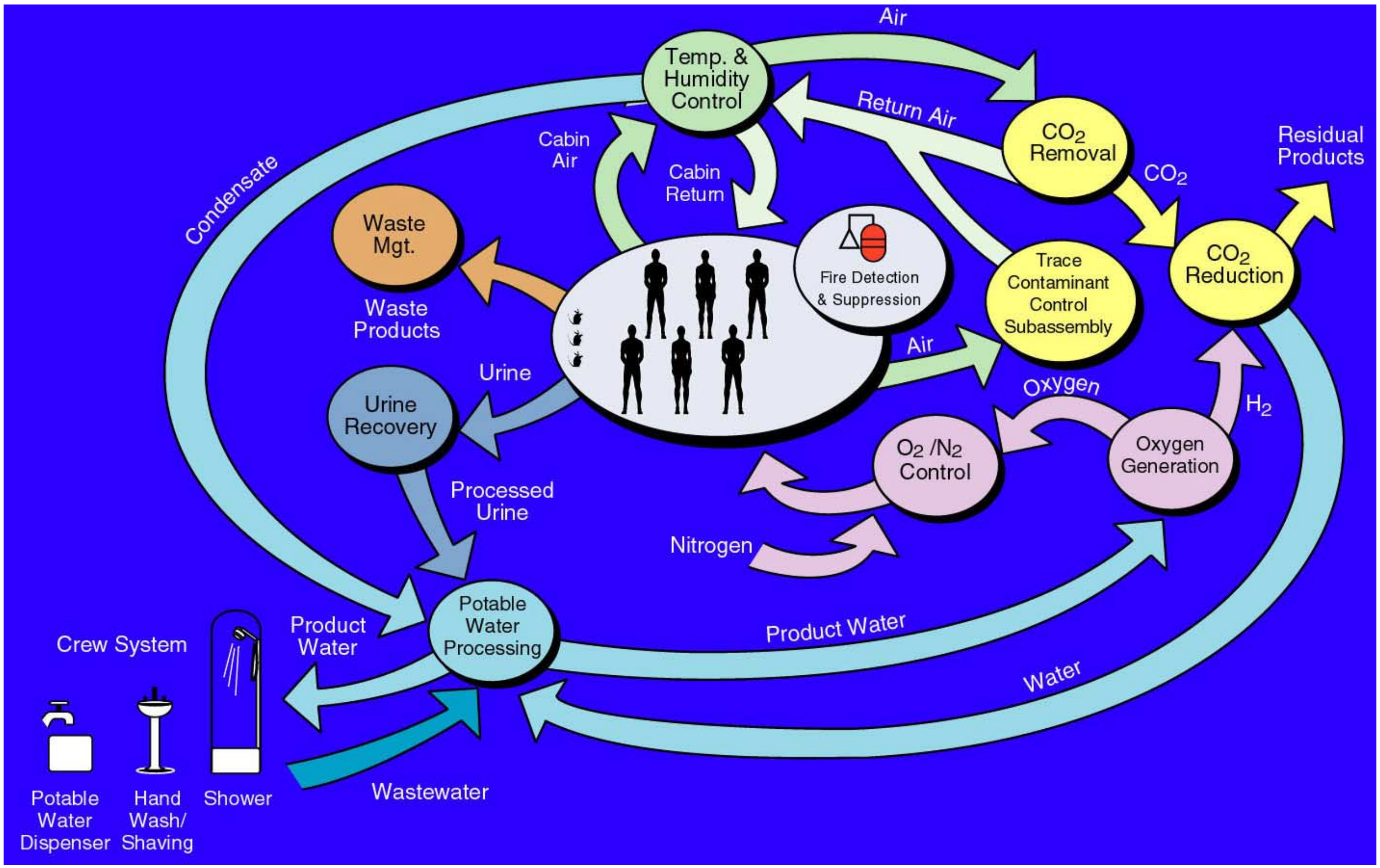
Waste Management Systems

- Urine Collection and Pre-treatment
- Fecal Collection & Processing

Human Friendly ECLSS Features

- Habitable noise level satisfies NC-50 Criteria *(MPLM and Node 2 met on ISS)*
- Low maintenance requirements (planned or unplanned)
- Personal hygiene support is simple and effective
- Comfortable environmental control (temperature/humidity/ventilation)
- Water management is "earth-like".
- Fire and smoke detection is reliable
- Robust (handles anomalies with minimal crew attention)
- Significant safety features for crew life support

Typical ECLSS Functions Including Regenerative

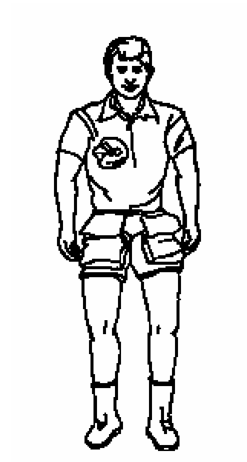


Environmental Control and Life Support Systems

Human Needs and Effluents Mass Balance (per person per day)

Needs

- Oxygen = 0.84 kg (1.84 lb)
- Food Solids = 0.62 kg (1.36 lb)
- Water in Food = 1.15 kg (2.54 lb)
- Food Prep Water = 0.76 kg (1.67 lb)
- Drink = 1.62 kg (3.56 lb)
- Metabolized Water = 0.35 kg (0.76 lb)
- Hand/Face Wash Water = 4.09 kg (9.00 lb)
- Shower Water = 2.73 kg (6.00 lb)
- Urinal Flush = 0.49 kg (1.09 lb)
- Clothes Wash Water = 12.50 kg (27.50 lb)
- Dish Wash Water = 5.45 kg (12.00 lb)
- Total = 30.60 kg (67.32 lb)



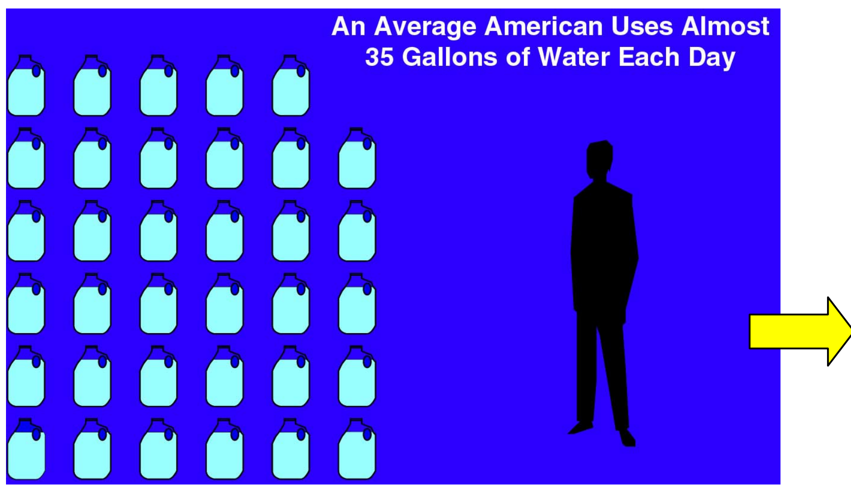
Effluents

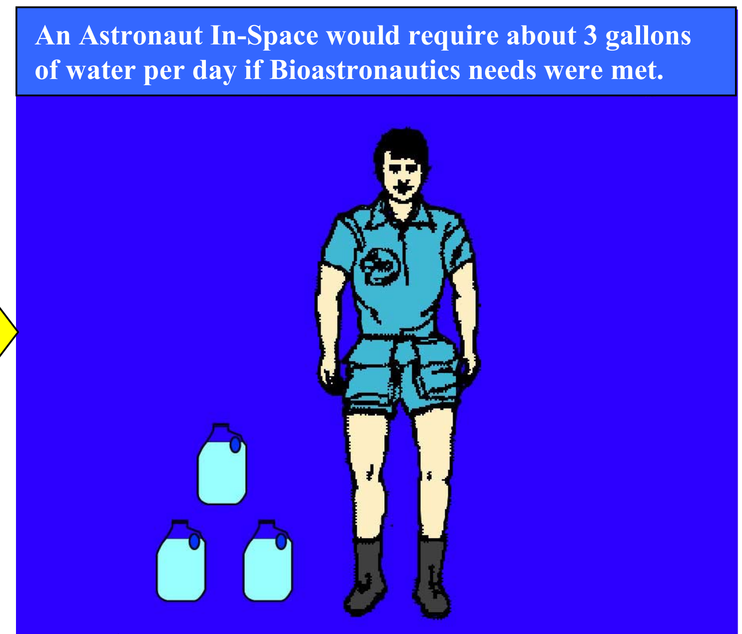
- Carbon Dioxide = 1.00 kg (2.20 lb)
- Respiration & Perspiration Water = 2.28 kg (5.02 lb)
- Food Preparation, Latent Water = 0.036 kg (0.08 lb)
- Urine = 1.50 kg (3.31 lb)
- Urine Flush Water = 0.50 kg (1.09 lb)
- Feces Water = 0.091 kg (0.20 lb)
- Sweat Solids = 0.018 kg (0.04 lb)
- Urine Solids = 0.059 kg (0.13 lb)
- Feces Solids = 0.032 kg (0.07 lb)
- Hygiene Water = 12.58 kg (27.68 lb)
- Clothes Wash Water
  - Liquid = 11.90 kg (26.17 lb)
  - Latent = 0.60 kg (1.33 lb)
- Total = 30.60 kg (67.32 lb)

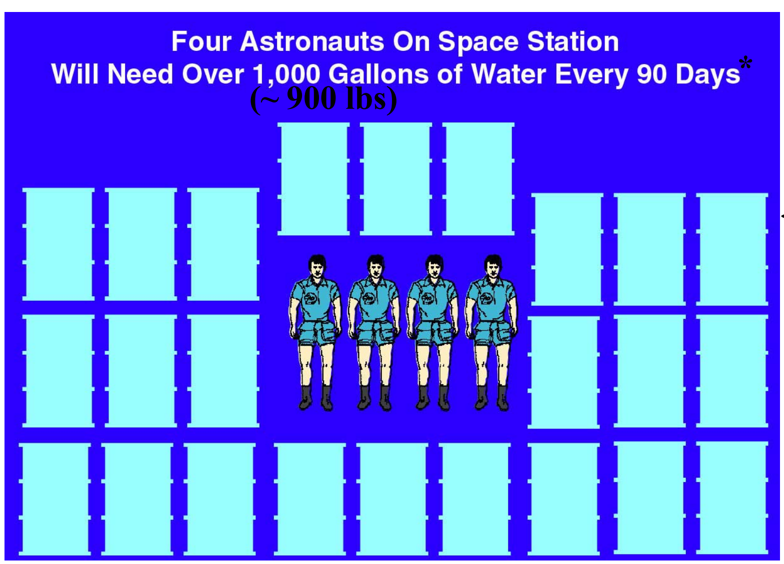
Note: These values are based on an average metabolic rate of 136.7 W/person (11,200 BTU/person/day) and a respiration quotient of 0.87. The values will be higher when activity levels are greater and for larger than average people. The respiration quotient is the molar ratio of CO_2 generated to O_2 consumed.

Regenerative Life Support Systems Required

(Example is reclamation of waste water)







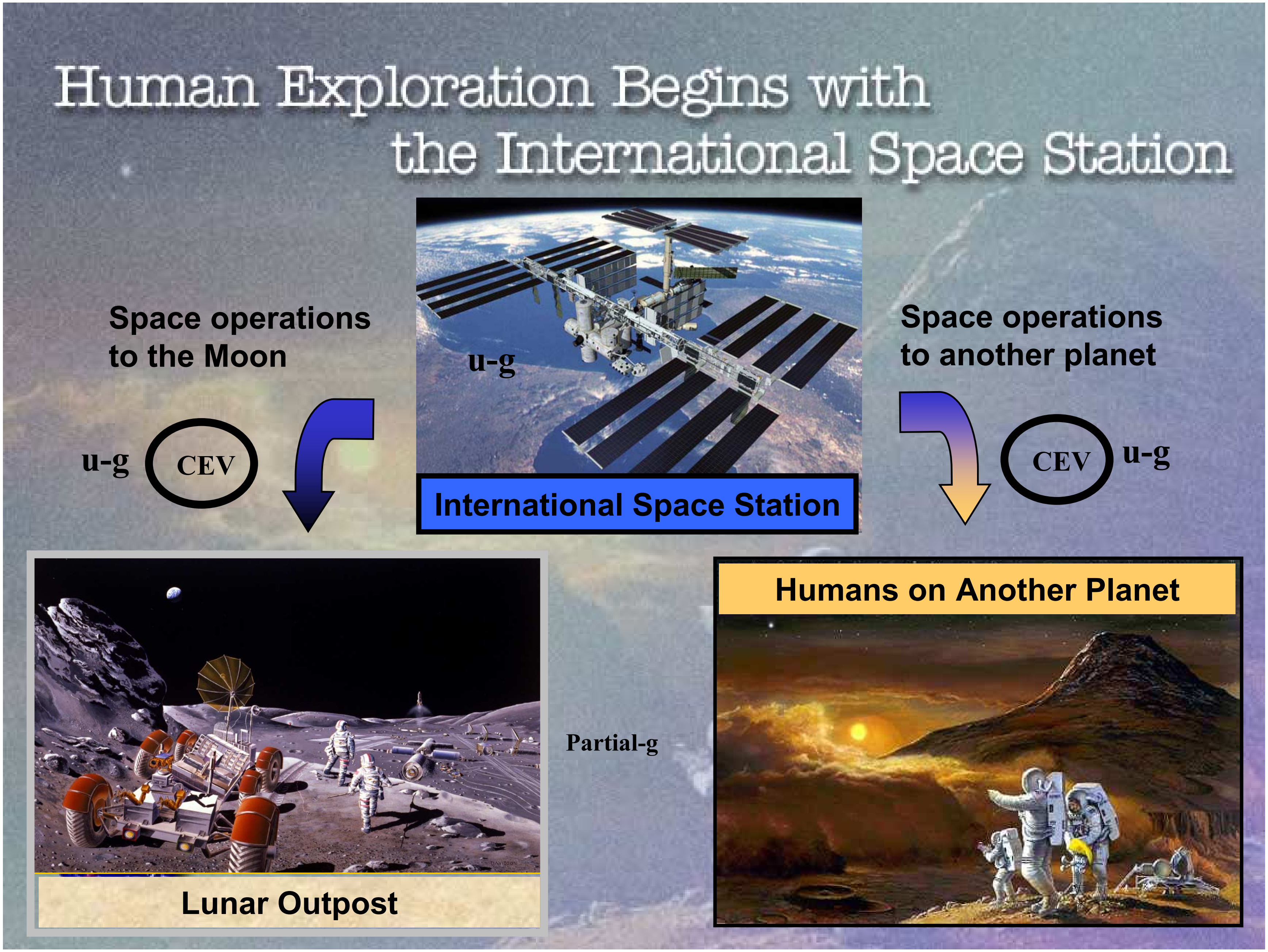
Water recycling is essential for human space exploration missions to be cost effective.

*Current ISS requirements lower than this.

NASA/CP—2004-213205/VOL1

Significant Water Storage Required on ISS without Regenerative System On-Board

Water Stowage Containers on ISS
- **Requires habitat volume**
- **Crew time**
- **Inventory Mgt.**


Human Exploration Begins with the International Space Station
Space operations to the Moon
u-g
CEV
u-g
International Space Station
Space operations to another planet
CEV
u-g
Lunar Outpost
Partial-g
Humans on Another Planet

