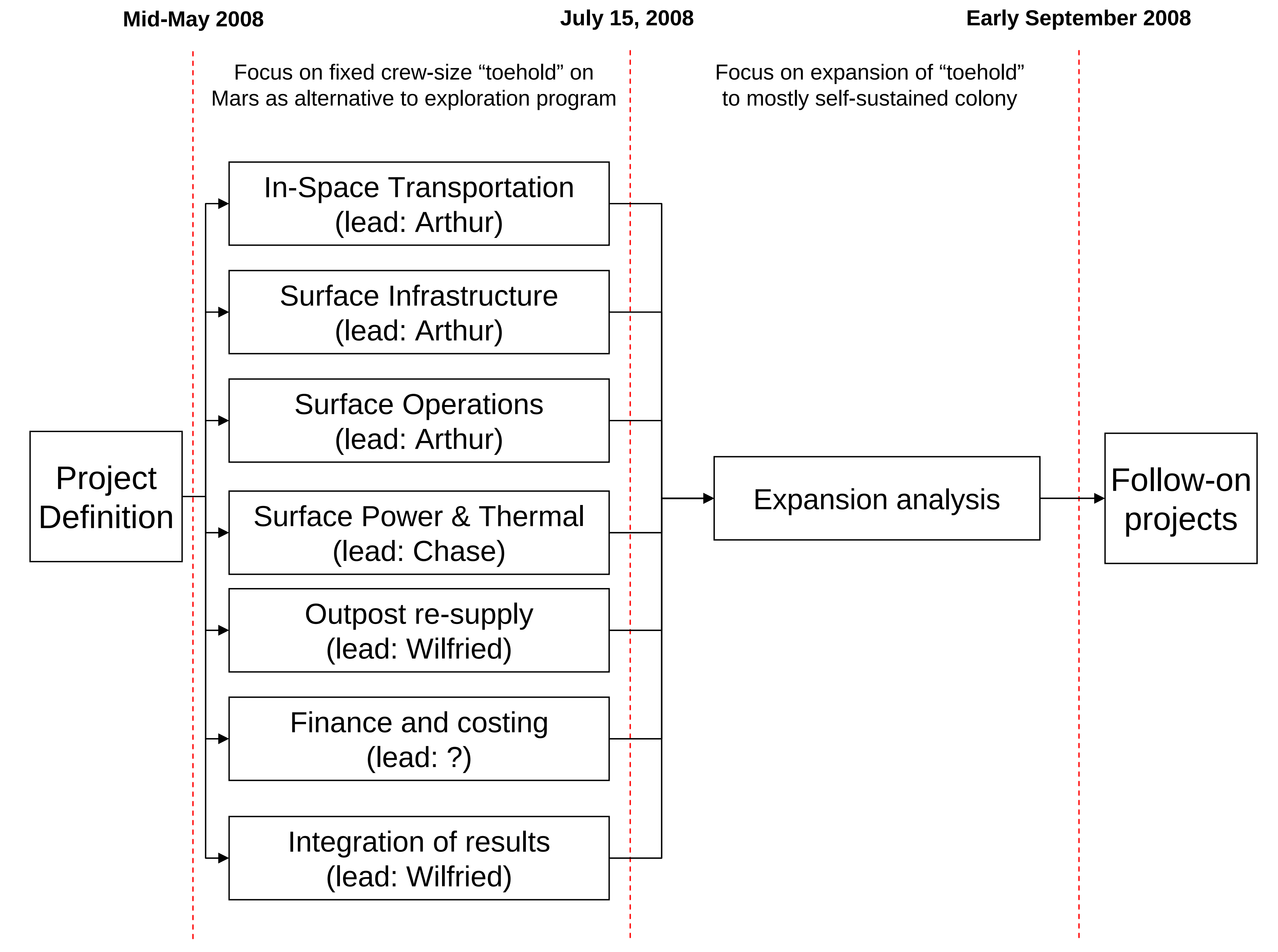
Near-Term Mars Colonization

-A DevelopSpace Project-

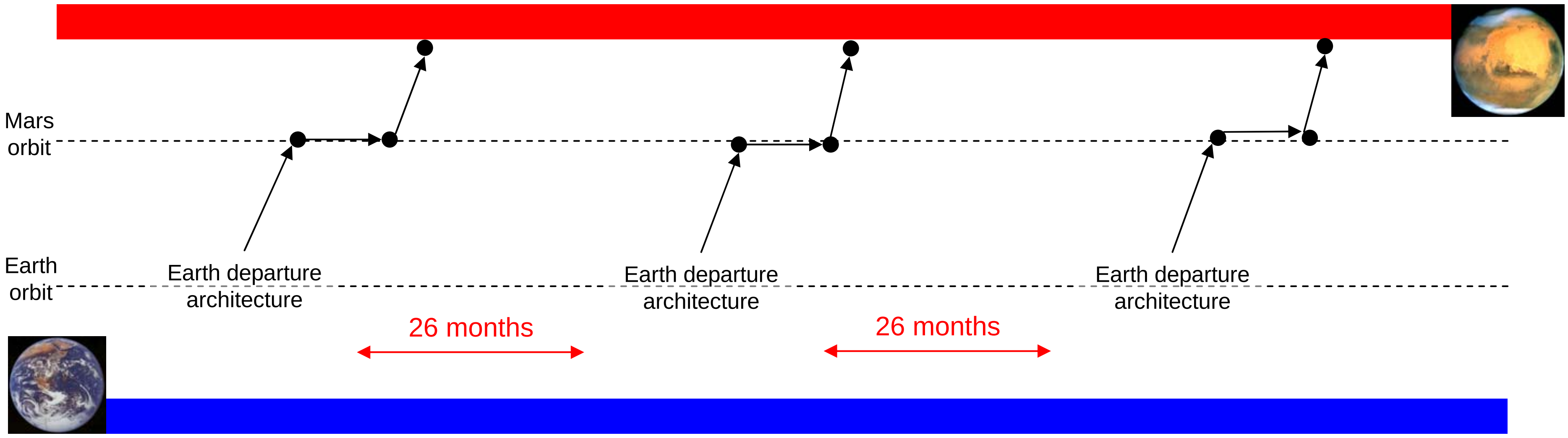
May 11th, 2008

Agenda

- Analysis framework and operational architecture
- Logistics update
- Power update
  - Including movie of Andrew’s solar thermal plant
- The Mars wish list (Paul)
- Notes on ISRU (Alar)
- Notes on SVN (Paul)

