OWWG Science Questions and Associated Objectives:

1. What are the conditions that lead to the formation of ocean worlds?
    - Investigate the composition of the primordial material that formed Ocean Worlds.
        - Identify the reservoirs of material from which Ocean Worlds formed
        - Constrain the phase, chemical, and isotopic composition of the building blocks of Ocean Worlds (organic matter, inorganic rocky materials, ices)
    - Understand how ocean worlds form within, and external-to, circumplanetary systems.
        - Determine the processes by which ocean worlds form within a circumplanetary system, identify which processes have occurred in each circumplanetary system, and constrain formation timescales.
        - Determine how dwarf planets form and constrain their formation timescales.
        - Assess the conditions that drive ocean worlds to differentiate, the mechanisms by which differentiation occurs, the consequences of differentiation for interior structure and composition, and the corresponding timescales.
    - Constrain the orbital evolution of Ocean Worlds.
        - Determine the current dynamical state of planet-satellite systems, including current dynamical interactions between objects within each system.
        - Identify possible past resonant and non-resonant interactions between bodies within each system and constrain the probability that such interactions occurred.
        - Identify and quantify processes capable of transporting dwarf planets from their region of origin to other parts of the solar system, including capture by larger bodies.
        - Assess whether possible past resonances or capture events had the potential to dissipate energy within Ocean Worlds.
    - Identify the sources and magnitude of heating within Ocean Worlds, and how energy is transported through them.
        - Measure the current surface heat flow of Ocean Worlds.
        - Constrain the heat flow from the rocky interior of Ocean Worlds.
        - Determine how and where tidal dissipation occurs on Ocean Worlds.
        - Determine when, where, and how energy is transferred through Ocean Worlds.
    - Investigate the surfaces of Ocean Worlds and constrain their geologic history.
        - Identify and assess the internal and external processes that generate stress within ice shells, drive tectonic deformation, and produce surface topography on Ocean Worlds.
        - Investigate exogenic processes, including impact cratering and space weathering, that have modified the surfaces of ocean worlds.
        - Evaluate whether aqueous or cryovolcanic processes have modified the surfaces of ocean worlds.
        - Constrain the physical (e.g., mechanical, electromagnetic, optical) properties of the near surface and regolith, including mass wasting processes.
    - Determine the composition of the non-ice materials on and within Ocean Worlds to study their origin and chemical evolution
        - Measure the composition and distribution of non-water ice materials (e.g., salts, organics, non-water ice) on the surface of ocean worlds.

    - Constrain the composition of the seafloor, including species indicative of water-rock interactions.

2. Where do water oceans exist in the interiors of outer solar system bodies?
   - Reveal interior structures of icy worlds
     - Determine the thickness and composition of the outer ice layer
     - Determine the spatial extent of any liquid water reservoirs
     - Determine the structure, density, and composition of the deep interior and how those properties change with depth
   - Examine the surfaces of ocean worlds to identify features indicative of an extant subsurface ocean.
     - Search for the existence of warm features that are indicative of current geologic activity or near-surface liquids
     - Assess whether the composition and spatial distribution of non-ice material reveals the existence of a present-day ocean
     - Search for surface changes indicative of current geologic activity
     - Evaluate whether surface geology is indicative of extant subsurface liquid water reservoirs
   - Explore atmospheres, exospheres, tori of Ocean Worlds
     - Detect and explore plumes to determine whether they connect to subsurface liquid reservoirs
     - Investigate the sputtered atmosphere to understand the composition of the surface and links to an ocean.
     - Determine whether the exosphere of Ocean Worlds is indicative of an extant ocean.
     - Determine whether the tori associated with Ocean Worlds are indicative of an extant ocean.

3. Do ocean worlds have past or present environments conducive to life?
   - Constrain the chemical composition and corresponding properties of the ocean
     - Constrain the salinity of the ocean
     - Measure the pH of the ocean
     - Determine the chemical composition of the ocean (inorganic species, organic compounds, dissolved gases)
     - Estimate the redox state of the ocean and quantify redox disequilibria
   - Determine the physical properties of the ocean
     - Determine the temperature and density of the ocean as a function of depth and identify any lateral variations.
     - Characterize the ice-ocean and ocean-rock interfaces.
     - Constrain the ocean circulation.
     - Evaluate the long-term stability of the ocean.
   - Identify the sources and sinks in the ocean that can maintain chemical disequilibria.
     - Characterize how exogenic processes (e.g., radiation) create oxidants, reductants, or other biologically useful material (e.g., tholins, certain metals) on the surfaces of ocean worlds.

    - Identify where and how material is exchanged between the surface, ocean, and interior of ocean worlds.
    - Assess whether hydrothermal activity, volcanism, or tectonism occurs at the ocean seafloor.
  - Determine the occurrence and properties of near-surface, localized liquids within the ice shell.
    - Characterize the depth and geological context of near-surface liquids
    - Measure the composition and properties (pH, redox conditions) of near-surface liquids
    - Assess the temperature of the near-surface liquids
    - Constrain the salinity of the near-surface liquids

4. Is there evidence for present or past life in plume material, on the surface, or in the interior of ocean worlds?
  - Search for organic signatures of present or past life.
    - Measure the relative abundances of relatively simple organic species, including amino acids, carboxylic acids, sugars, and nucleobases/nucleotides.
    - Determine the level of complexity in organic molecules.
    - Measure the chirality of amino acids and sugars.
    - Measure carbon chain lengths and geometry of lipids
    - Search for biopolymers (proteins, carbohydrates, RNA, DNA, or information-containing polymers not present in terrestrial biology).
    - Search for organic molecules with metabolic function (i.e., ATP).
    - Search for pigments or fluorescence.
  - Search for inorganic signatures of present or past life.
    - Measure isotopic fractionation
    - Search for biominerals
    - Determine the elemental distribution (CHNOPS and trace elements)
    - Measure chemical disequilibria (redox pairs)
  - Search for morphologic signatures of present or past life.
    - Identify cell-like structures, biomineral structures, and biofabrics.
  - Search for active microbial life.
    - Assess cell motility.
    - Measure metabolic response to stimuli.
  - Explore and understand the abiotic background