Partial-Gravity Environments Benefit ECLSS Design/Operations

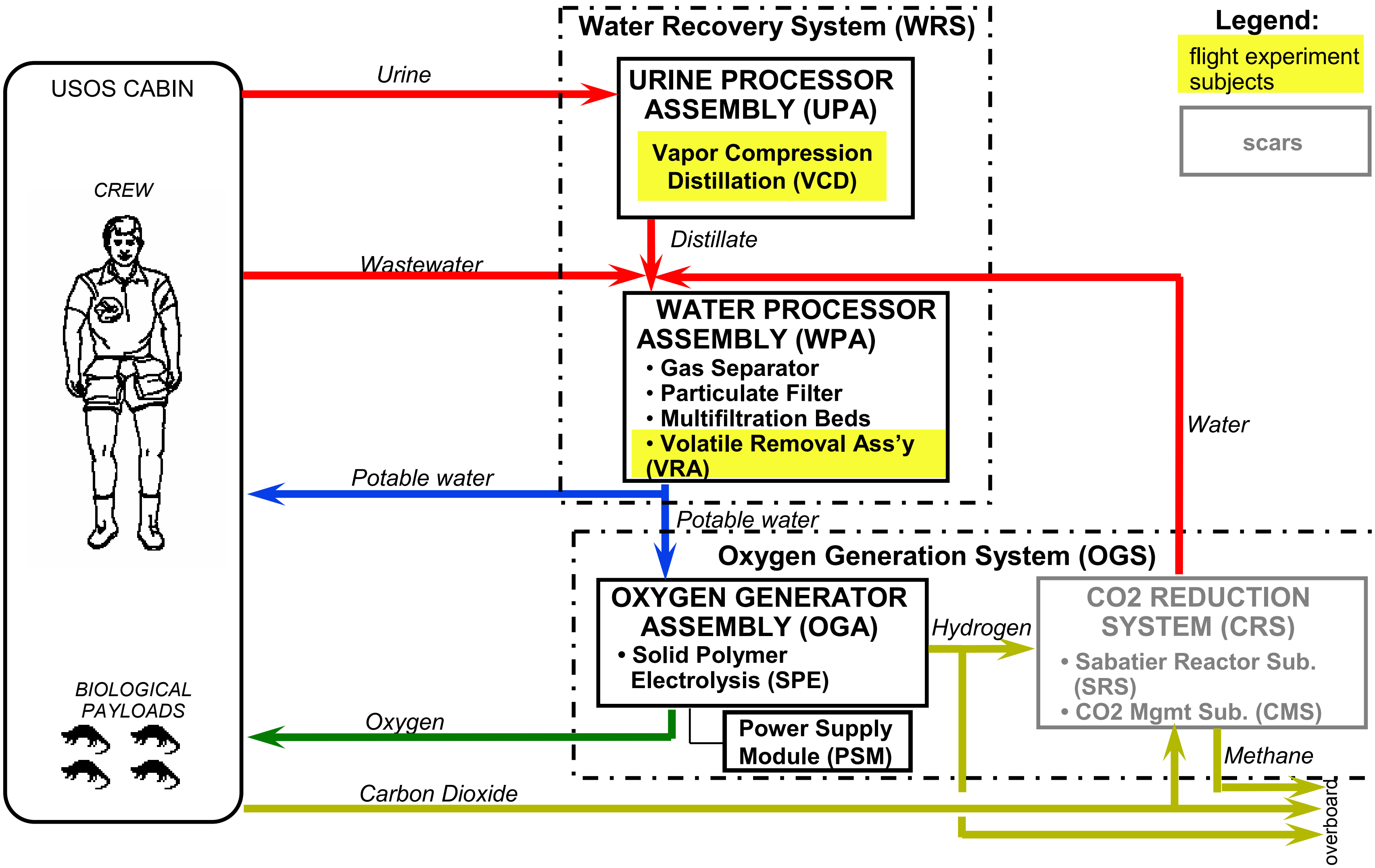
Lunar Outpost

Humans on Another Planet

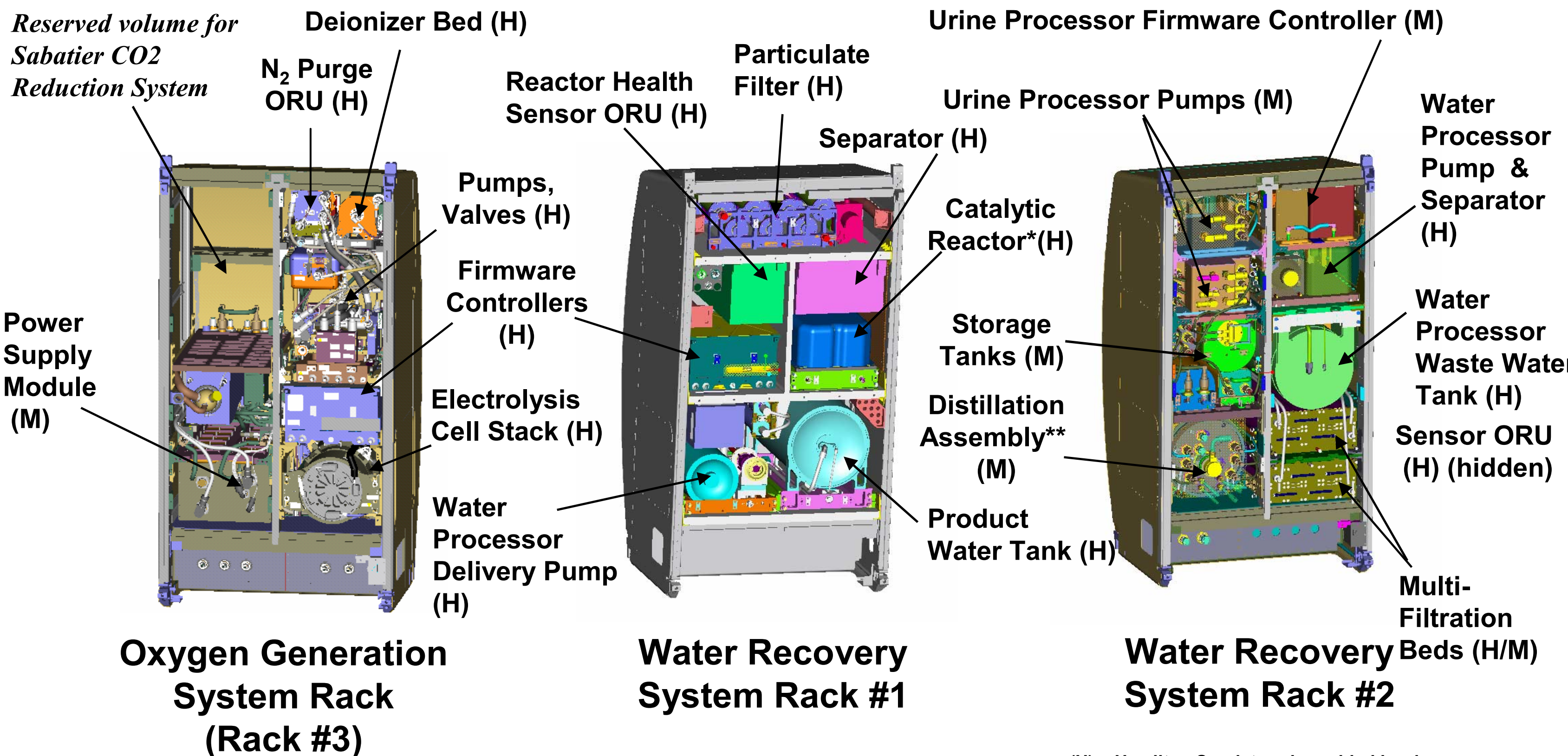
Design Simplications	Benefits
- Eliminates need for liquid/gas phase separation	Saves development costs, power, mass, volume, and reduces contribution to noise.
- Fire suppression easier	Suppressant "falls" on fire
- Smoke detection easier	Integrate detectors for natural convection
- Ventilation systems more "Earth-like"	Easier to design/integrate air flow for thermal comfort, CO2 removal, etc. and reduces noise production associated with fans.
- Water distribution systems utilize gravity	Simplifies water management hardware.
- Human hygiene functions more "Earth-like"	Urine/fecal collections systems lower weight, volume, power. Easier to recycle waste.

Regenerative ISS ECLSS Architecture Overview

(Complete Atmosphere Revitalization System not shown)



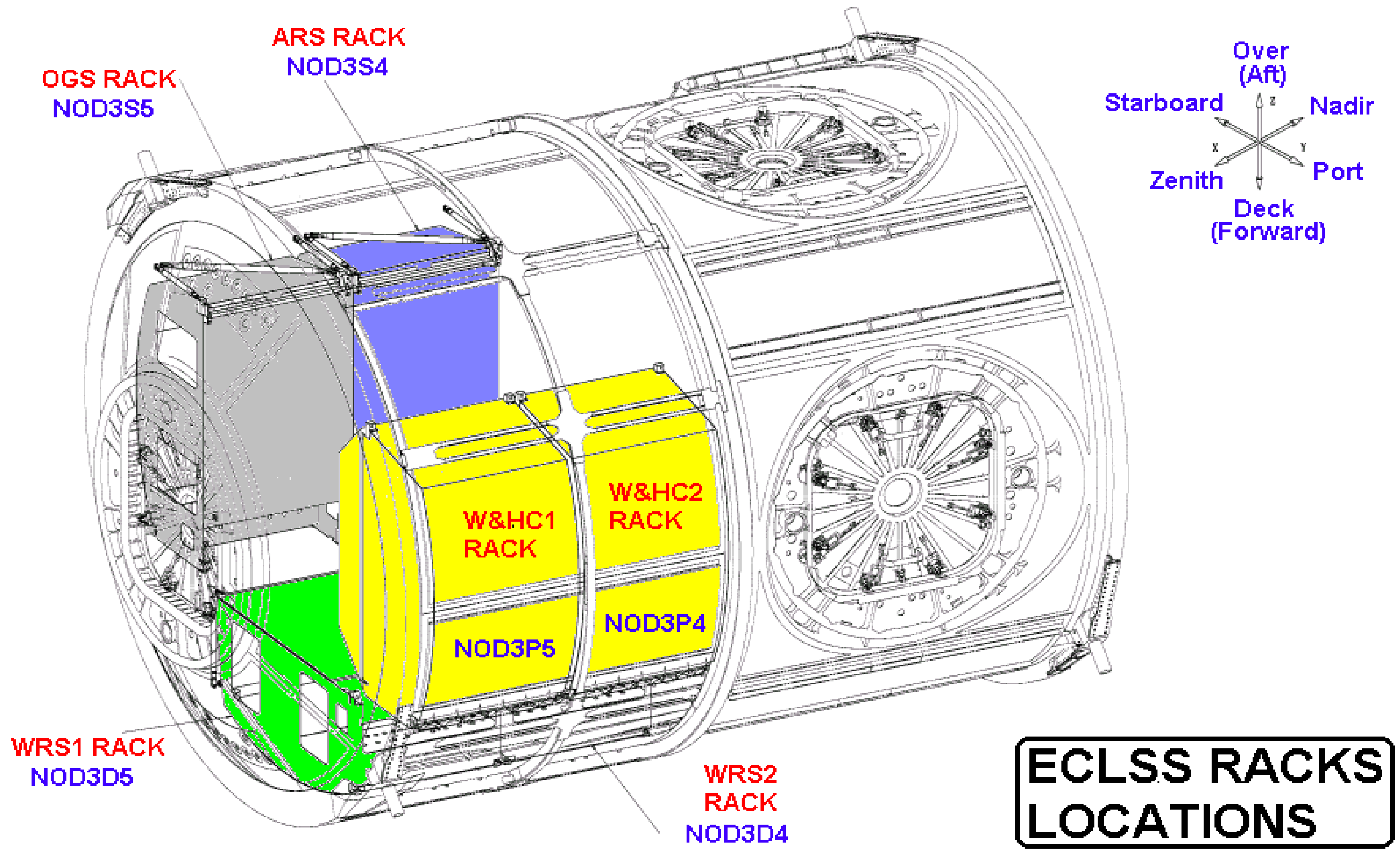
ISS Node 3
Regenerative ECLSS Racks



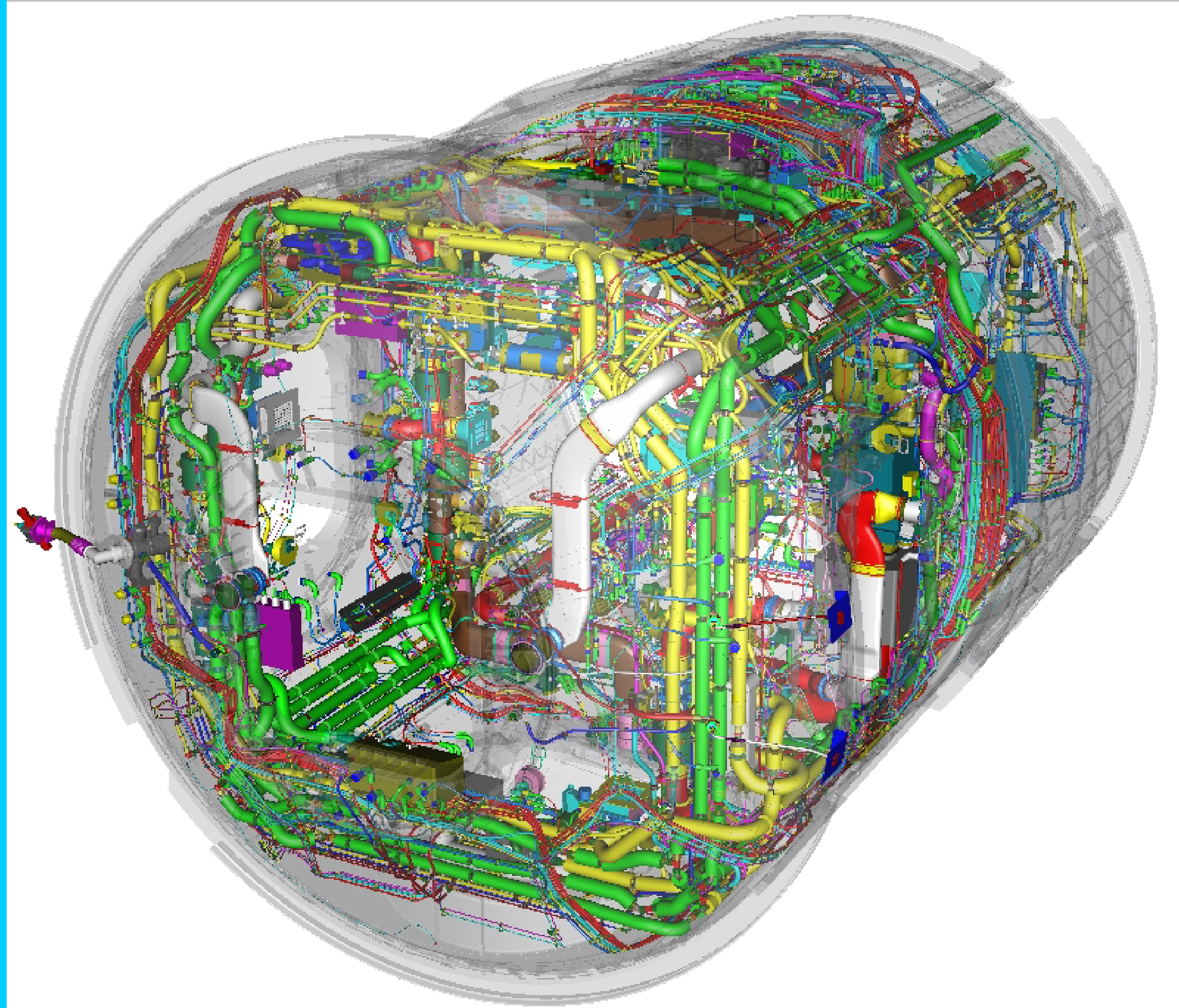
* Volatile Removal Assy Flight Experiment successfully flown on Flight 2A.1, May 1999.
** VCD Flight Experiment successfully flown on STS-107, January 2003

(H) = Hamilton Sundstrand provided hardware
(M) = MSFC provided hardware
Hamilton Sundstrand responsible for rack analytic integration for WRS#1
MSFC responsible for rack analytic integration for WRS#2 & OGS racks; physical integration for all 3.

ISS Node 3 Architecture
(MSFC Manages Node 3 DDT&E)



Node 3 Plumbing/Harnesses/Ducting Integrated with Primary/Secondary Structure



NASA/CP—2004-213205/VOL1

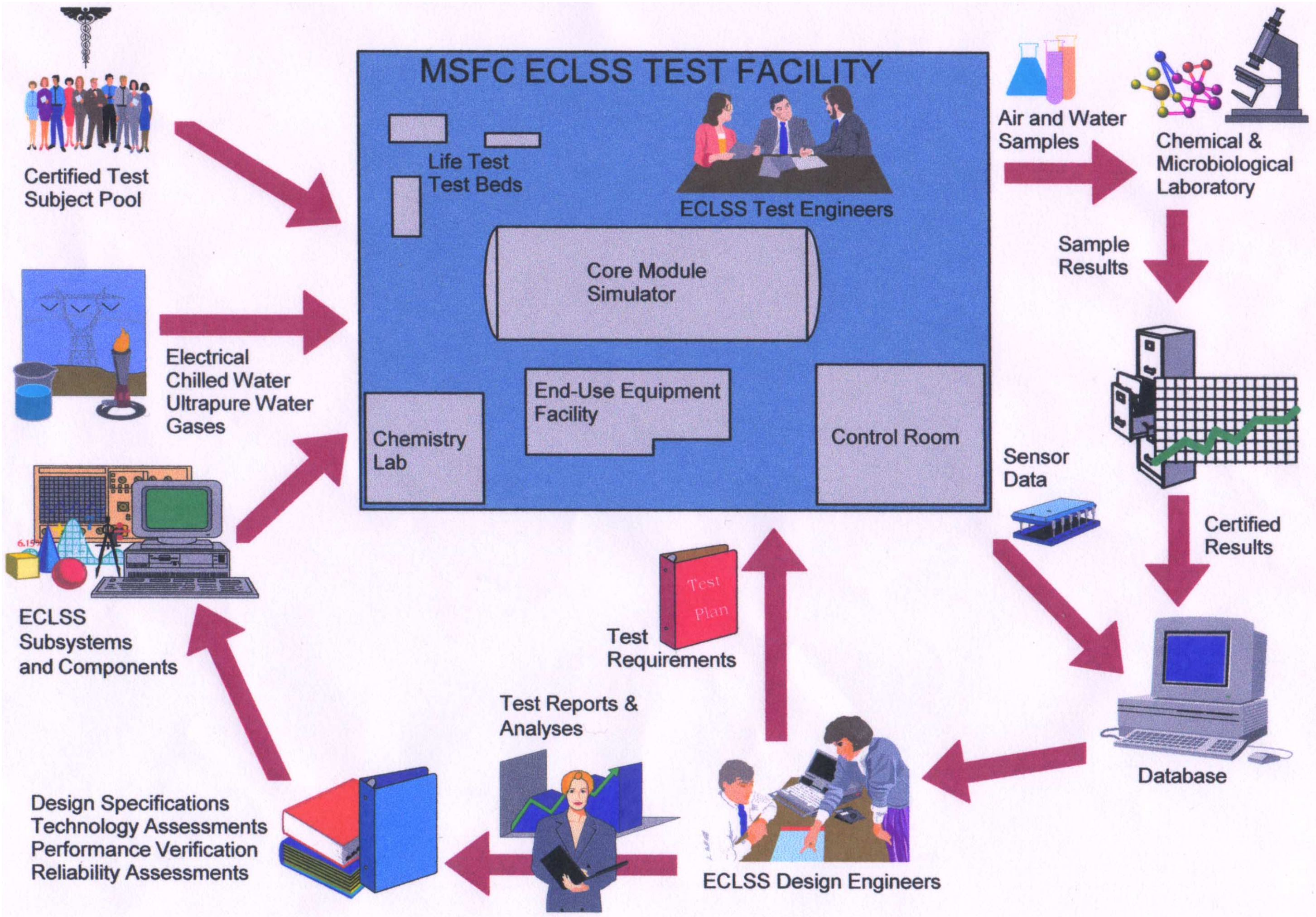
How Did ISS ECLSS Get To Where It Is?