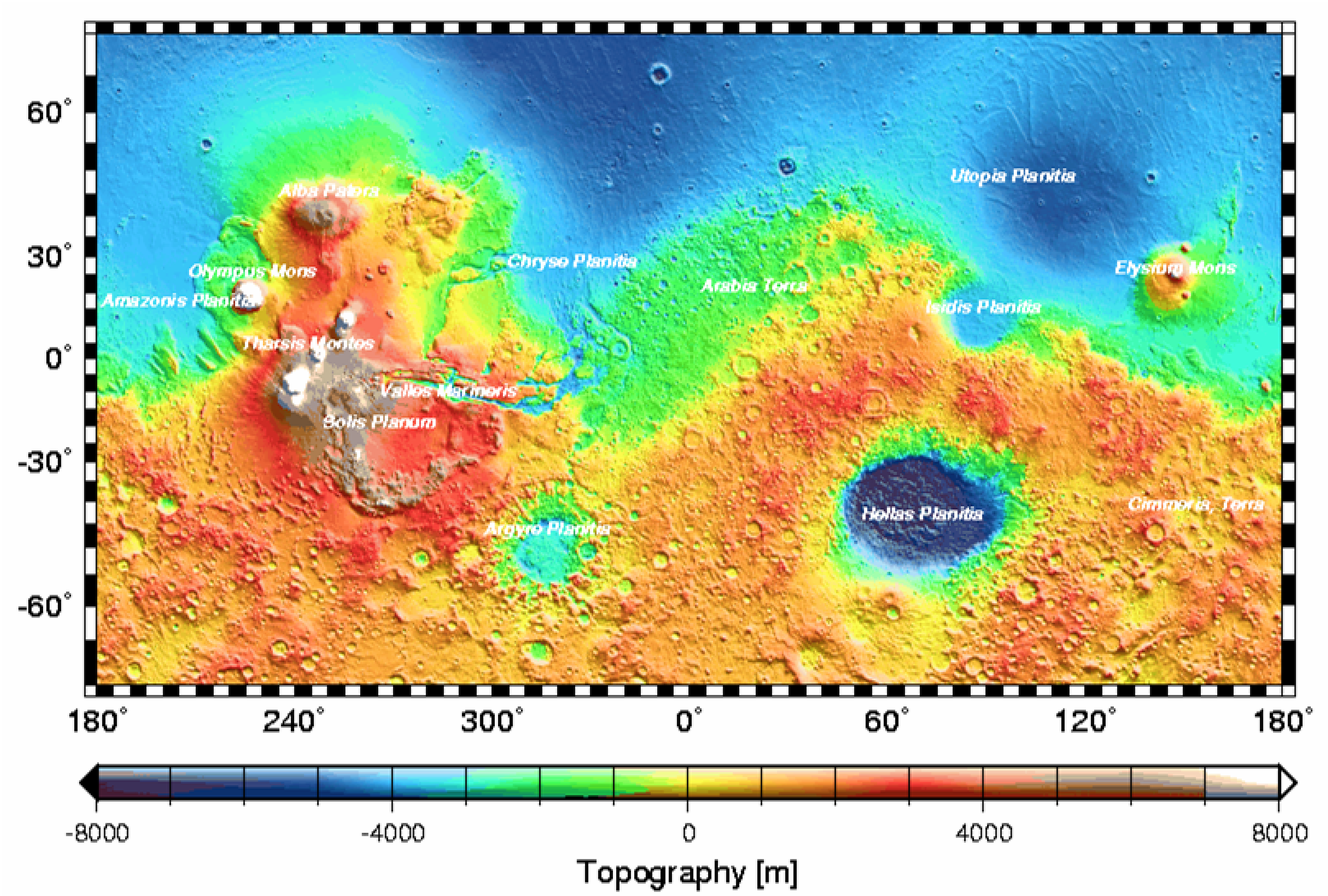

Mid-May 2008
July 15, 2008
Early September 2008
Focus on fixed crew-size “toehold” on Mars as alternative to exploration program
Focus on expansion of “toehold” to mostly self-sustained colony
Project Definition
In-Space Transportation (lead: Arthur)
Surface Infrastructure (lead: Arthur)
Surface Operations (lead: Arthur)
Surface Power & Thermal (lead: Chase)
Outpost re-supply (lead: Wilfried)
Finance and costing (lead: ?)
Integration of results (lead: Wilfried)
Expansion analysis
Follow-on projects

