Plasma-Based Sustainability Architecture for Space Habitation: *Perspective*

Kenneth Engeling, Deborah Essumang, and Ryan Gott

Kenneth.Engeling@nasa.gov, Deborah.Essumang@nasa.gov, ryan.p.gott@nasa.gov

NASA Kennedy Space Center, Applied Chemistry Laboratories

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Overview of Presentation

Perspective on plasma applications and technologies for sustainable presence off-planet

- **Focus on low temperature plasma applications**
  - **Life support systems, Space Crop Production, In-Situ Resource Utilization**
  - **Exception of thermal waste gasification**
- **Acknowledge electric propulsion and exploratory applications**
  - **In-depth discussion is outside scope of this talk**
- **Economically viable solutions for logistical needs**
  - **Cost of power supply mass-launch verses continuously resupply missions**
    - **Some resupplies needed for on-demand, point-of-use resource production via plasma**

Infrastructure and Sustainability

INCREASING INDEPENDENCE

1. **Path to living off-planet:**
   - Spacecraft
     - Small, short duration
     - Carry supplies for mission duration
       - Limited recycling or reuse
     - Small scale ECLSS support, chemically based
       - Efficient, economic but consumable
2. **Orbital stations**
   - Large, connected habitable capsules
   - Medium scale ECLSS support
     - Chemical, some consumables
     - Some near loop closure
   - Waste management considerations
   - Small scale space crop production
     - Mainly scientific studies
3.
4.



The Space Shuttle launching from Kennedy Space Center. Taken from nasa.gov.

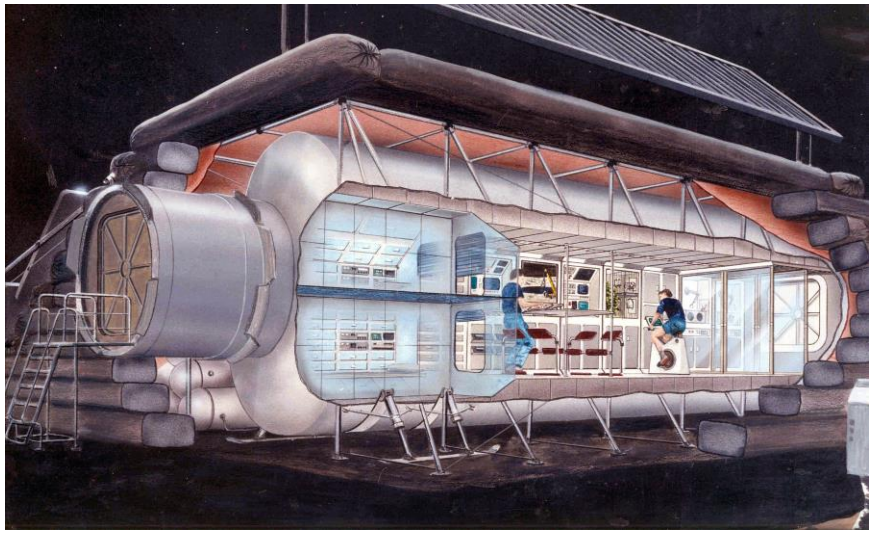


Image of the International Space Station. (ISS) Taken from nasa.gov.

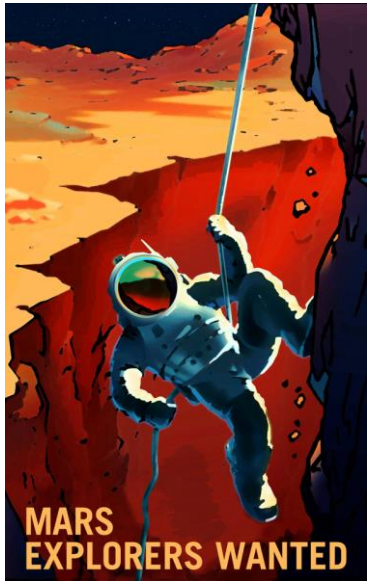
Removing Reliance on Earth

INCREASING INDEPENDENCE

1. 3. Planetary bases
   - Low-level dependence on Earth
   - Resupply logistics arrive with crew
     - Periods of dormancy
       - Decrease of system complexity or maintenance
2. 4. Colony developments
   - Near independence from Earth
     - Specialty goods (i.e. electronics, exotic metals, chemicals)
   - Complete crop production cycle
     - Nutritional and caloric needs
       - Selective crop cycle
3. - Water and air remediation
     - Chemical, scrubbing, passive (plants)
   - Waste handling and reutilization
     - Available resources
4.



Concept image from NASA Lunar Base Circa 1990. Taken from nasa.gov.





Advertisements within the Mars Exploration Program. Taken from nasa.gov.