- Comparative Testing of Technologies
- Down Selecting Technologies
- Integrated System Testing
- Integrated System/System Testing
- Proceed with Flight Hardware Development

NASA/CP—2004-213205/VOL1

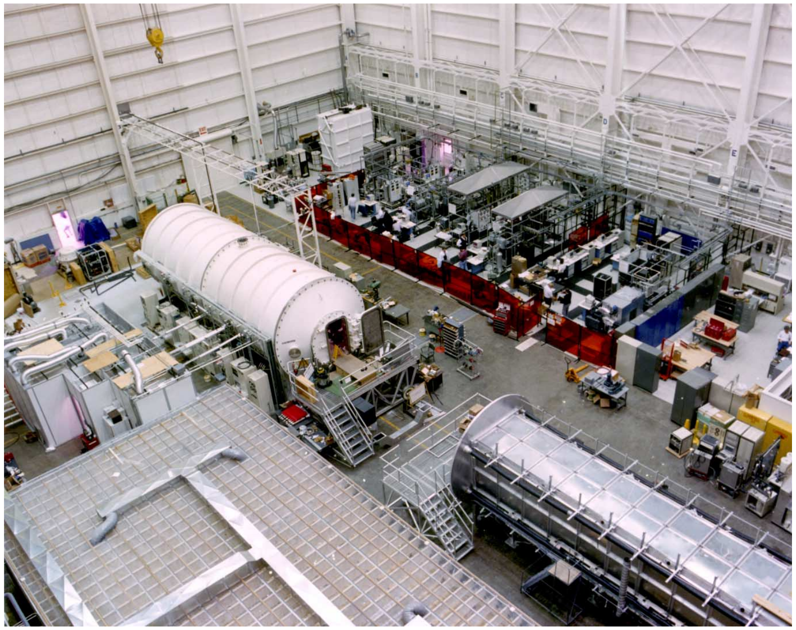
ECLSS Test Facility at NASA/MSFC

ECLSS DEVELOPMENT TESTBED RESOURCES

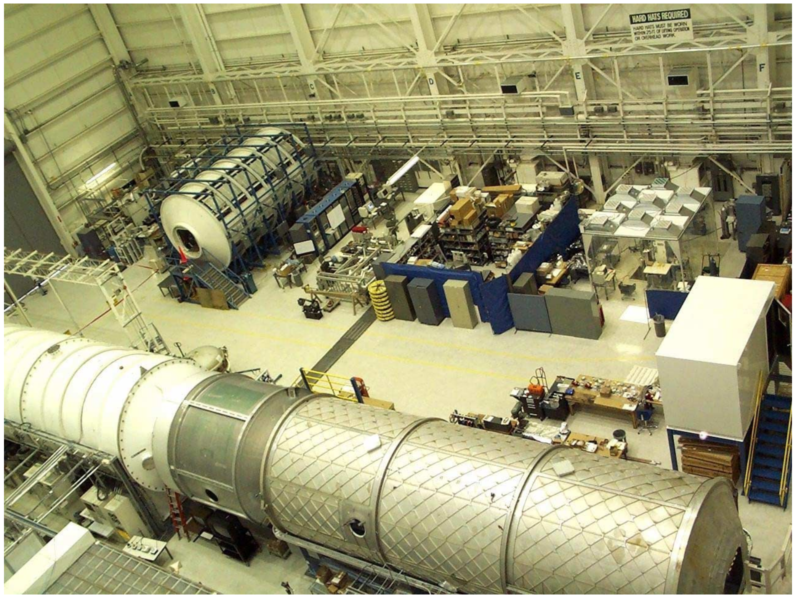


History of MSFC ECLSS Test Beds

MSFC Building 4755 in 1989-1992 for Comparative Testing of ECLSS Technologies for Space Station Freedom Program

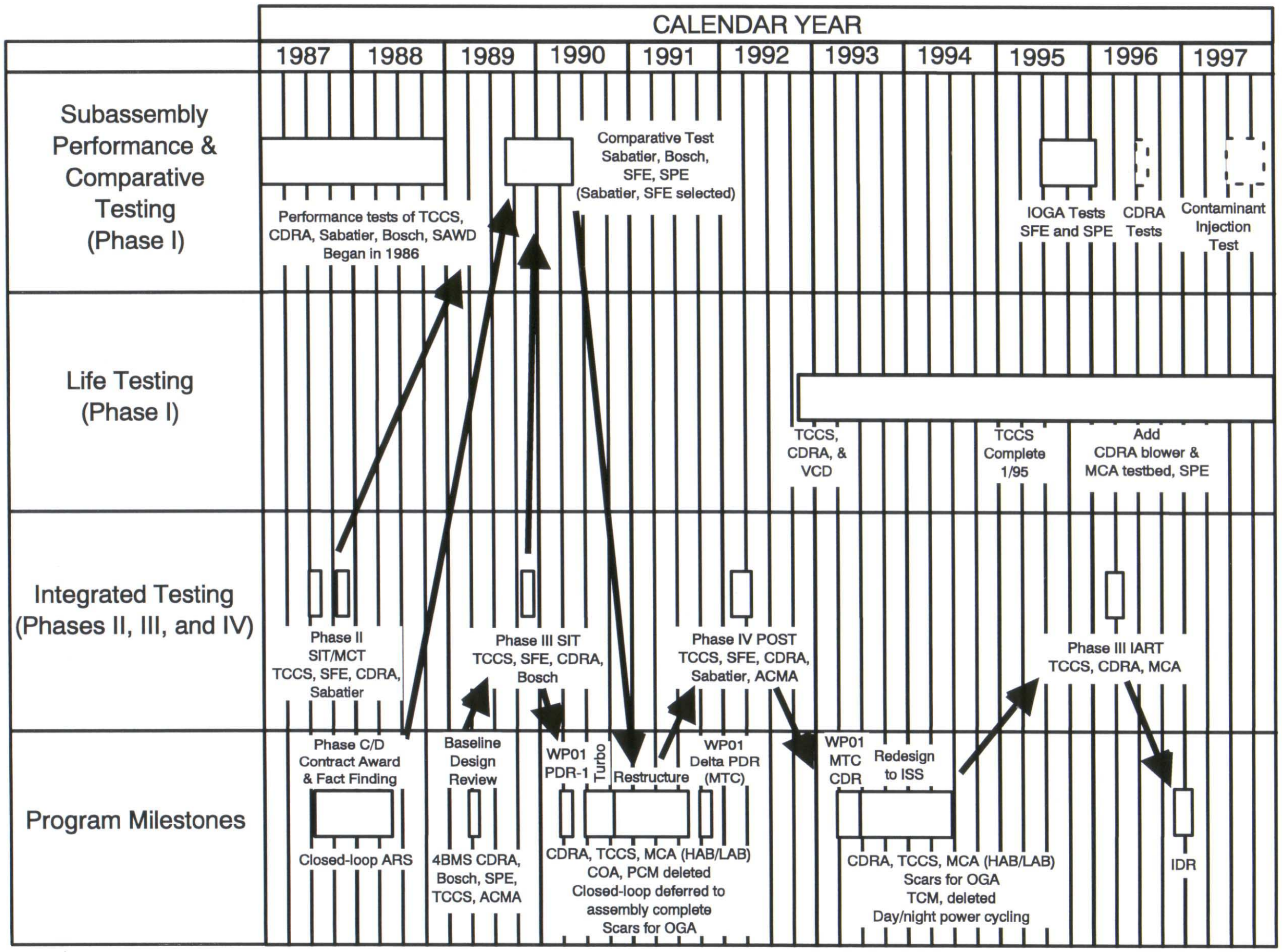


MSFC Building 4755 in 2004 for International Space Station ECLSS/Thermal Test Beds



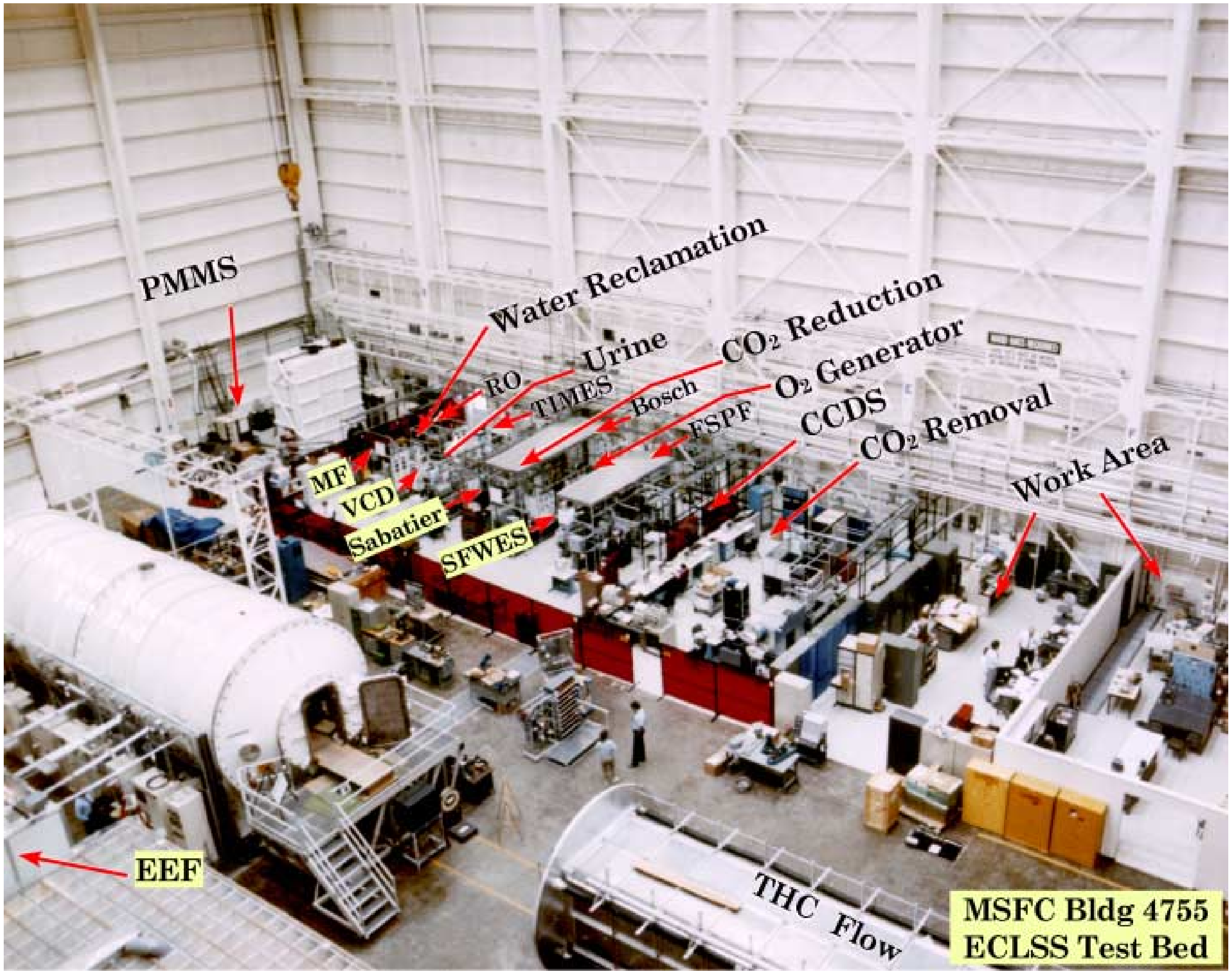
Focused Technology Testing for C/D Milestones

(Illustrates Technology Development Supporting Program Needs)



ECLSS Comparative Technology Testing (1990 – 1992)

(MSFC Building 4755, North End)



Water Reclamation
- Multi-filtration (MF)
- Reverse Osmosis (RO)
- TIMES
- Vapor Compression/ Distillation (VCD)

Oxygen Generation
- Static Feed Electrolysis
- Solid Polymer

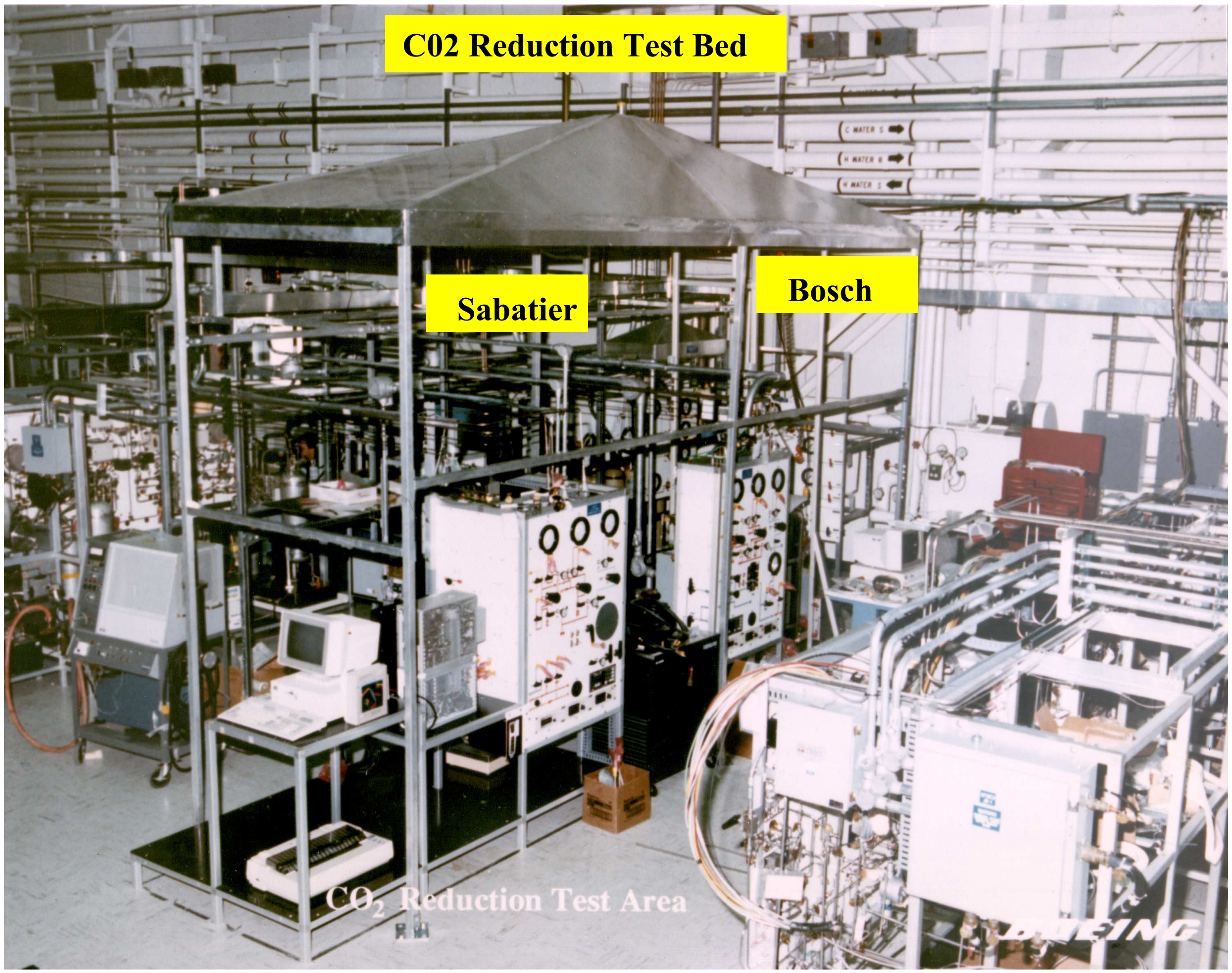
C02 Reduction
- Sabatier
- Bosch

C02 Removal
- Molecular Sieve

Trace Contaminant Cont.