Operational Architecture

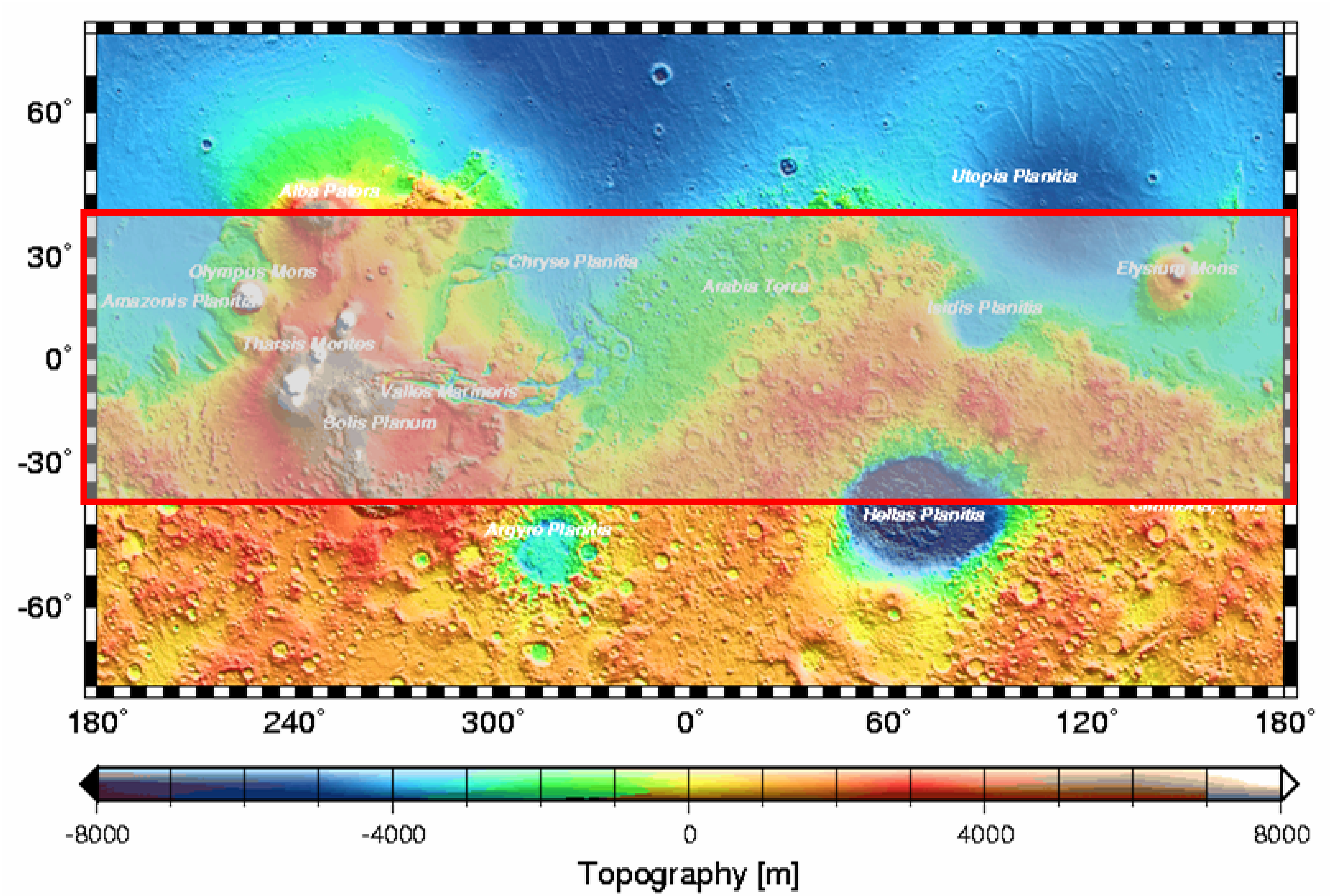


- The overall operational architecture for the initial toehold is based on one-way flights delivering cargo and crew to the Martian surface
  - Potentially with an emergency return capability
- Mars capture is assumed to be accomplished by aerocapture
- Subsequent lifting entry and propulsive descent are used to deliver payloads to the single surface outpost site
  - Outpost location is subject to a variety of factors (insolation, water, elevation)
- The exact size and payload capability of each lander depends on the Earth departure architecture and entry body chosen