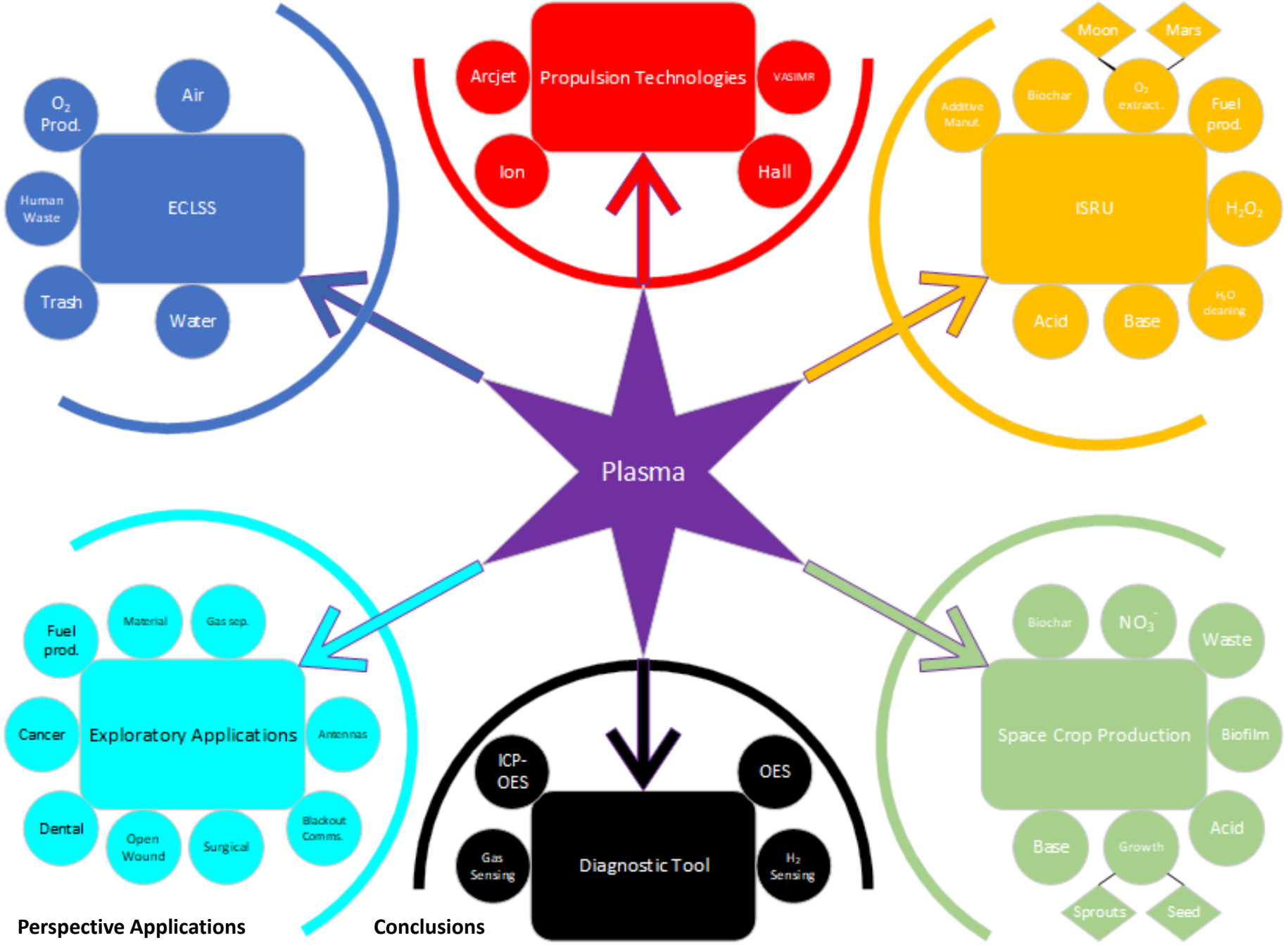
Novelties of Plasma

Plasma produces useful compounds

- Examples In liquids:
  - Acid production (Nitric acid)
    - pH control
  - Sanitizing agents
    - Hydrogen Peroxide
- Examples In gases:
  - Oxygen recovery from CO_2
  - Reactive Oxygen and Nitrogen Species
    - Ozone, NO_x
  - H^+ ion production
    - Readily reduces difficult compounds
    - Extraction of oxygen from regolith
  - Methane production