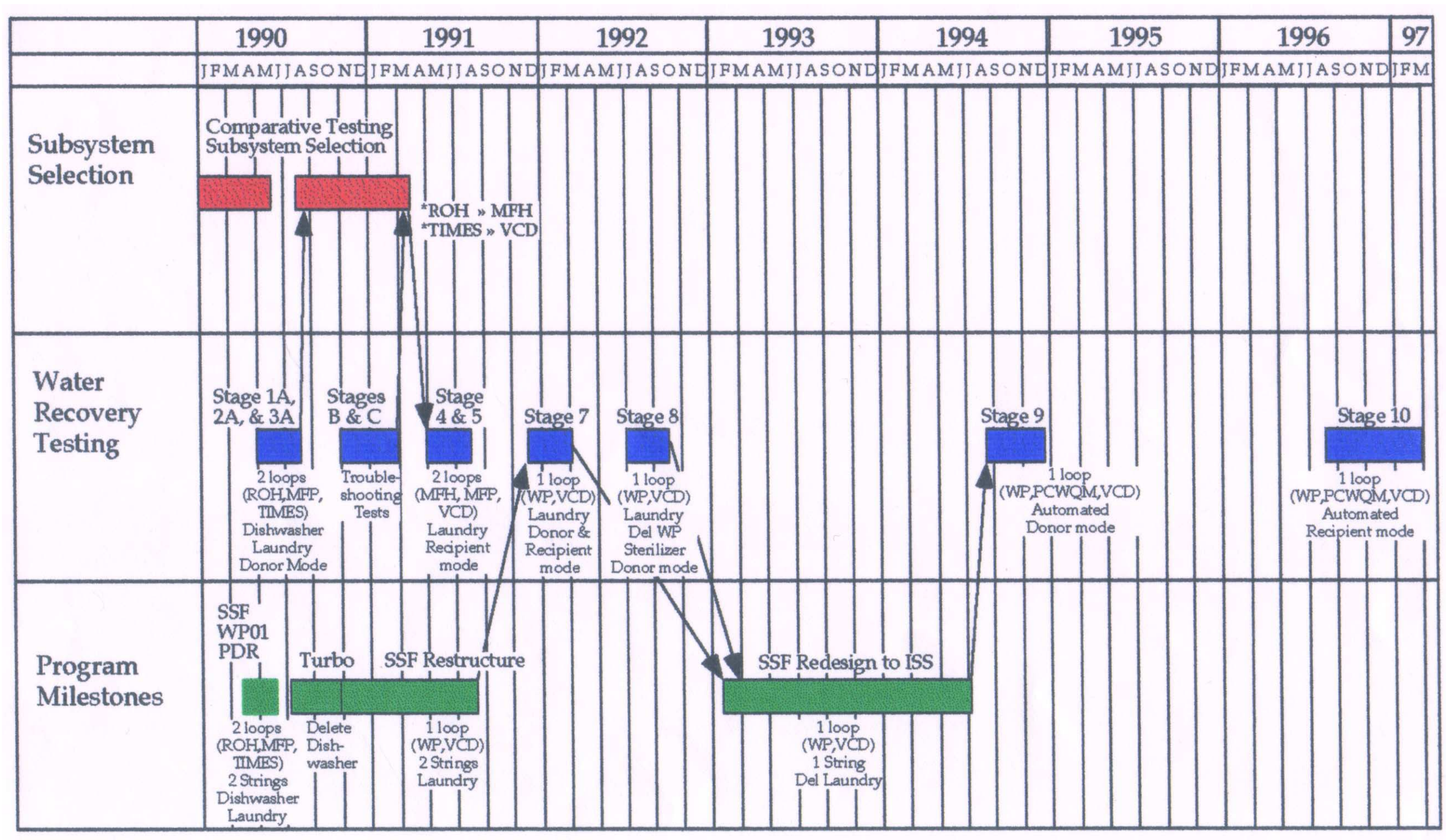
ECLSS Comparative Technology Test Bed

(MSFC testing for Space Station application)

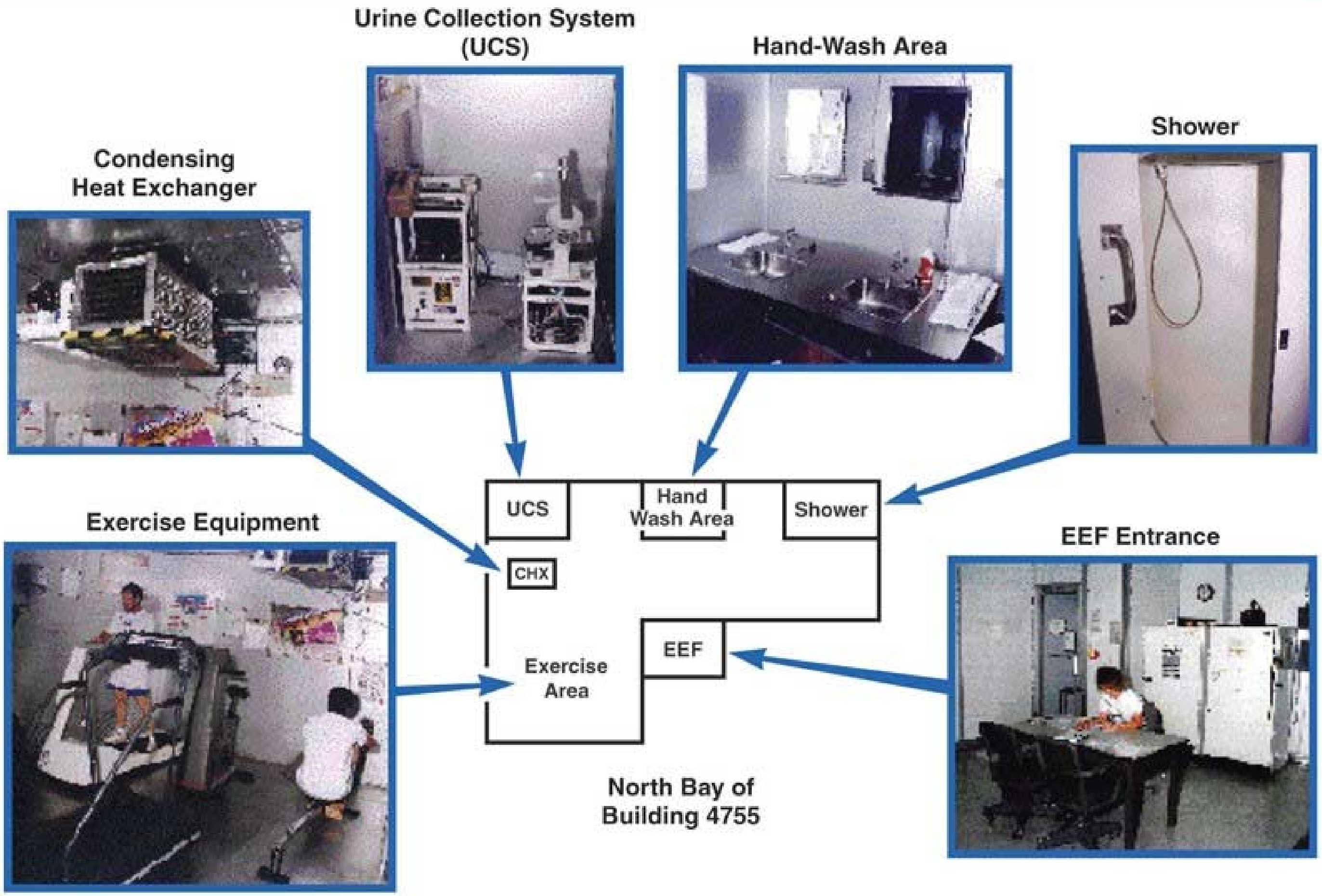


WATER RECOVERY TEST HISTORY

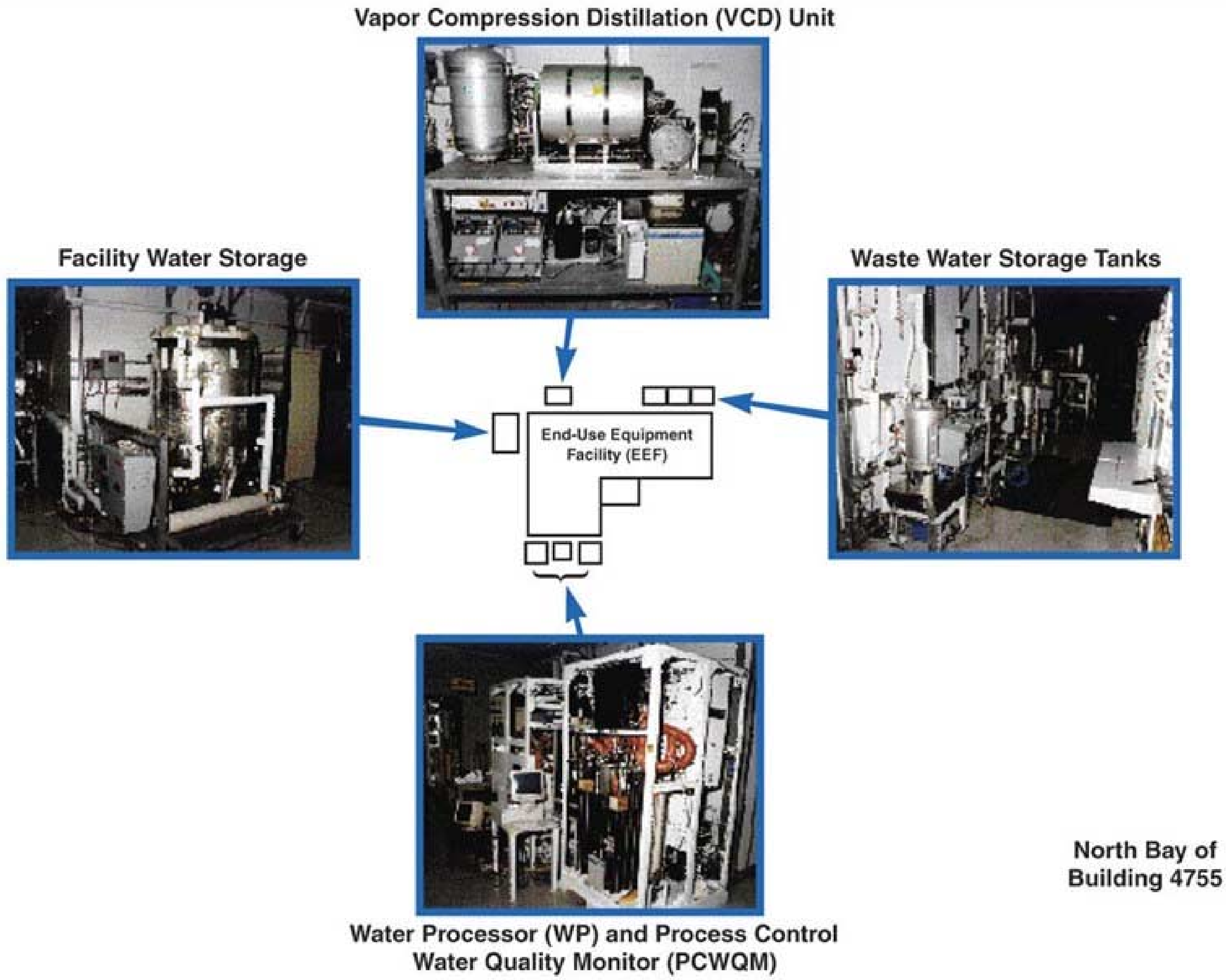
(Illustrates Technology Development Supporting Program Needs)



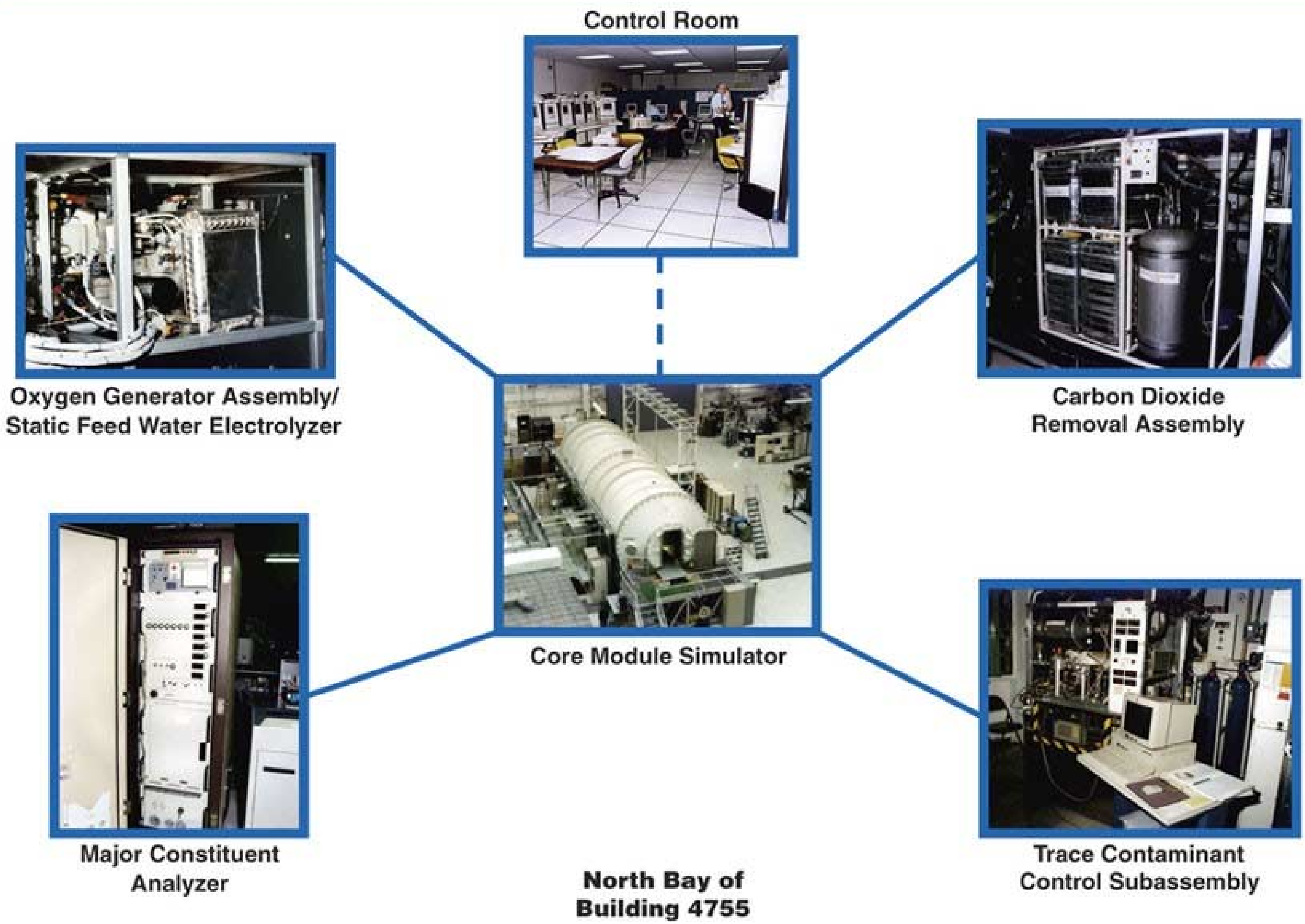
End-Use Equipment Facility (EEF)



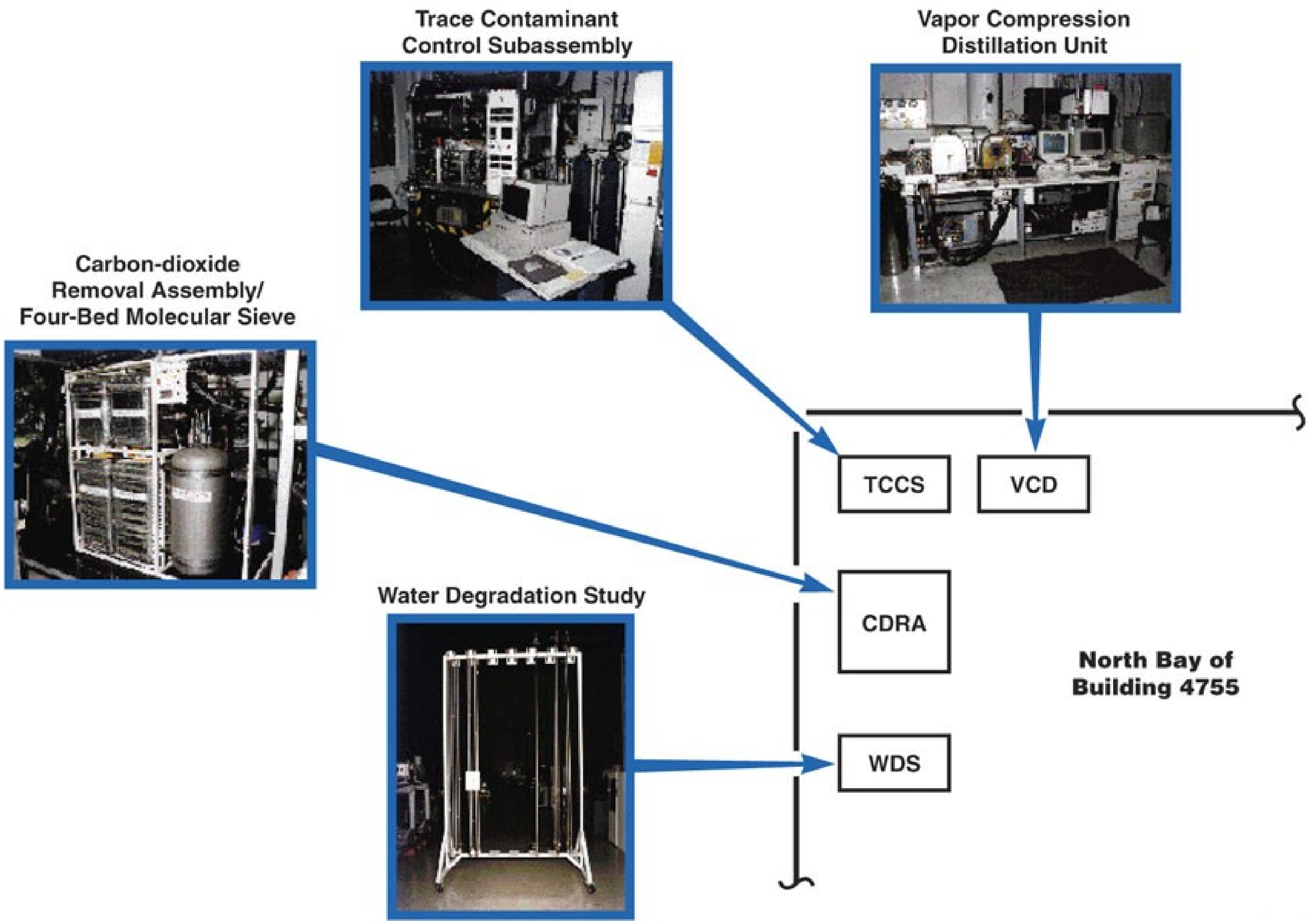
Space Station ECLSS
Water Recovery Testing Area



Space Station ECLSS Air Revitalization Test Area



Space Station ECLSS Life Testing Area



NASA/CP—2004-213205/VOL1

Status of ISS Regenerative ECLSS Development

The following charts give the technology development status of the current ISS Program regenerative ECLSS Water Management System and Oxygen Generation System hardware.