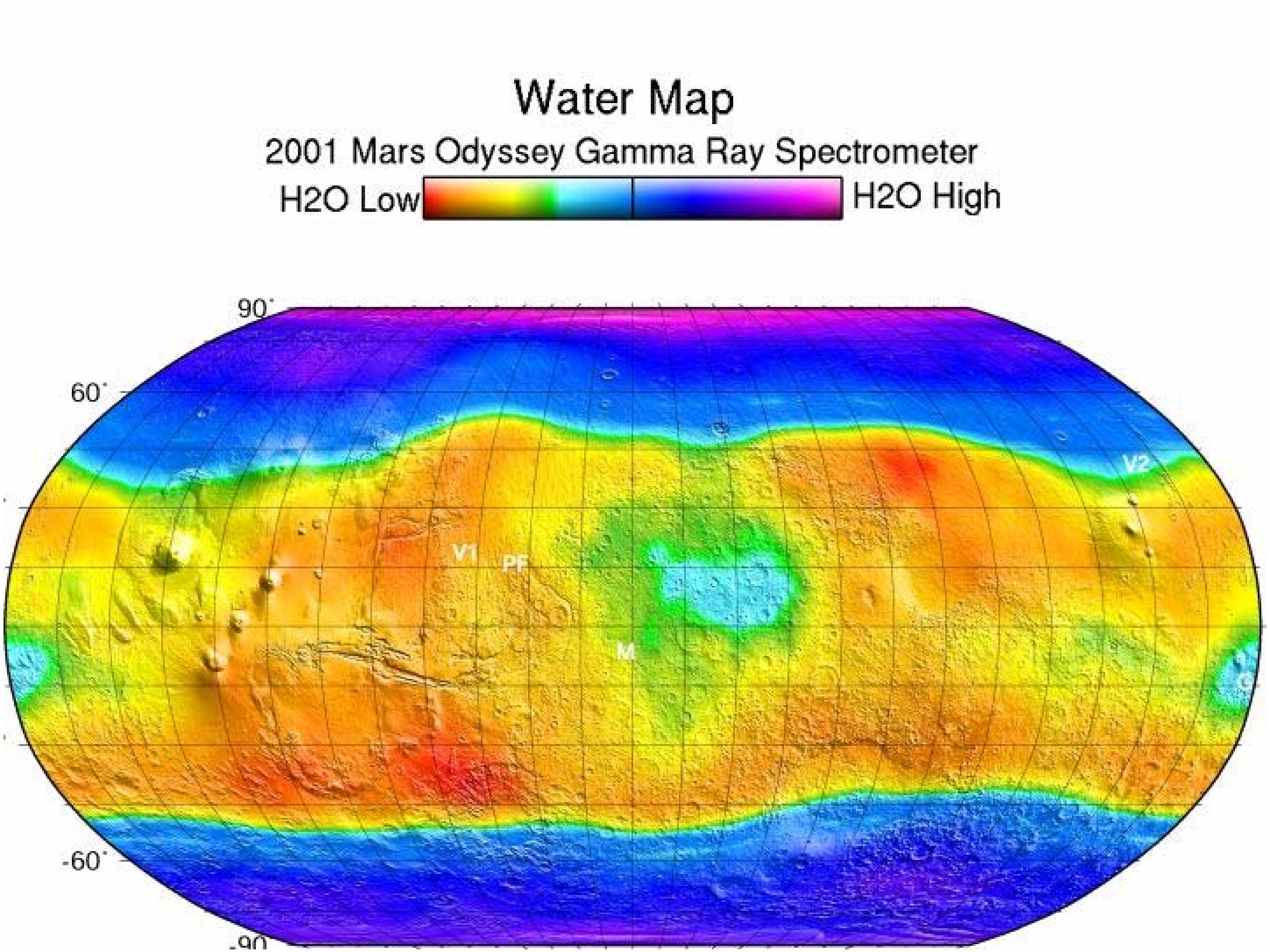
Toehold Location: Topography



Toehold Location: Solar Power



Toehold Location: Water



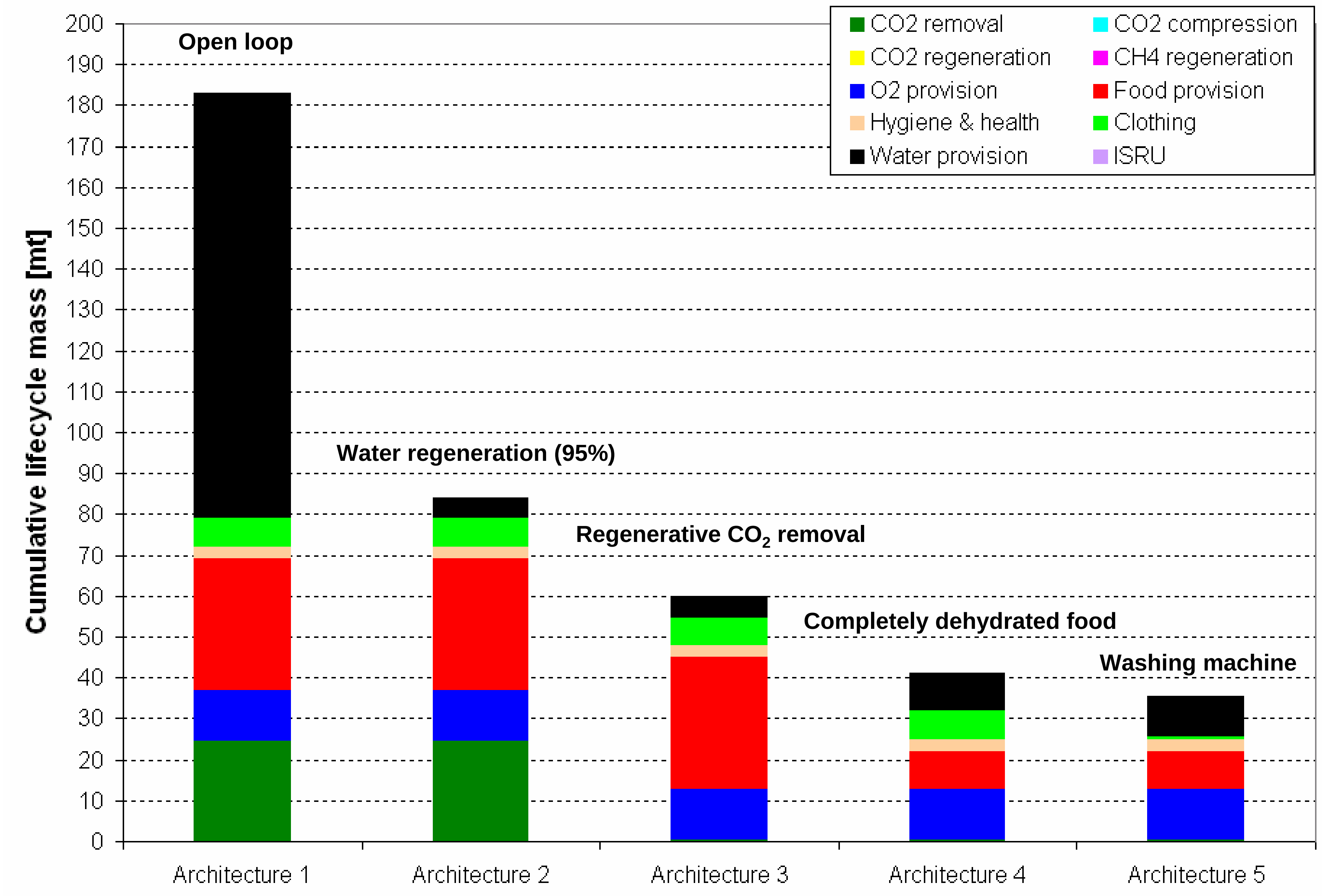
Life Support, Crew Systems, ISRU

Logistics Assessment - Update

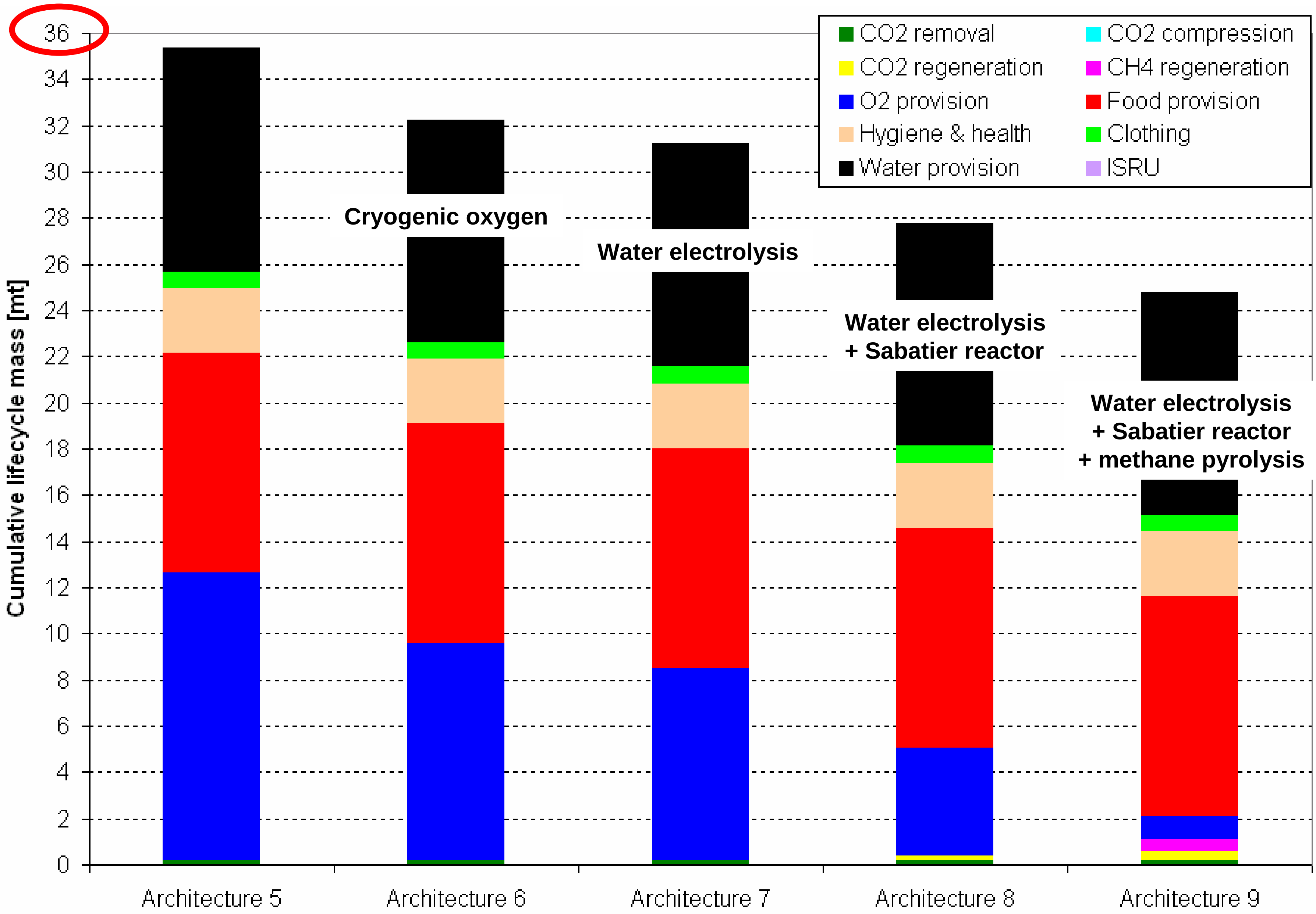
General Study Objectives

- Carry out an assessment of re-supply needs for the outpost given different technologies
  – Including high-closure life support, ISRU
- Identify key re-supply drivers and carry out in-depth analyses
- Identify interesting technologies with high payoff in re-supply mass reduction
  – Carry out initial modeling and testing of these technologies
- Formulate plan for further technology development