UPA Development History

- **Technology Selection: based on comparative testing & analysis conducted during Space Station Freedom program**
  - **Selection methodology and rationale documented in “Space Station Freedom Environmental Control and Life Support System Regenerative Subsystem Selection”, NASA TM 4340, February 1992.**
- **Process Demonstration: thousands of hours of ground testing (bench & integrated system).**
- **Flight Demonstration: full size unit delivered for micro-gravity demonstration on STS-107**
- **Life Demonstration: Distillation Assembly compressor, Purge Pump, Fluids Pump life demonstrated during 3,000-17,000 hr life-test programs during SSF.**
- **ISS Development Testing:**
  - **DA Stationary Bowl condensate control: developed & demonstrated heater-based controls**
  - **Materials compatibility: bearings & seals with pretreated urine**
  - **Acoustic Testing: analytical flight predictions based on ORU-level test data show that planned attenuation measures will meet rack acoustic requirements**
  - **Micro-gravity Disturbance: identified and quantified major disturbers (pumps and DA); data is being used to refine ISS micro-g model predictions; candidate materials received for testing to finalize micro-g isolators design**
  - **Hose Gas Permeation: characterize gas introduction through flex hoses & impacts on UPA pressure control/operability**

Urine Processor Assembly Technology Development Status

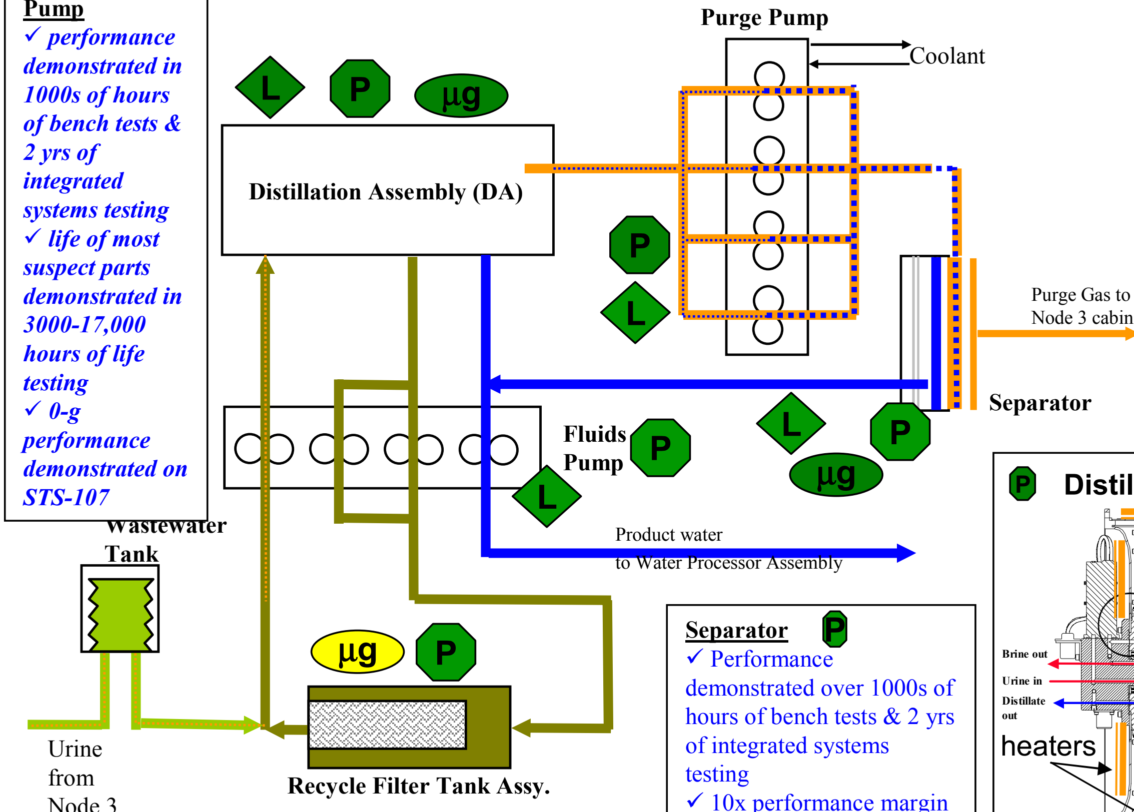
Development Concerns Legend:

Red: Significant unresolved issues
Yellow: Open validation remaining
Green: Ready to proceed for flight

µg Microgravity Sensitivities
L Life
P Performance

Distillation Assy, Purge Pump, Fluids Pump P L

- ✓ *performance demonstrated in 1000s of hours of bench tests & 2 yrs of integrated systems testing*
- ✓ *life of most suspect parts demonstrated in 3000-17,000 hours of life testing*
- ✓ *0-g performance demonstrated on STS-107*



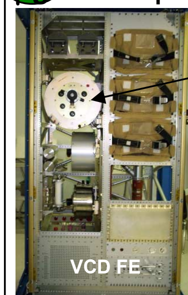
Separator P

- ✓ Performance demonstrated over 1000s of hours of bench tests & 2 yrs of integrated systems testing
- ✓ 10x performance margin demonstrated in bench tests
- ✓ system schematic modified to mitigate impact of failure

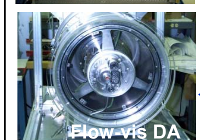
Recycle Filter Tank µg

- ✓ Filter is oversized and should minimize any gravity sensitivity of internal filter loading (& hence tank change out frequency)

µg DA & Separator Micro-g Risk Mitigation

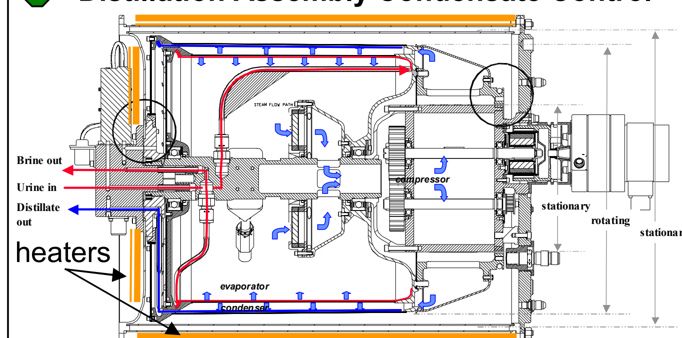


- ✓ *VCD Flight Exp't*
- ✓ *Full-scale DA*
- ✓ *steady state & transient ops*
- ✓ *STS-107*
- ✓ *functionality confirmed*



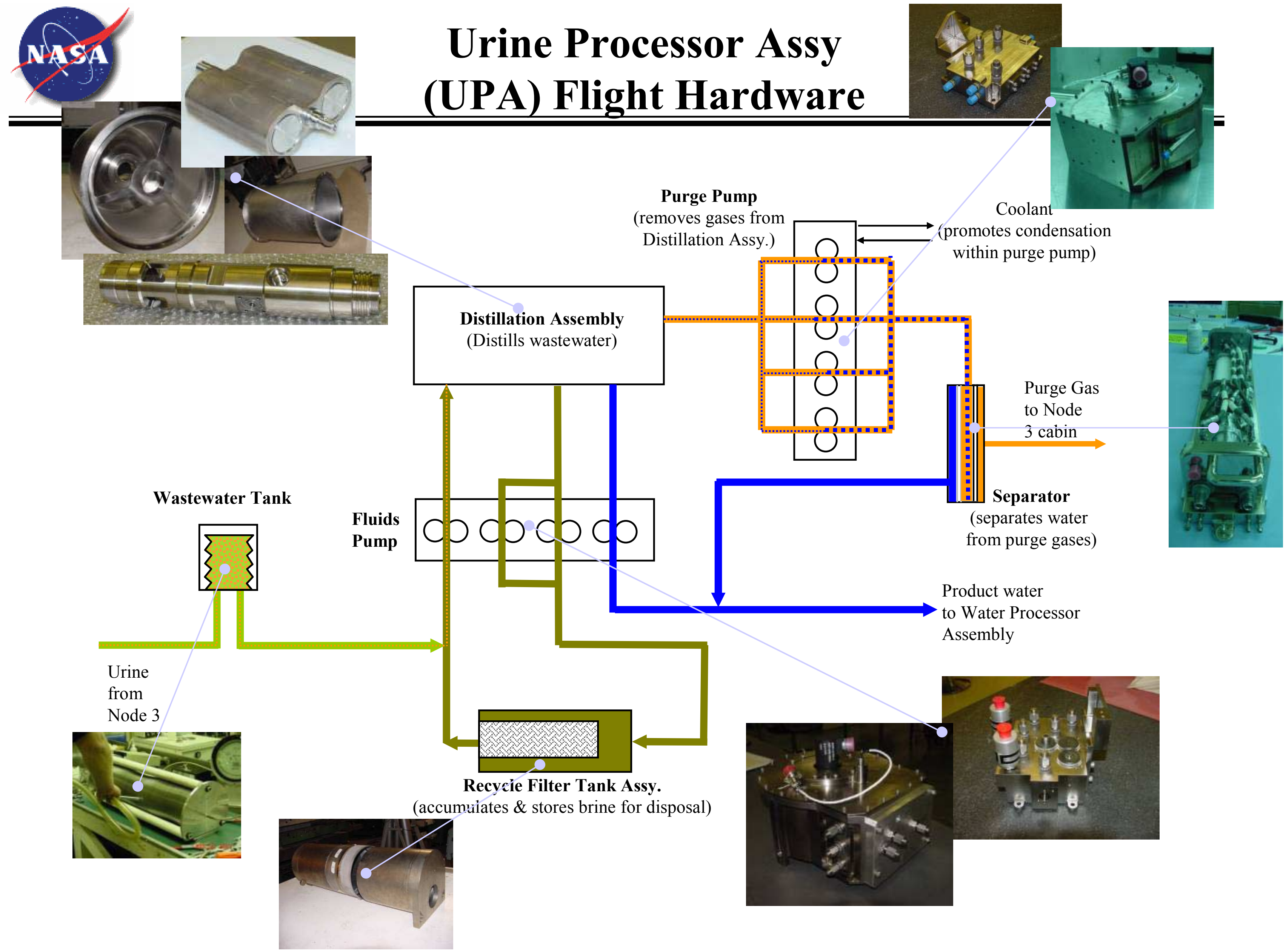
- ✓ *KC-135 "flow visualization" testing Feb '02*
- ✓ *observed flow patterns & fluid distrib'n*

P Distillation Assembly Condensate Control



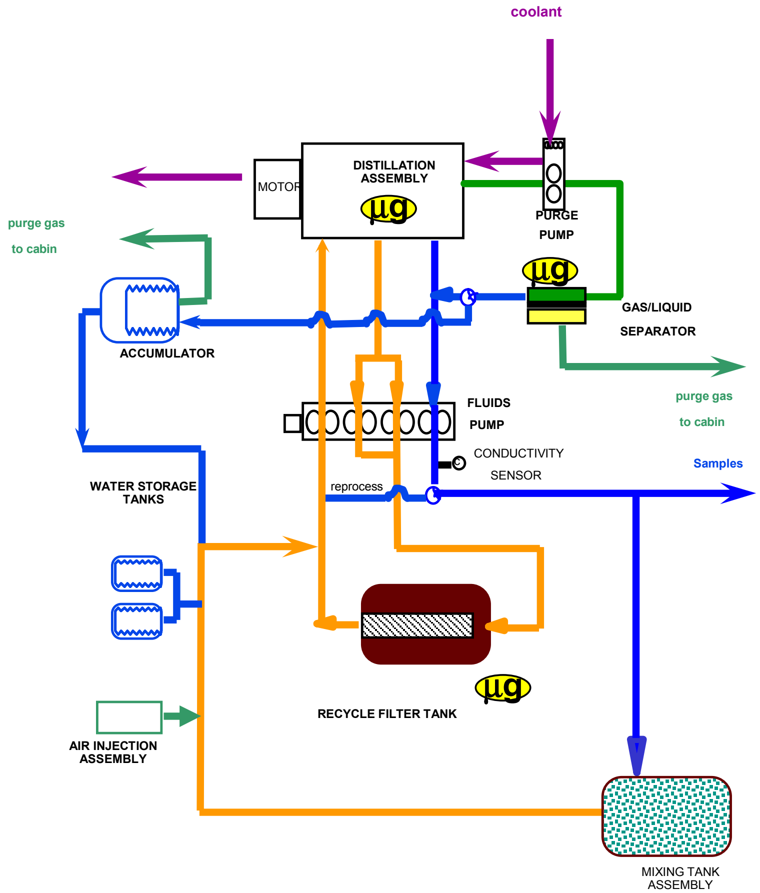
- ✓ ***external heaters added to prevent condensation in stationary bowl***
- ✓ ***design finalized; release complete 8/02***

Urine Processor Assy (UPA) Flight Hardware

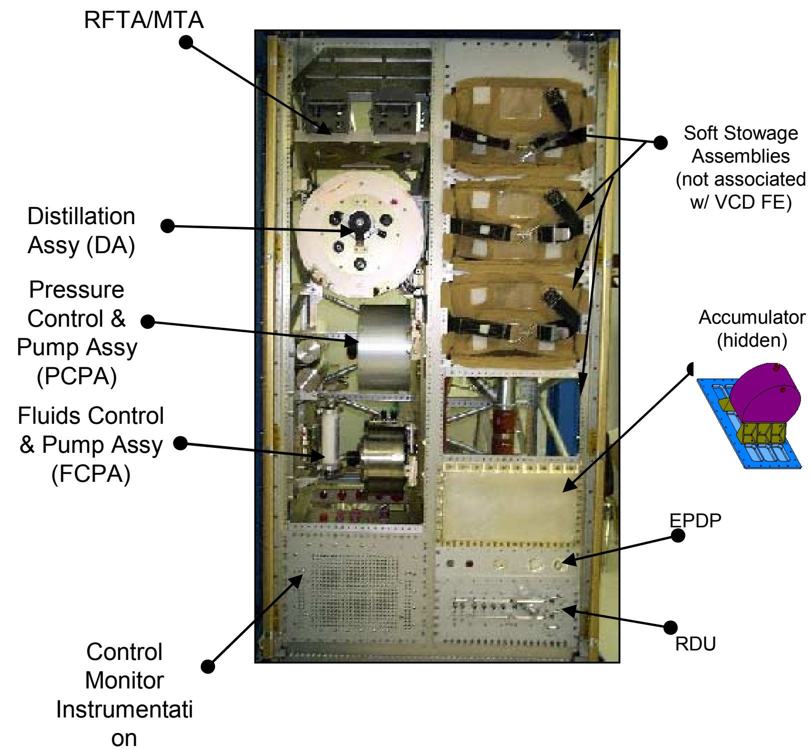


VCD Flight Experiment STS-107

VCD FE Schematic



Flight Experiment in Spacehab Rack (prior to acoustic treatment)

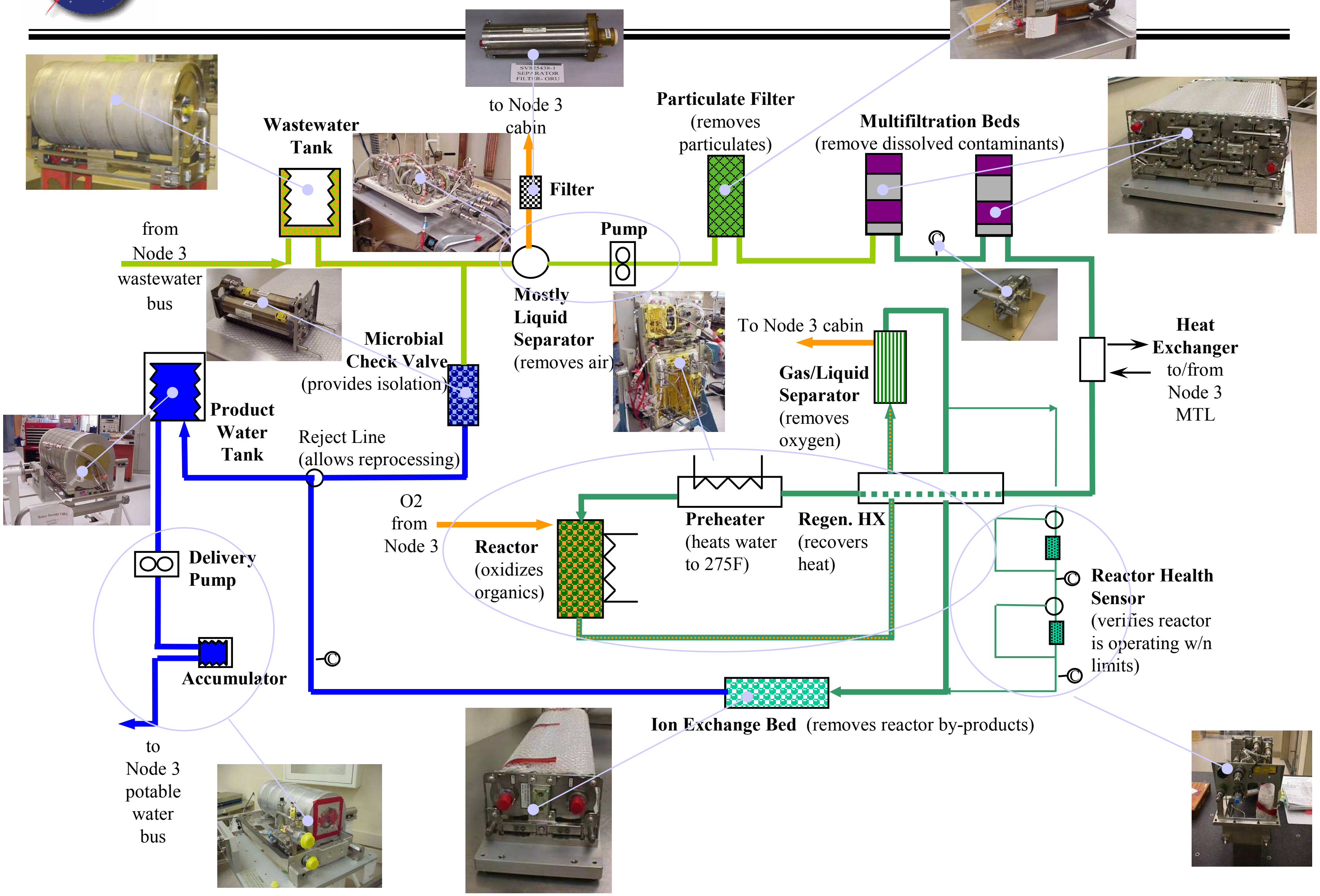


"Successful Demo"

ISS Water Processor Development History

- **Technology Selection: based on comparative testing & analysis conducted during SSF**
  - Selection methodology and rationale documented in NASA TM 4340, February 1992.
- **Process Demonstration: 1000’s of hours of ground testing (bench & integrated system).**
- **Flight Demonstration: multiphase catalytic reactor performance demonstrated in Volatile Removal Assembly Flight Experiment, STS-96 (May ’99) & KC135 tests;**
  - extent of gas occlusion in micro-g shown to be same as in 1-g
  - O_2 utilization less in micro-g due to differences in gas distribution; factored into final flight sizing and performance predictions
- **Life Demonstration:**
  - Pumps: Ceramic gear pumps; 17,733 hours on process pump to date (vs. 8,000 hr.goal); 18,626 hours and 560,000 on/off cycles on delivery pump to date (vs. 8,760 hour/1 year life requirement)
  - Tanks: Dev. bellows tested 560,000 cycles (delivery tank) and 35,000 cycles (waste tank) = 4 x life
  - GLS: 1200 hrs on modules (=150 days operation); 6 mo. life demonstrated w/ 90 ppb reactor fines (expect 10 ppb actual fines); integrated flight-like GLS operated 2 months at max O2 flow w/ no degradation
  - Catalyst: > 1 yr demonstrated w/o performance degradation; testing continuing
- **ISS Development Testing:**
  - MLS: optimized to work w/ foaming soaps; demonstrated operation in various 1-g orientations
  - GLS: demonstrated robustness of hollow fiber membranes against degradation due to fine particulates released from upstream reactor
  - Catalyst: Monometallic catalyst developed to replace original bimetallic– reliable performance achieved w/ repeatable manufacturing process
  - Pumps: Redesign after qual cycle life failures to eliminate gear wear caused by axial load. Redesign complete, pumps in final integration. Qualification tests Aug-Sep ’03
  - pH Adjuster (MgO): Material selection and chemical performance characterization.

ISS Water Processing Assembly (WPA) Flight Hardware



ISS OGA Development History (page 1)

- **Technology Selection: based on comparative testing & analysis conducted during Space Station Freedom program**
  - Selection methodology and rationale documented in NASA TM 4340, February 1992.
- **Process Demonstration: membrane electrolyzers investigated & tested since 1960s and now used commercially (laboratories, utilities) and by Navy.**
- **Flight Demonstration: VRA FE (& ground tests) highlighted susceptibility of membrane gas separators to contamination-induced fouling in micro-g; system configuration changed to cathode feed to eliminate separators**
- **Life Demonstration:**
  - Electrolytic Cells: Ongoing single cell tests >12,000 hours, integrated anode feed system >20,000 hours, integrated cathode feed system >2985 hours in OGA test bed
  - Pump: (common with WPA pump). >2.4x required life demonstrated w/o degradation
  - Hydrogen Sensor: confirmed required operational life of 90 days (dry gases)
- **ISS Development Testing:**
  - see next page

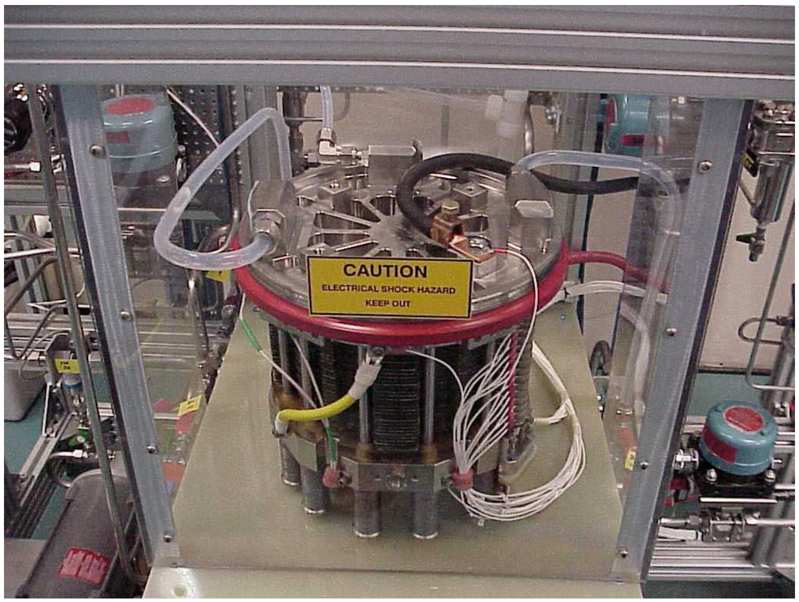
ISS OGA Development History (page 2)

Test	Finding	Resolution
VRA Flight Experiment/OGA Life Test	Established sensitivity of membranes to particulate and microbial contamination, exacerbated by micro-G	Eliminated membrane phase separators-cathode feed cell stack and rotary phase separator
Venturi Testing	Established performance and performed acoustic measurements to compare to specification	Testing Complete – Unit to Dev Test Bed
Absorber Development Unit	Established performance and life, and compared to calculated requirements.	Testing Complete – Unit to Dev Test Bed
Cathode Feed Cell Stack	Development cell stack successfully assembled and tested.	Testing Complete on Rig 275 - Unit to Dev Test Bed
Cathode Feed Single Cell Testing	Characterized cell voltage rise and life under controlled conditions: Temperature, pressure, cycling, MSFC development processed water	Compatibility verified, all MSFC product water consumed, testing continues with DI water.
Water Diffusion (Cell Stack Vacuum Test)	Verified analysis predicting diffusion of water, hydrogen, and oxygen through the edges of the cell stack membranes. Correlated results between anode feed vs cathode feed (18 cells vs 28 cells).	Testing Complete.
H2 Sensor Challenge Test	Established operational life using 2 sensor assemblies containing 3 sensors each. Gases flowing through the sensors was dry.	Operational life of 90 days confirmed. (dry gases)
Rotary Separator Development Unit	Fabricated/tested proof-of-concept and development units. Established performance and verified critical design characteristics: separation and level sensing.	Testing Complete. Unit to Dev Test Bed.
TFS Sensor (optical gas bubble sensor)	Established performance in detecting bubbles of various sizes over the specified flow range.	Bench testing, vibration, and thermal cycling complete - Unit to Dev Test Bed.

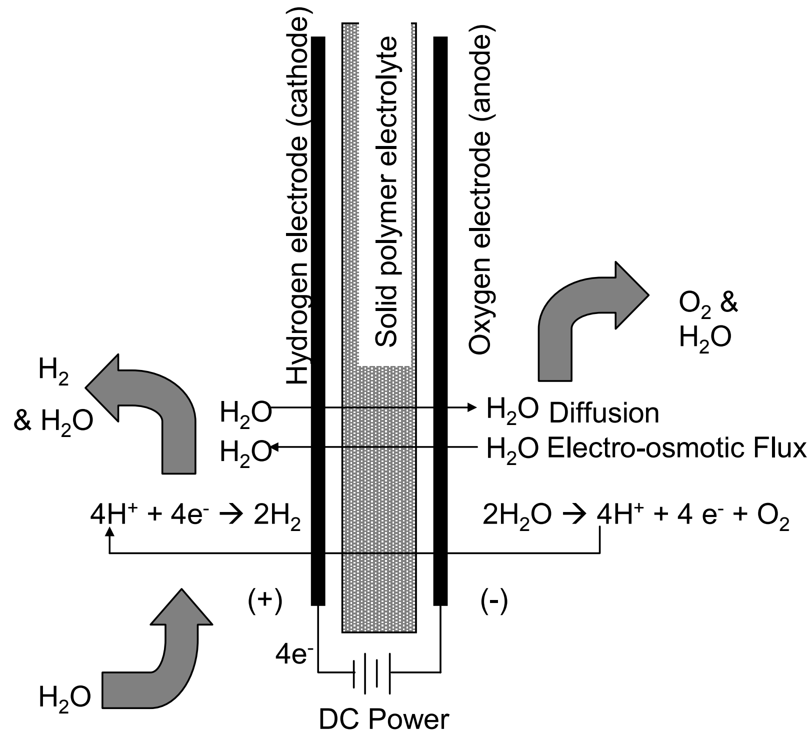
International Space Station Oxygen Generator System (OGS) Description

- Core Technology: Solid Polymer Electrolysis (cathode feed)

Cell Stack



Electrolysis Cell Reactions

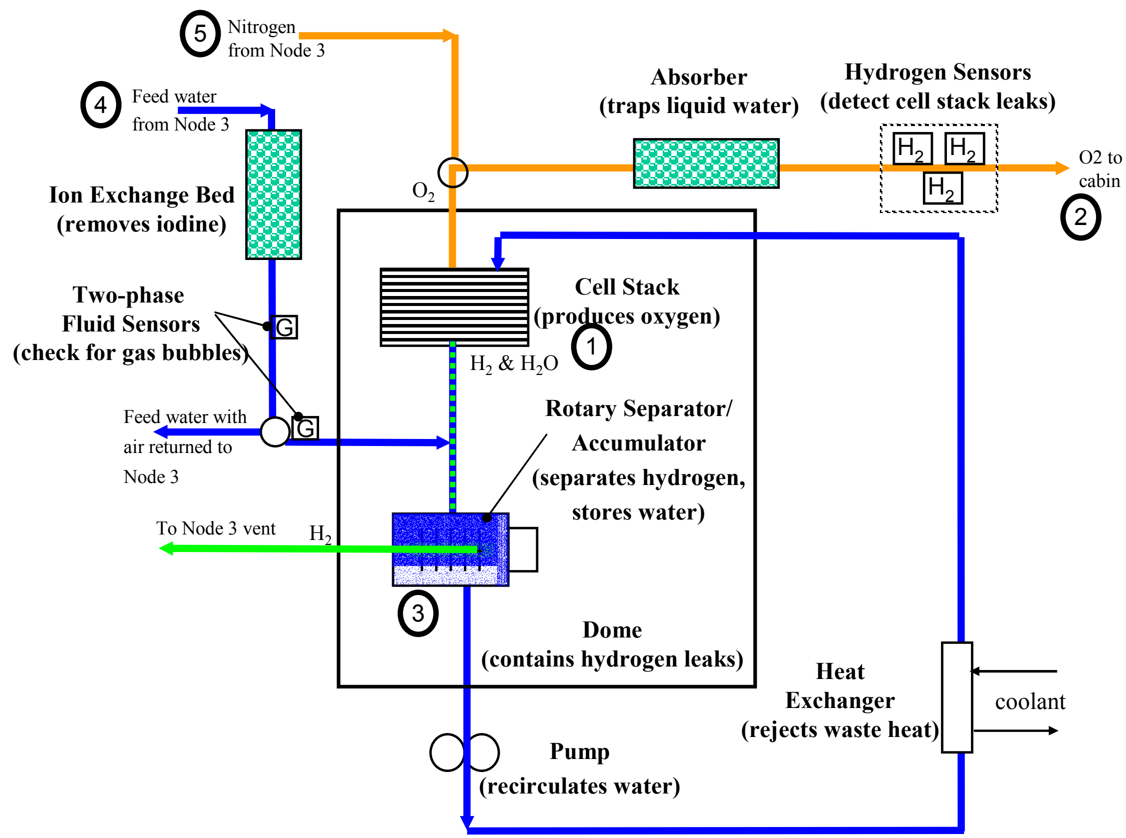


NASA/CP—2004-213205/VOL1

ISS Oxygen Generator System Description

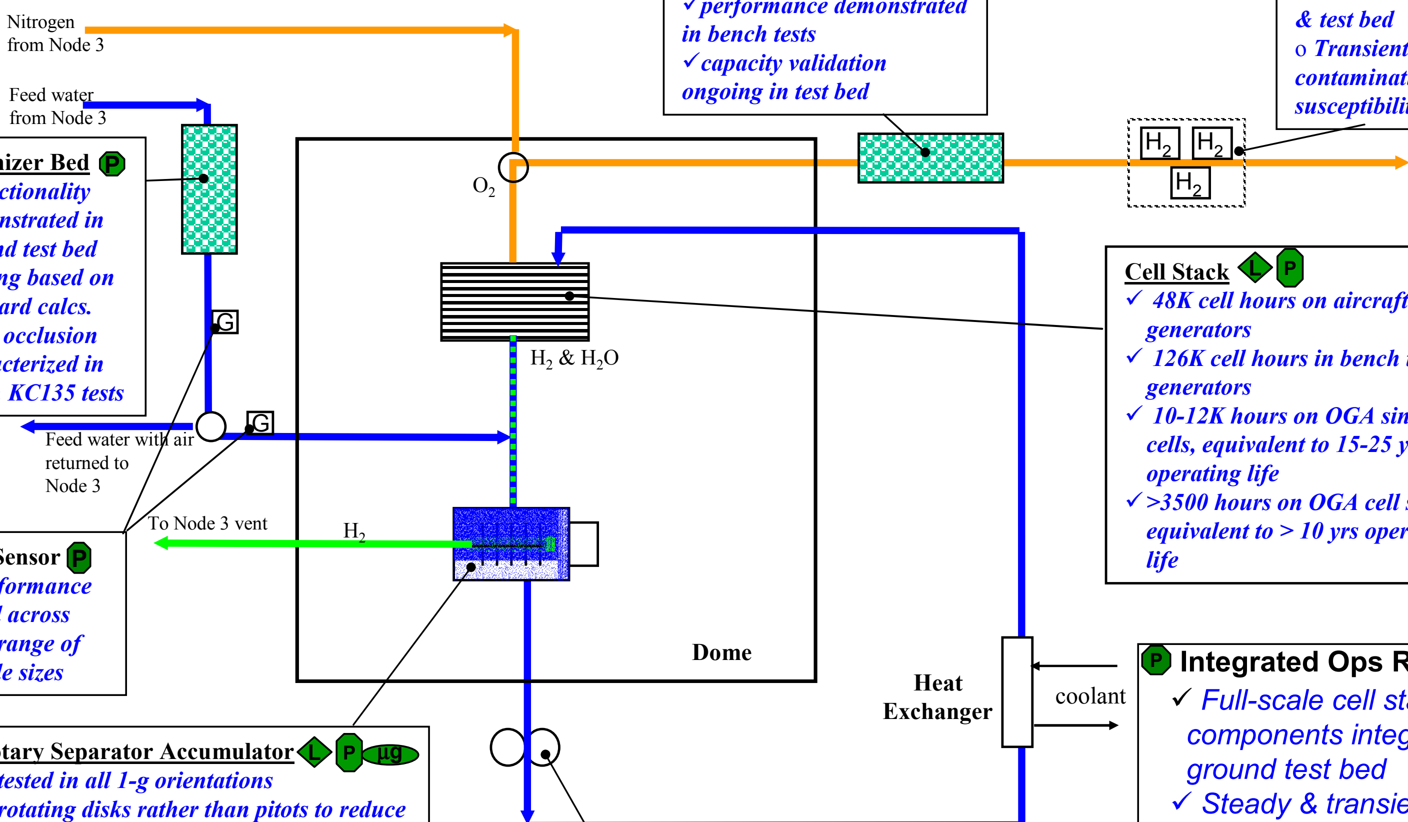
Integrated Process

1. Oxygen & hydrogen produced in 28-cell stack
2. O_2 delivered to cabin
3. H_2 mixed with excess re-circulated water, separated dynamically, and vented overboard (ISS baseline)
4. Makeup water periodically added and stored within rotary separator
5. Oxygen lines purged with nitrogen for safety after shutdowns



NASA/CP—2004-213205/VOL1

ISS Oxygen Generator Assembly Technology Development Status



Water Absorber (P)
✓ *performance demonstrated in bench tests*
✓ *capacity validation ongoing in test bed*

H_2 Sensor (P)
✓ *general performance demonstrated in bench tests & test bed*
o *Transient performance & contamination susceptibility open issues*

Deionizer Bed (P)
✓ *functionality demonstrated in ground test bed*
✓ *sizing based on standard calcs.*
✓ *gas occlusion characterized in 1-g & KC135 tests*

Cell Stack (L) (P)
✓ *48K cell hours on aircraft O2 generators*
✓ *126K cell hours in bench top H2 generators*
✓ *10-12K hours on OGA single cells, equivalent to 15-25 yrs operating life*
✓ *>3500 hours on OGA cell stack, equivalent to > 10 yrs operating life*

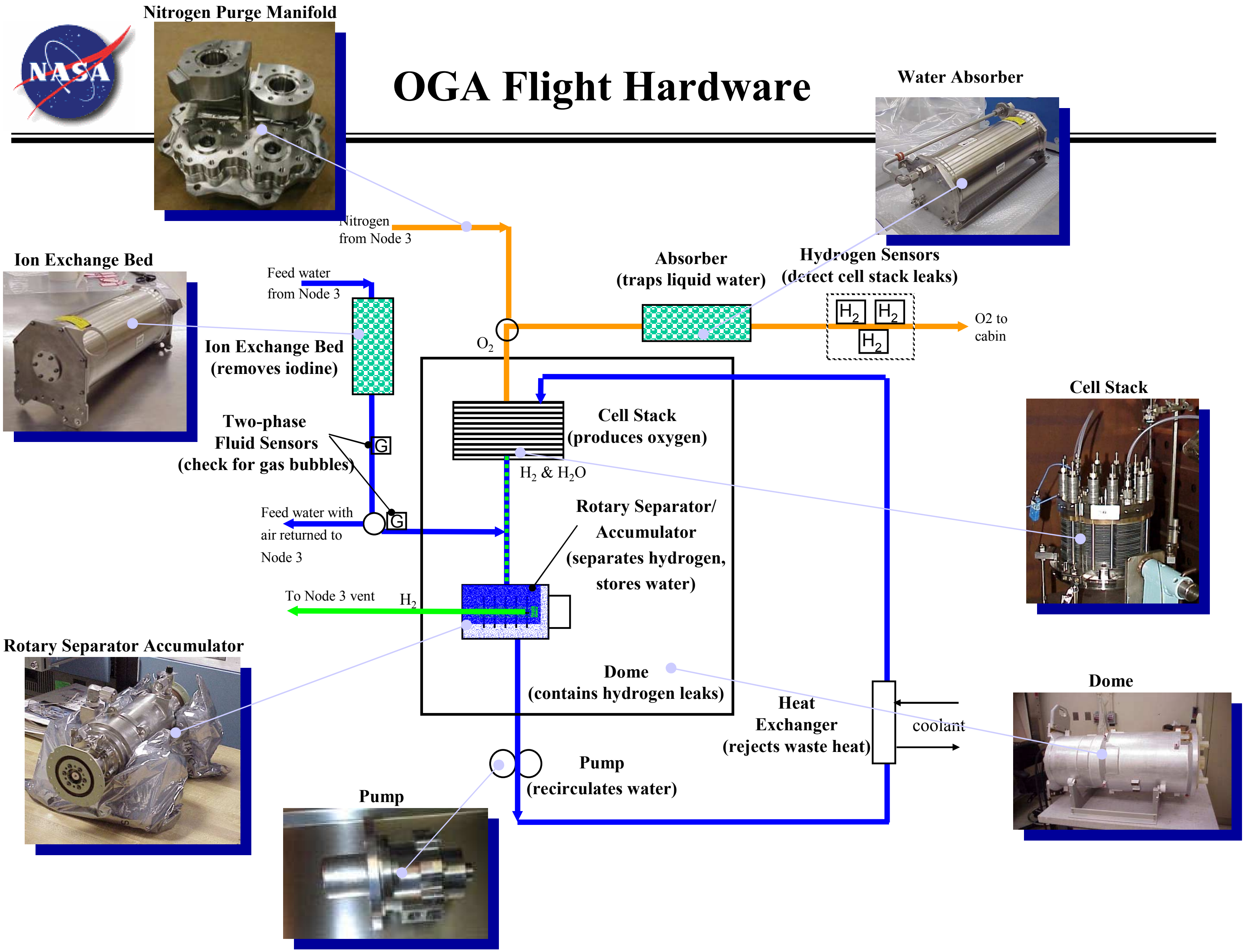
Gas Sensor (P)
✓ *performance tested across wide range of bubble sizes*