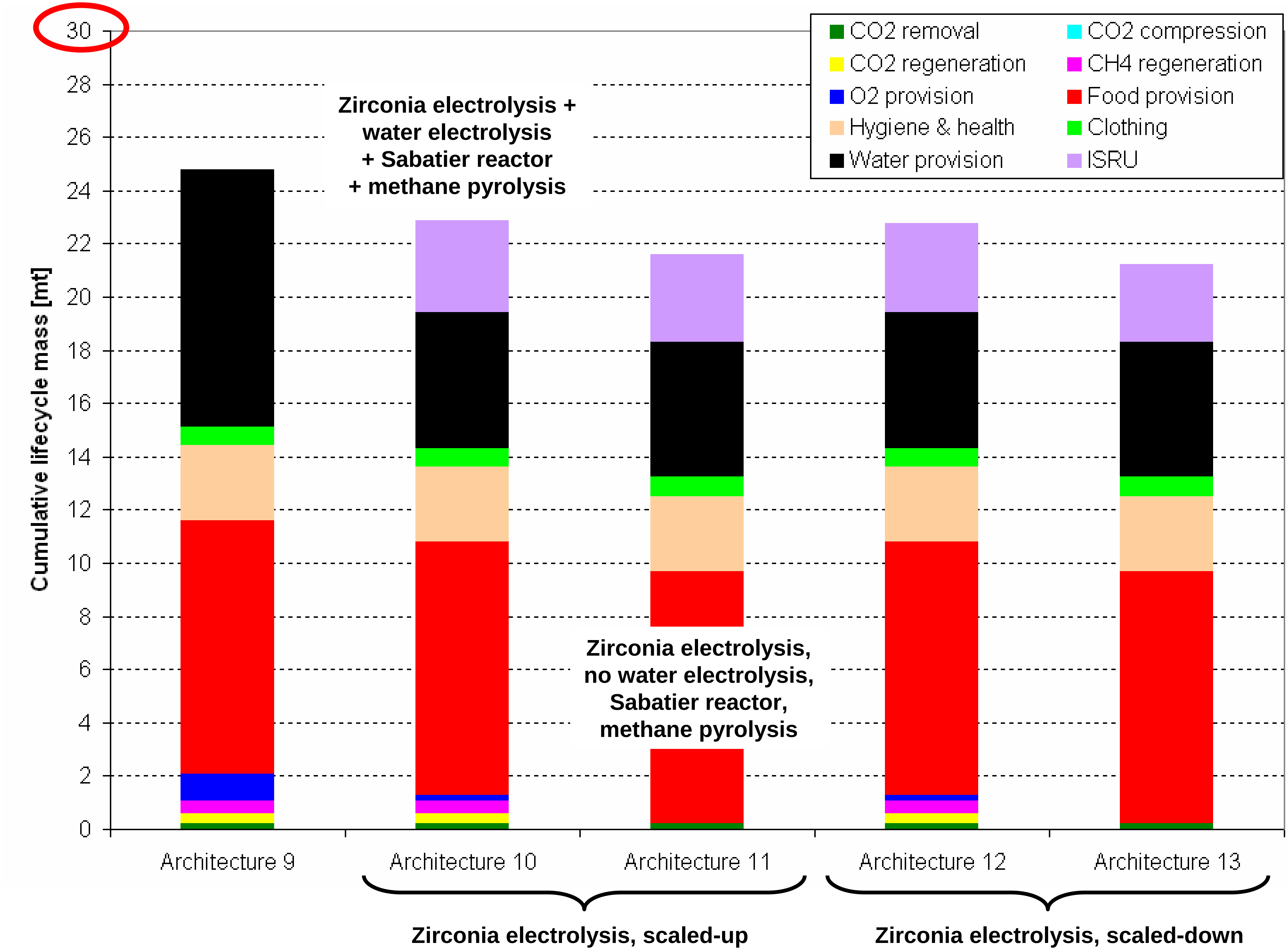
Mars Surface Habitat Architectures 1-5



Mars Surface Habitat Architectures 5-9



Mars Surface Habitat Architectures 9-13



Preliminary Insights

- Existing technologies allow for re-supply masses per opportunity of ~2 mt / person
  - This includes fairly conservative tare fractions on pressurized logistics and fluid re-supply
- Remaining high-mass re-supply items are:
  - Food
  - Spare parts (fans, multi-filtration beds, etc.)
  - Hygiene & health re-supply (soap, first-aid, etc.)
  - Hydrogen for ISRU

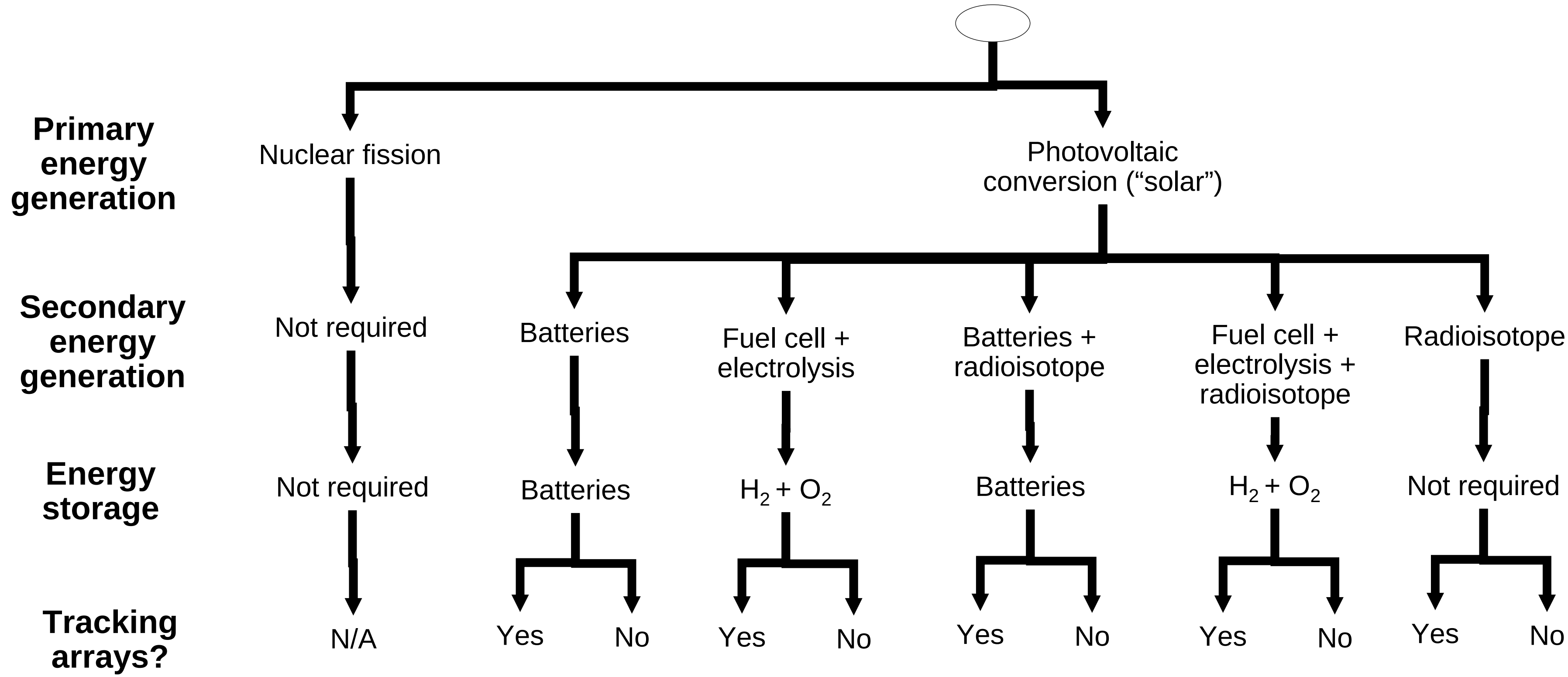
Food Logistics Reduction

- Many options for closure of the food loop have been investigated over the decades
- Two major families of options:
  - 1. Chemical regeneration of food from waste
    - Synthesized chemicals suitable for long-term ingestion include: glucose, glycerin, ethanol, formose sugars
  - 2. Biological regeneration of food from waste
    - Algae (also for CO_2 regeneration)
    - Higher plants (wheat, corn, vegetables, etc.)
    - Animals (fish, chicken)