Integrated Ops Risk Mitigation (P)
✓ Full-scale cell stack & dev components integrated in ground test bed
✓ Steady & transient ops
✓ Software algorithm validation

Rotary Separator Accumulator (L) (P) (µg)
✓ *tested in all 1-g orientations*
✓ *rotating disks rather than pitots to reduce clogging potential & reduce carryover*
✓ *hydrodynamic bearings – avoids life-limiting wear*

Pump (L)
✓ ***pump: dev pump 2.4x life tested w/o degradation***
o ***pump: WPA qual pump cycle failures; redesign complete, retest in 6/03***
✓ ***motor: 1.3x life tested w/o degradation***

Development Concerns Legend:
Red: Significant unresolved issues
Yellow: Open validation remaining
Green: Ready to proceed for flight
(µg) Microgravity Sensitivities
(L) Life
(P) Performance

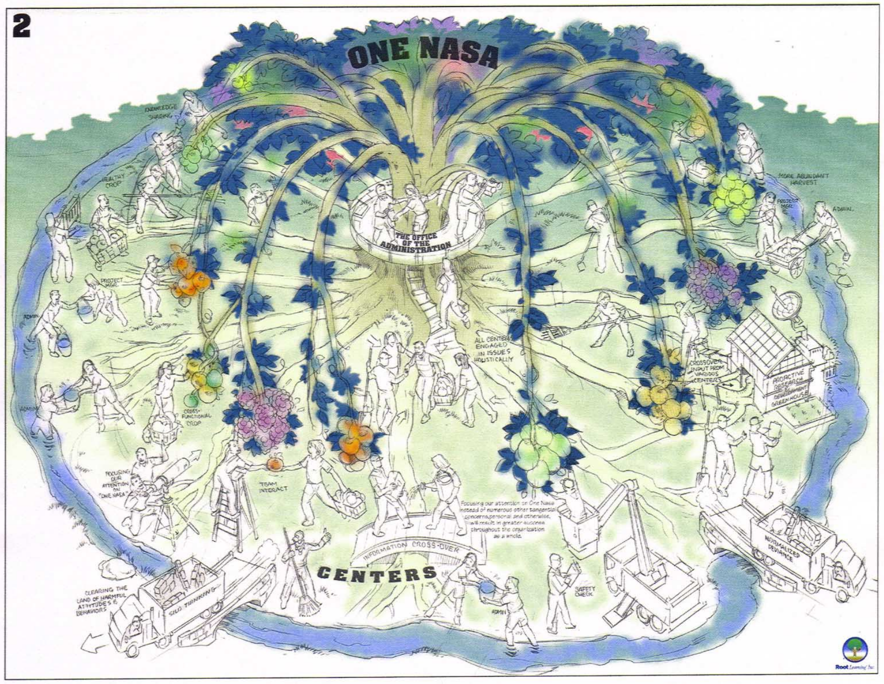

OGA Flight Hardware
Nitrogen Purge Manifold
Water Absorber
Nitrogen from Node 3
Ion Exchange Bed
Feed water from Node 3
Absorber (traps liquid water)
Hydrogen Sensors (detect cell stack leaks)
H_2
H_2
H_2
O2 to cabin
O_2
Ion Exchange Bed (removes iodine)
Cell Stack
Cell Stack (produces oxygen)
Two-phase Fluid Sensors (check for gas bubbles)
G
G
H_2 & H_2O
Feed water with air returned to Node 3
Rotary Separator/ Accumulator (separates hydrogen, stores water)
To Node 3 vent
H_2
Rotary Separator Accumulator
Dome (contains hydrogen leaks)
Dome
Heat Exchanger (rejects waste heat)
coolant
Pump (recirculates water)
Pump

What's Next?

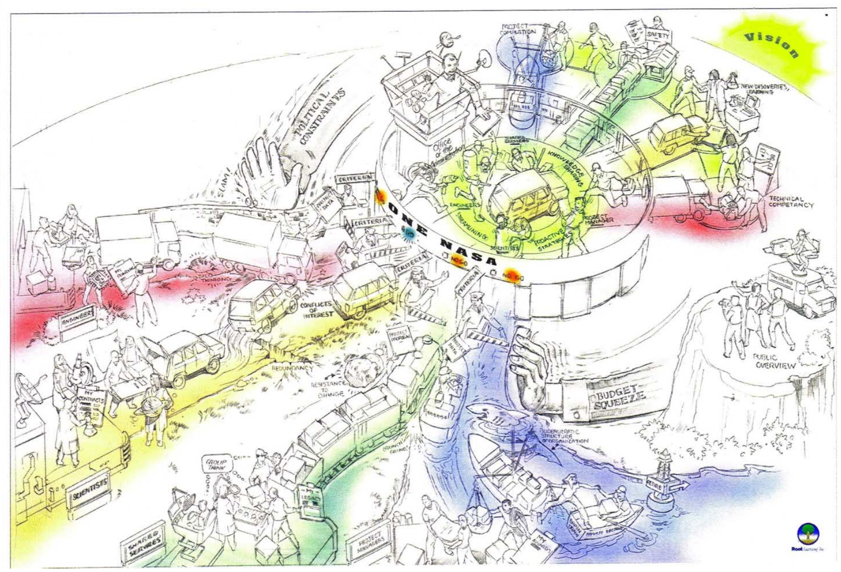
Advanced ECLSS for New Space Initiative

Strategic Roadmap to Success

THIS!



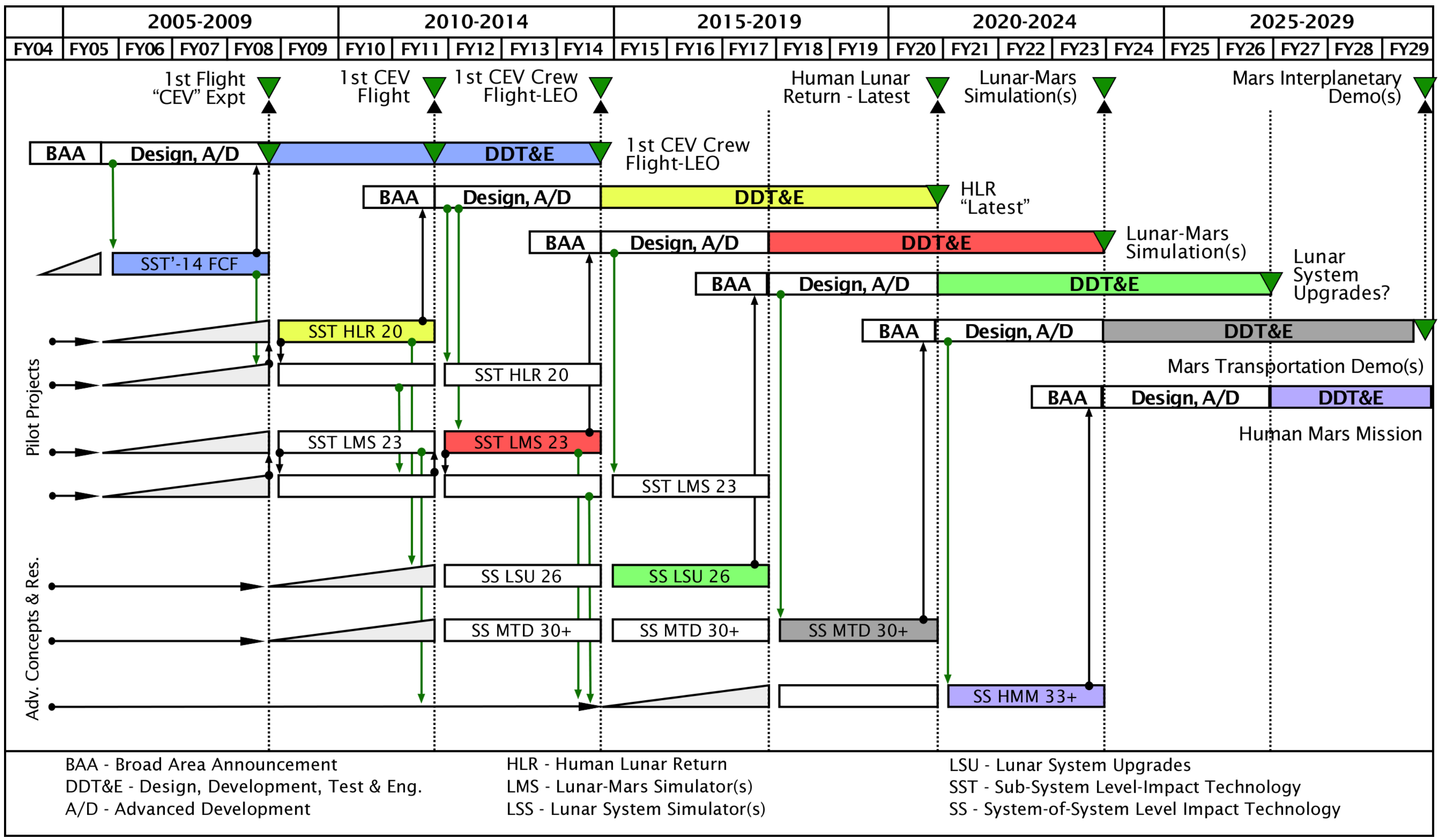
NOT THIS!



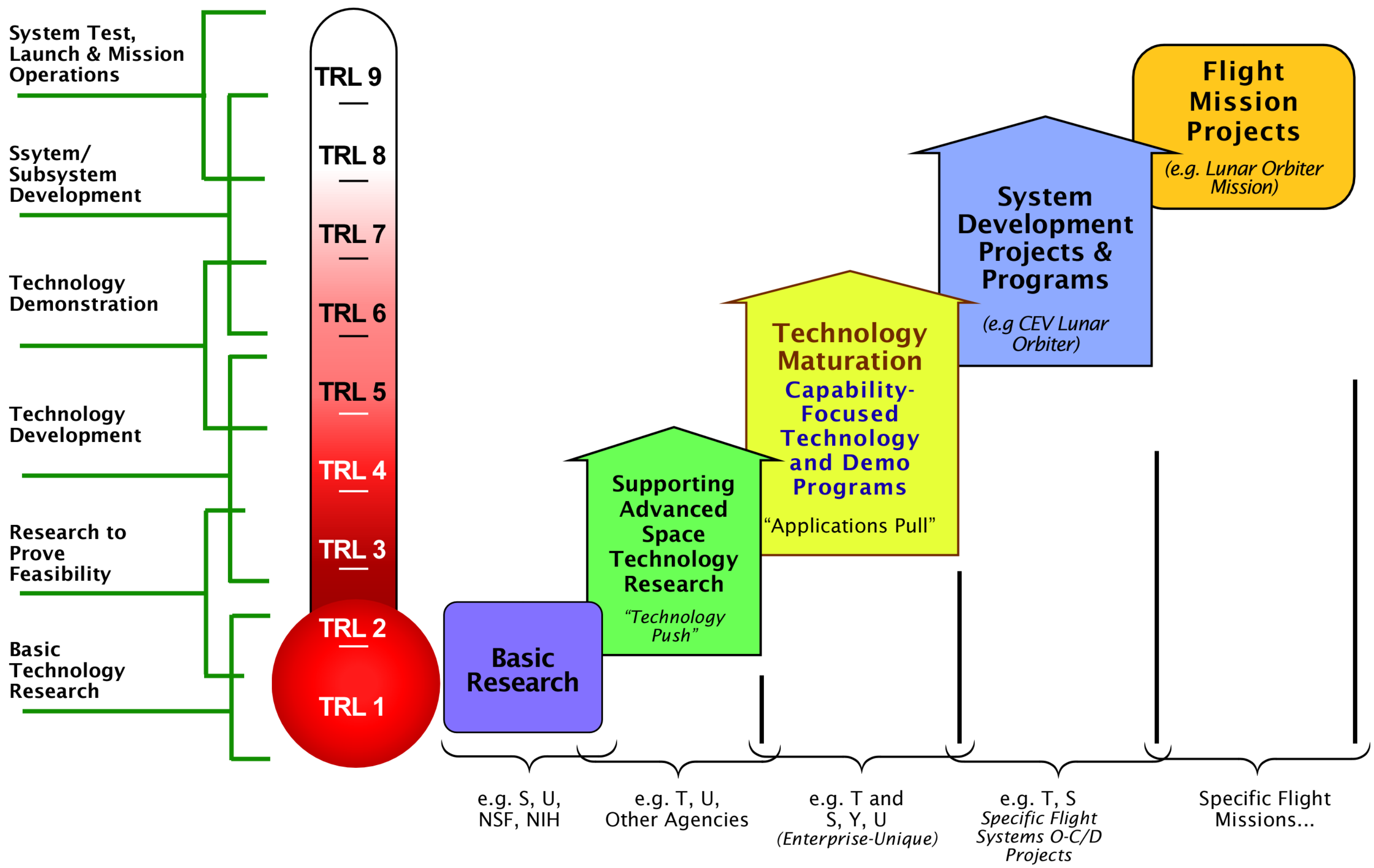
The Future

1. It's essential that we all understand NASA/HQ program needs for advanced ECLSS.
2. It's essential we communicate on common ECLSS technology interests. MSFC wants to work with HQ and other NASA centers/industry/universities to assure maximum return on investments and avoid duplication of efforts.
3. It's essential we use common terminology to define what we're doing and where we are in doing it.
4. Managing a technology development program is different than managing development of flight hardware.

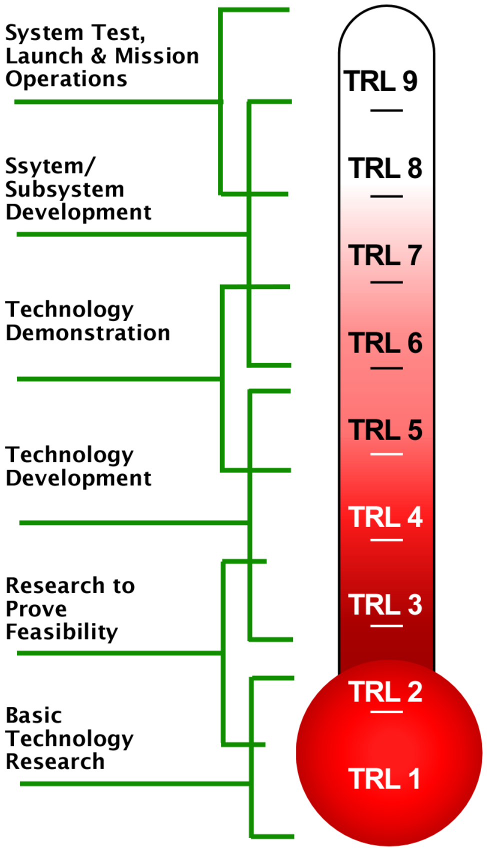
H&RT Cycles of Innovation and Spiral Development



Code T/H&RT Strategic Technology/Systems Model



Technology Readiness Levels (TRLs)



Actual system “flight proven” through successful mission operations

Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)

System prototype demonstration in a space environment

System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

Component and/or breadboard validation in relevant environment

Component and/or breadboard validation in laboratory environment

Analytical and experimental critical function and/or characteristic proof-of-concept