Mars Surface Power Generation and Energy Storage

Power Update

Surface Power Architecture Tree



- There are two basic types of analyses that can be carried out:
  - Equal power analysis: all systems provide the same (constant) power output at any point in time
  - Equal energy analysis: all systems provide the same usable energy per day (for photovoltaic systems this means increased power generation during the day)

Modeling

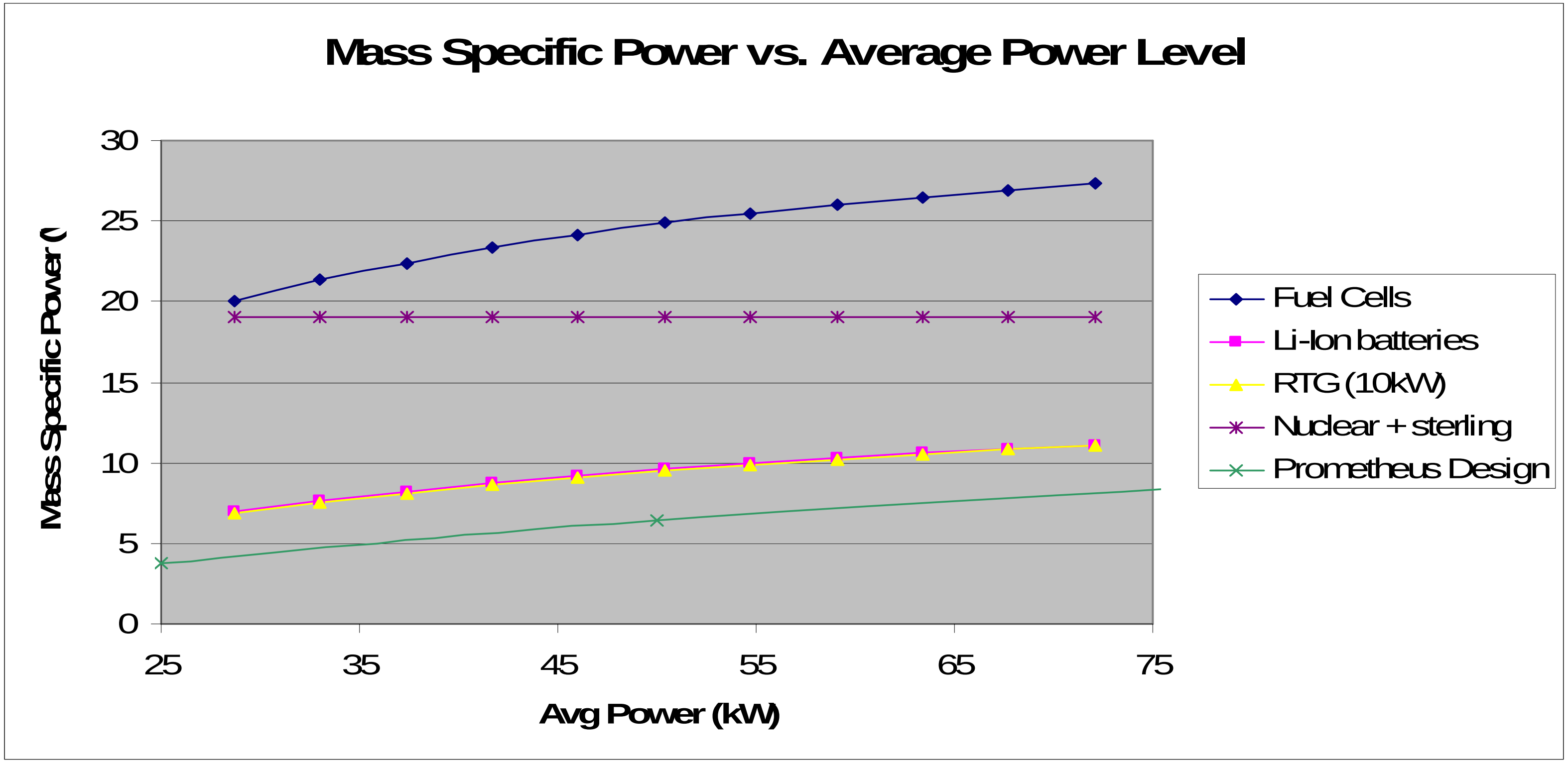
- Created model for a Mars solar array based on following major requirements:
  - Array must be sized for end-of-life power generation capabilities
  - Array must be sized to provide the required power during the year's minimum incident solar energy period

- Model Assumptions:
  - Optical depth of 0.4 and secondary power source as backup for less ideal atmospheric conditions
  - Degradation per year only from radiation due to a dust protection/removal mechanism (dust protection/removal system needs development)

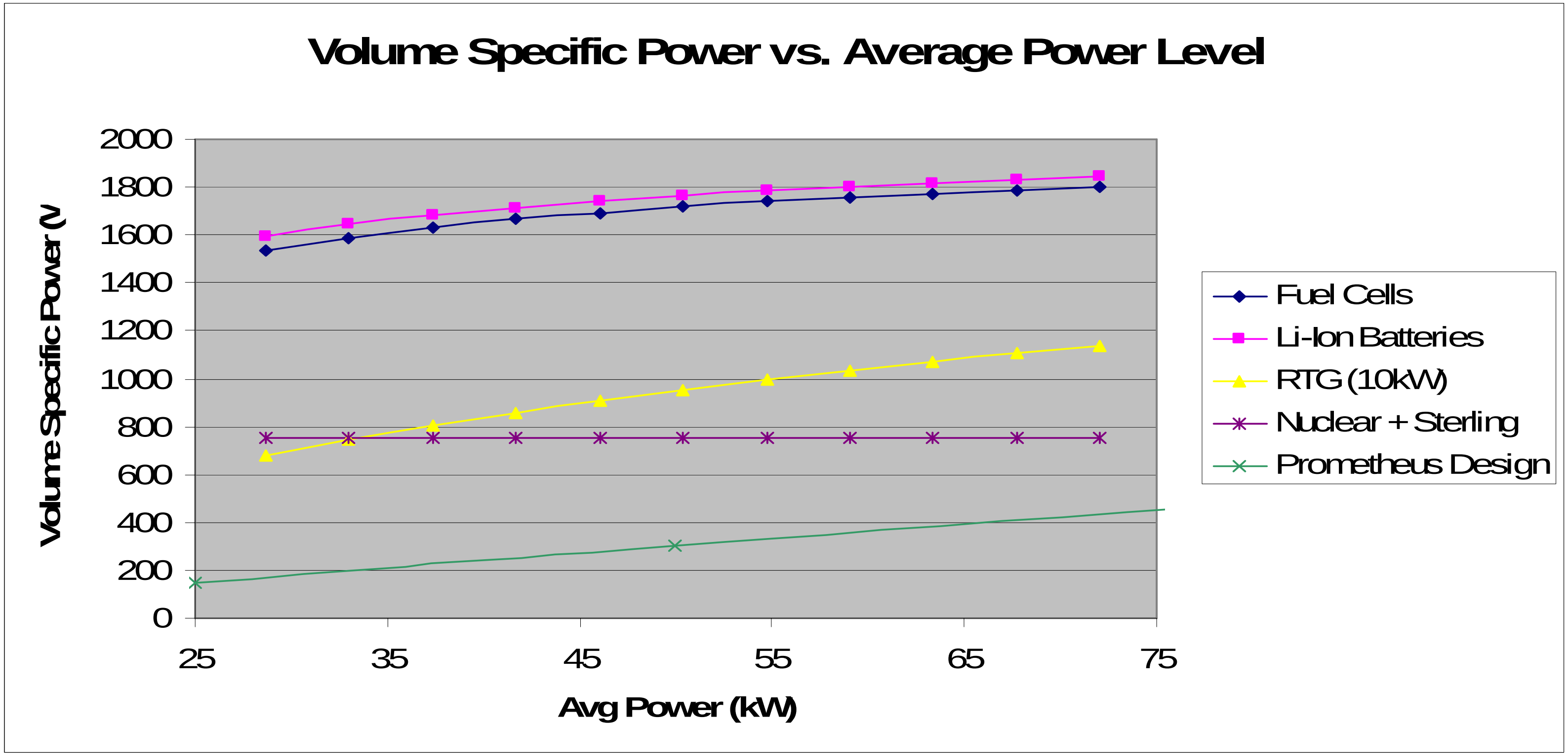
Model Inputs and Outputs

- Inputs:
  - Minimum solar energy
  - Eclipse Time
  - Daytime/nighttime power req.
  - Power distribution eff.
  - Solar array eff.
  - Degradation per year
  - Array lifetime
  - Optical depth
  - Latitude
  - Array packing density
- Outputs:
  - Array area
  - System mass
  - System volume

Initial Results



Initial Results Cont.



Future Work

- Reassess architecture options in MinMars colony context. Previous power analysis for shorter round trip mission.
- Analysis and development of deployment techniques for large surface arrays.
- Operations considerations such as dust removal and maintenance.
- Dust storm power generation.
- Investigate more architecture options such as solar-thermal.

Mars Wish List

Transportation

- Automated Mars landing and hazard avoidance navigation systems
- Mars in-situ propellant production friendly rocket combustion / performance characterization (C_2H_4/LOX; CH_4/LOX); more important if people want to come back
- Large-scale (20mt+) Mars aero-entry (and EDL more generally) technology
- Low mass, cost, power and ideally autonomous deep-space (out to at least ~2 AU) navigation systems (software, hardware)

Power

- Automated, large scale (football field+) solar array transport, surface deployment, and maintenance systems
- High energy density electrical power storages systems (aiming in particular towards high energy density relative to Earth imported mass)
- Mars surface internal combustion engines (LOX, plus various fuels, e.g., C2H4, CH4, CO, etc), possibly with water exhaust reclamation.

Life Support, Logistics, ISRU

- Mars atmosphere collection systems (at minimum CO_2; adding N_2 and Ar is useful; H_2O depends on energy/mass intensity relative to other options)
- Mars permafrost mining systems (for varying wt% H_2O); note, this is much easier than mining putative lunar ice
- Good, high capacity Mars surface cryocoolers (options for just soft/medium cryogens (e.g., LOX, CH_4, C_2H_4), or also for hard cryogen (LH_2))
- Earth-Mars hydrogen transport systems (not necessarily as LH_2)
- Basic ISRU chemical processing systems (e.g., H_2O electrolysis, Sabatier, RWGS, CO_2 electrolysis, ethylene production, etc.)
- High closure physical-chemical life support systems (e.g., air revitalization, water recycling)
- "Food system" for food supplied from Earth. Consider being able to survive on food shipped 5 years ago.
- Mars surface food production systems
- Simple in-situ manufacturing systems (e.g., for spare parts)
- Simple raw materials production (e.g., plastics such polyethylene, epoxies, ceramics, etc.)

Outpost Ops and Surface Exploration

- Mars surface communication and navigation systems (e.g., for rovers), sans extensive satellite constellation
- Very high data rate Mars-Earth back-haul comm system
- Good Mars surface EVA suits
- Data collection, analysis in support of landing site / outpost location selection
- Very long distance surface mobility systems (including with people)
- Solar flare / SPE warning systems

Notes on ISRU (Alar)

Notes on SVN