Technology concept and/or application formulated

Basic principles observed and reported

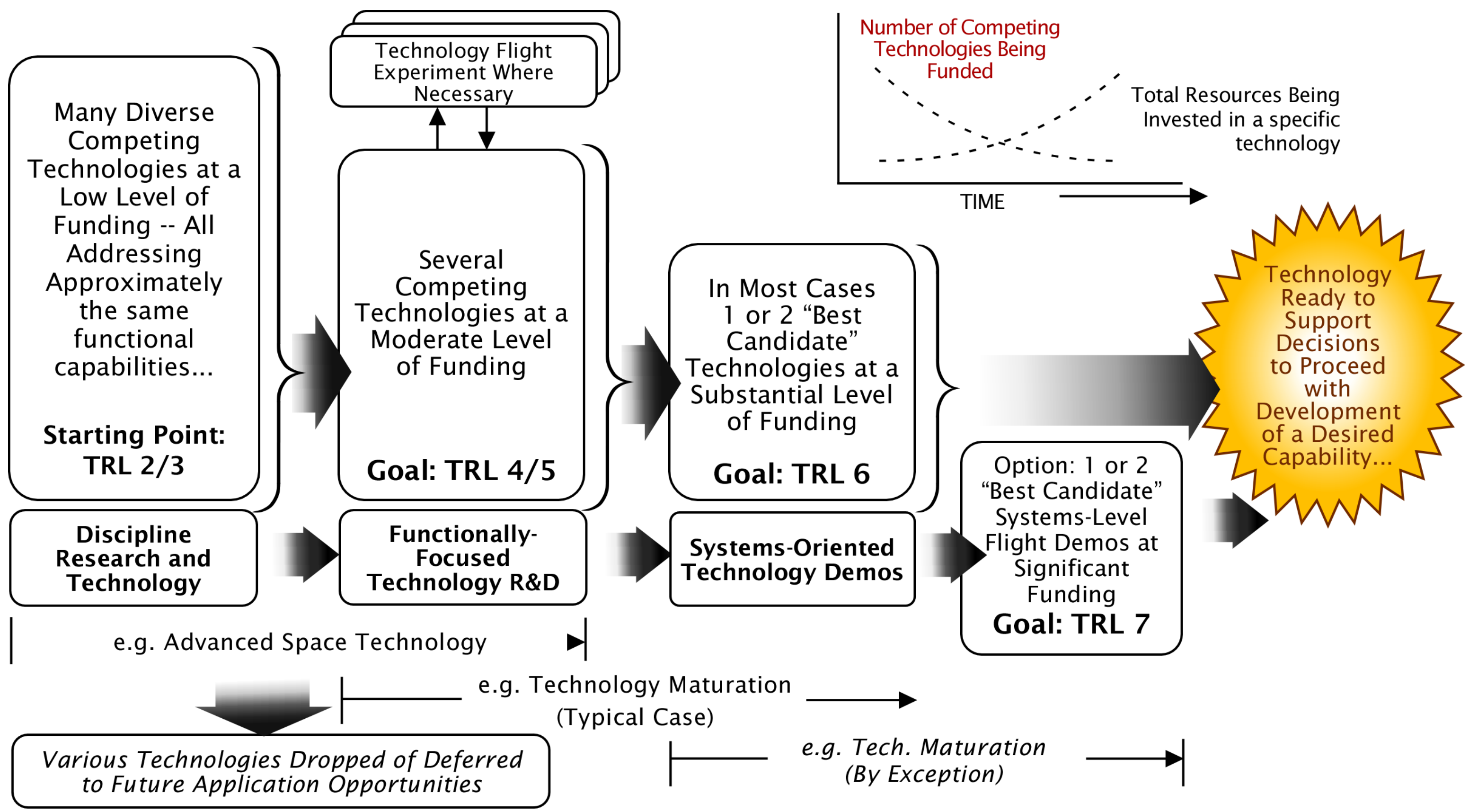
Defining ECLSS Technology Development Terminology
(Calendar Year 2004)

- **Advanced Technology = speaks to technology that is further than 6 years (2010) from reaching TRL 6.**
- **Far-Term Technology = speaks of technology that is required in the 6 – 20 year time frame. This technology will tend to be at very low TRL (0-3). This is an activity that requires long-term development and is usually discipline-oriented.**
- **Mid-Term Technology = speaks of technology that is required in the 3-6 year time frame. In general, this technology tends to be mid-TRL (3-5) that is oriented toward specific functional applications.**
- **Near-Term Technology = speaks of technology that is needed in the 1-3 year time frame. This technology, because of its time constraints, must be at least at mid-TRL (5-8) and must focus on tailoring the technology to program-specific requirements and on demonstration of technology at the component, subsystem, or system level through ground-based test beds and, if required, in space.**
- **Technology Pull = is that technology which has been accepted as an integral part of an Enterprise mission study or mission requirement. It is supported with a technology program.**
- **Technology Push = is that technology that is supported solely by a technology program. Potential for application to a mission problem. It is "push" until it is accepted by the mission, at which point it becomes a "pull" and remains "pull" until it is either successfully integrated into the mission architecture or rejected as unsuccessful.**

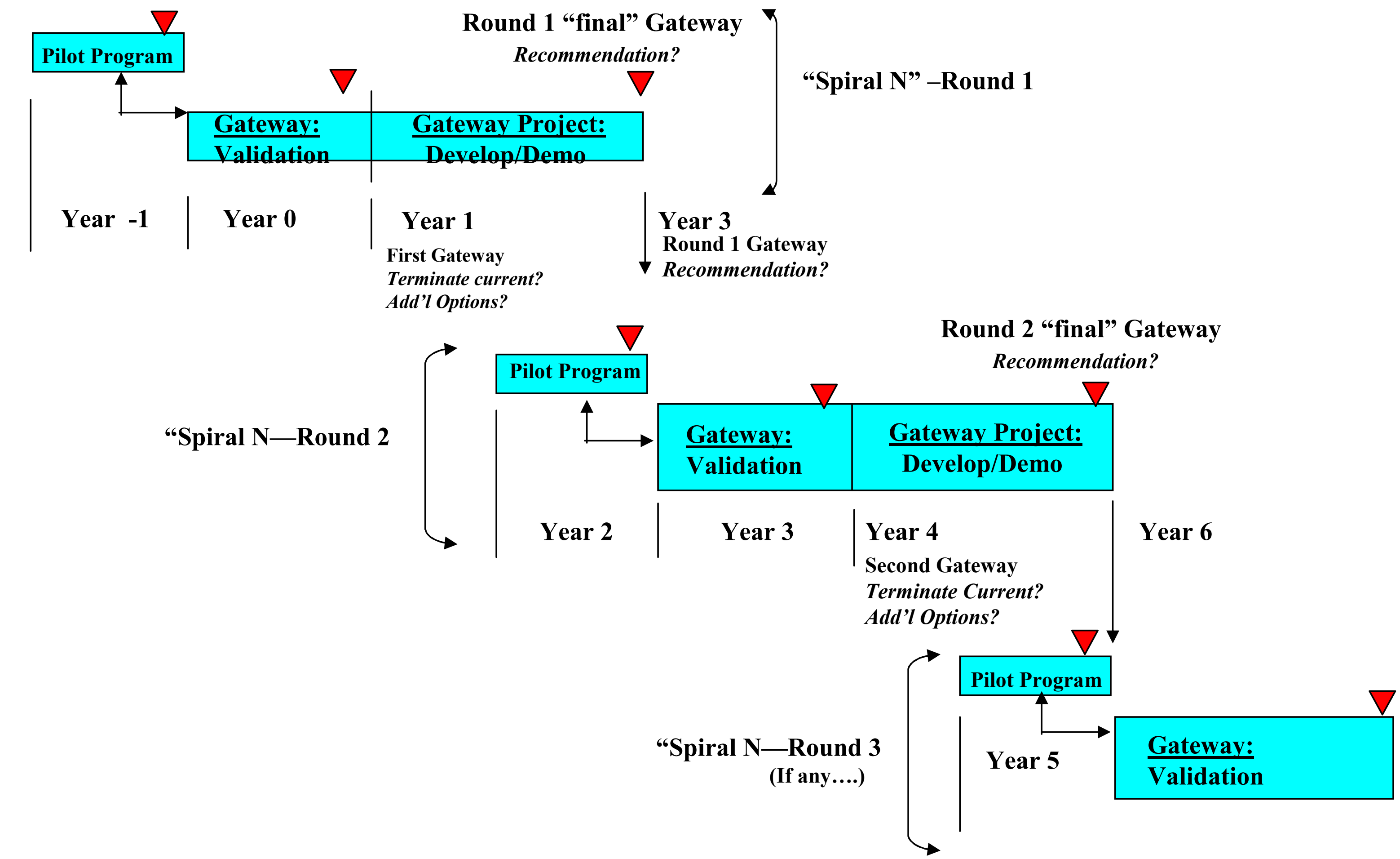
Definition of ECLSS Hardware, Models, Concepts and Units

- **Proof of Concept = Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and flight units.**
- **Breadboard Unit = A unit that demonstrates function only, without respect to form or fit. It has no flight hardware/software.**
- **Brassboard Unit = A unit that lies somewhere between a breadboard unit and prototype unit. It typically tries to make use of as much flight hardware/software as possible.**
- **Development Unit = Any series of units built to evaluate various aspects of form, fit, and function or combinations thereof.**
- **Engineering Unit = A unit that demonstrates critical aspects of the engineering processes involved in the manufacturing of the flight unit. In some cases, the engineering unit will become the prototype, the flight qualification unit or even a flight qualified unit.**
- **Prototype Unit = A unit which demonstrates form, fit and function. It is to every possible extent identical to flight hardware/software and is built to test the manufacturing and testing processes and is intended to be tested to flight qualification levels. The only difference from the flight unit is that it is realized from the start that elements of the prototype unit will in all probability be changed as a result of experiences encountered in its dev./test.**
- **Flight Proven = Hardware/software that is identical to hardware/software that has been successfully operated in a space mission.**
- **Flight Qualification Unit = Flight hardware that is tested to the levels that demonstrate the desired margins, typically 20 – 30%. Sometimes this means testing to failure. This unit is never flown.**
- **Flight Qualified Unit = Actual flight hardware/software that has been through acceptance testing.**

Code T/H&RT Competitive/Portfolio Approach to New Technologies and Systems



Code T Implementing a Competition-Rich R&D Portfolio Phasing Approach (Typical Life Cycle of a Technology Project within HR&T)



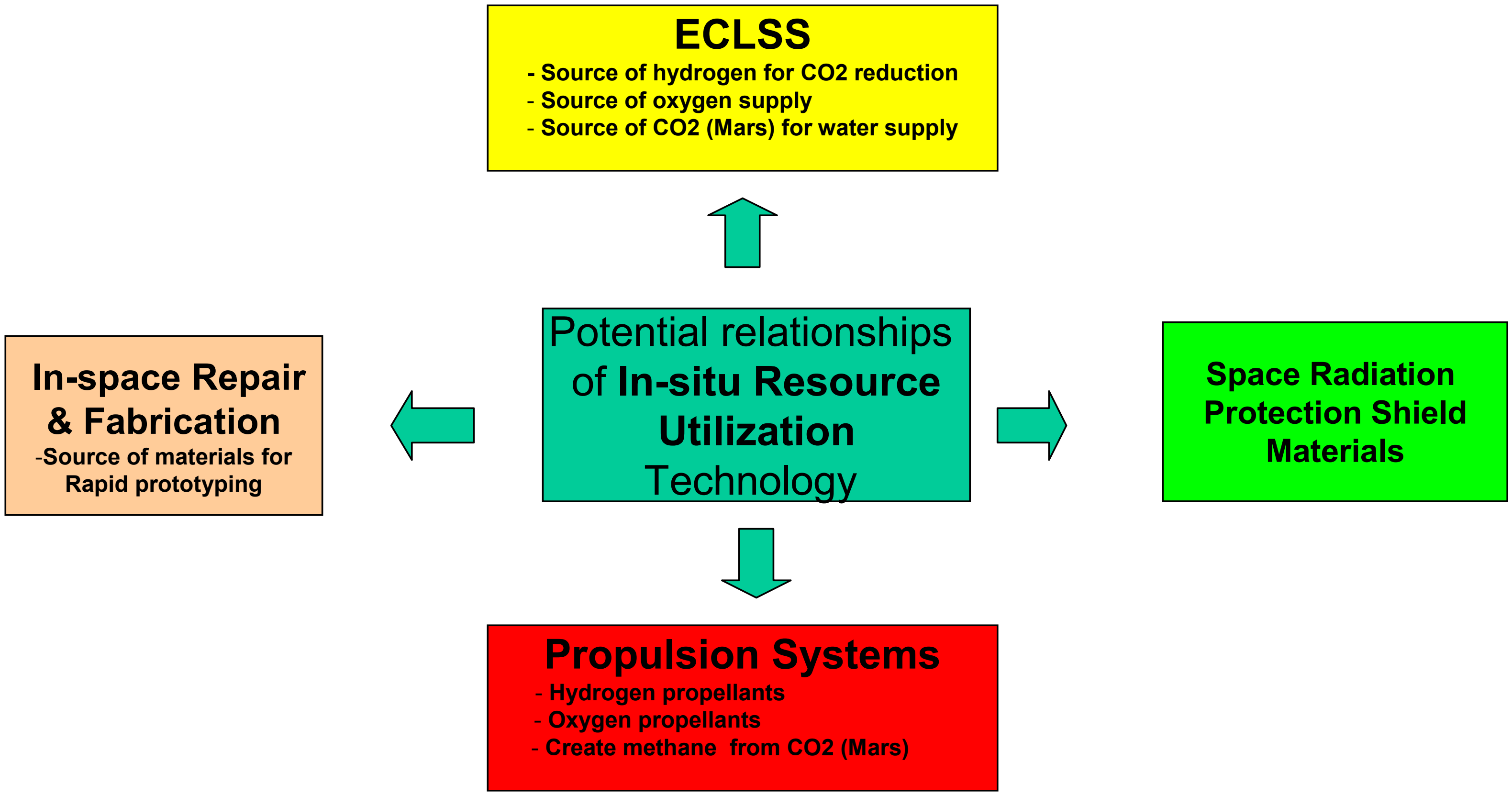
Code T/H&RT Strategic Technical Challenges Regarding "System-of-System" Level Issues.

- **Margins and redundancy** in diverse subsystems, systems and systems-of-systems---but particularly those that must execute mission critical operations (such as transportation or life support) with the prospect of significant improvements in robustness in operations, reliability and safety.
- **Reusability** using vehicles and systems during multiple phases of a single mission, and/or over multiple missions instead of "throwing away" crew transportation, service modules, propulsion stages, and/or excursion systems after only a single mission.
- **Modularity** employing common, redundant components, subsystems and/or systems that can improve reliability and support multiple vehicles, applications and/or destinations—with the potential for significant reductions in cost per kilogram.
- **Autonomy**– making vehicles and other systems more intelligent to enable less ground support and infrastructure, including the goal of accelerating application of 'COTS' and COTS-like computing and electronics in space.
- **In-Space Assembly**– docking vehicles and systems together on orbit instead of launching pre-integrated exploration missions from Earth using very heavy launch vehicles, and including in-space manufacturing, servicing, reconfiguration, evolution, etc. for exceptionally long-duration deep space operations.
- **Robotic Networks**– robots that can work cooperatively to prepare landing sites, habitation, and/or resources and to extend the reach of human explorers.
- **Affordable Logistics Pre-positioning**-- sending spares, equipment, propellants and/or other consumables ahead of planned exploration missions to enable more flexible and efficient mission architectures.
- **Energy-rich Systems and Missions**—including both cost-effective generation of substantial power, as well as the storage, management and transfer of energy and fuels to enable the wide range of other system-of-systems level challenges.
- **Space Resource Utilization**– manufacturing propellants, other consumables and/or spare parts at the destination, rather than transporting all of these from Earth.
- **Data-rich Virtual Presence**– locally & remotely, for both real-time and asynchronous virtual presence to enable effective science and robust operations (including tele-presence, tele-supervision, tele-science, etc.) .
- **Access to Surface Targets**– that is precise, reliable, repeatable and global for small bodies, the Moon, Mars, and other destinations through the use of advanced mobility systems (accessible from orbit on other planetary surface).

Well-Planned Advanced ECLSS Technology Development Program for New Space Initiative

- Establish meaningful objectives and milestones for achieving goals
- Multiple paths to success for supporting lunar and Mars exploration
- Fallback positions when pursued technology efforts fail
- Quantifiable milestones for management of cost/schedules for technology
- Periodic “gates” for changing program directions when needed
- Maximize the probability of success
- Establish schedules that will maximize probability of success
- Live within the costs allocated to the program
- An integrated approach with other new space initiative efforts
- Agreed to metrics for assessing technology development progress
- Strong technical peer group for
    - conducting reviews of proposed technology pursuits
    - prioritizing technologies to pursue
    - conducting reviews of progress made in technology
    - also, an Independent Advisory Group to program manager

ECLSS Partnership with *In-situ Resource Utilization* Proposals
(Lunar and Planetary Surface Operations)



ECLSS Partnership with *In-space Repair & Fabrication* Proposals

(Surface Manufacturing and Construction Systems)

Logistics/Spares
- ECLSS ORU's
- TCS ORU's
- Propulsion systems
- Power systems

Potential relationships of **In-space Repair & Fabrication** Technology

In-situ Resource Utilization
-Source of materials for Rapid prototyping

Space Environment Protective Shields
- Meteroids
- Radiation
- Dust Storms

Maintenance
- IVA tools
- EVA tools
- Plumbing

ECLSS Partnership with *Lab-on-a-Chip* Research Proposals

(Advanced Sensor Concepts)

Potential benefits of **Lab-on-a-chip** Technology

- **Advanced atmosphere monitoring**
  - **Habitable environments**
  - **Martian surface environments**
- **Microbial monitoring of TCS fluids**
- **Microbial monitoring of ECLSS water systems**
- **Specific trace contaminant monitoring**
- **Portable systems**
- **Reliable**
- **Lower weight**
- **Flexible applications (upgraded in-situ)**

How Can NASA Use Ionic Liquids?

- In-Situ Resource Utilization or Analysis?
- CO2 Removal/O2 Release?
- Space Lubricants?
- Biomaterials Processing?
- New Materials?
- Thermal Fluids?
- Radiation Shielding?
- Fuel Cells?
- Batteries?
- Energetic Liquid Propellants?
- Ion Drive Propulsion?

ECLSS Partnership with *Ionic Fluid* Technology Proposals
(Advanced Materials)

ECLSS
-CO2 removal
- C02 reduction
- Regen. waste mgt.

In-situ Resource Utilization
(Lunar or Martian missions)

Potential relationships of **Ionic Fluid** Technology

Space Radiation Protection Shield
(Lunar or Martian missions)

Thermal Control Systems
- Active thermal control system fluid
- Tailored to mission environments on lunar and/or Martian surfaces
- Prometheus heat rejection system