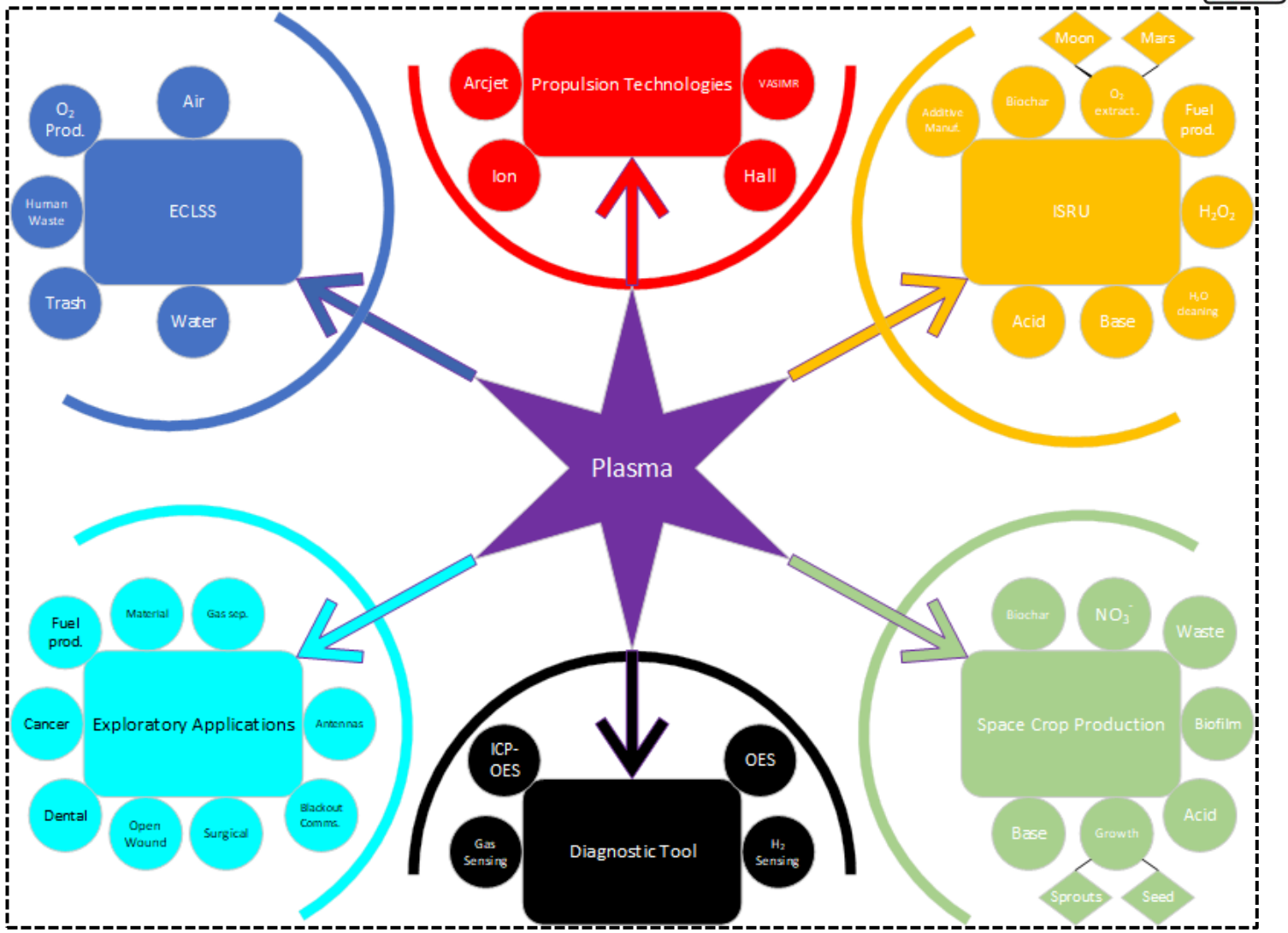
Plasma breaks down challenging compounds

- Examples In liquids:
  - Per- and polyfluoroalkyl substances (PFAS)
  - Methylene Blue Dye
  - 1,4 Dioxane
- Examples In gases:
  - Volatile Organic Compounds
    - Benzene, Pentane, Acetone, Ethanol
- Examples In solids:
  - Cellulose structures in inedible biomass
    - Accelerated composting
    - Build towards closed-loop agriculture


Propulsion Technologies
Arcjet
VASIMR
Ion
Hall
ECLSS
Air
O_2 Prod.
Human Waste
Trash
Water
ISRU
Moon
Mars
Additive Manuf.
Biochar
O_2 extract.
Fuel prod.
H_2O_2
Acid
Base
H_2O cleaning
Plasma
Exploratory Applications
Fuel prod.
Material
Gas sep.
Cancer
Antennas
Dental
Open Wound
Surgical
Blackout Comms.
Diagnostic Tool
ICP-OES
OES
Gas Sensing
H_2 Sensing
Space Crop Production
Biochar
NO_3^-
Waste
Biofilm
Acid
Base
Growth
Sprouts
Seed

A Common Tool for Crewed and Robotic Space

- **Versatile applications**
  - Low temperature plasmas
  - High temperature plasmas
  - Diagram highlights space applications
- **Simple commodities/consumables**
  - Electricity
  - Feedstock gas (occasional)
  - Electrodes
    - Minimal wear in most apps
    - Avoidable with RF plasma
- ***Assists in sustainable, crewed spaceflight and planetary habitation***

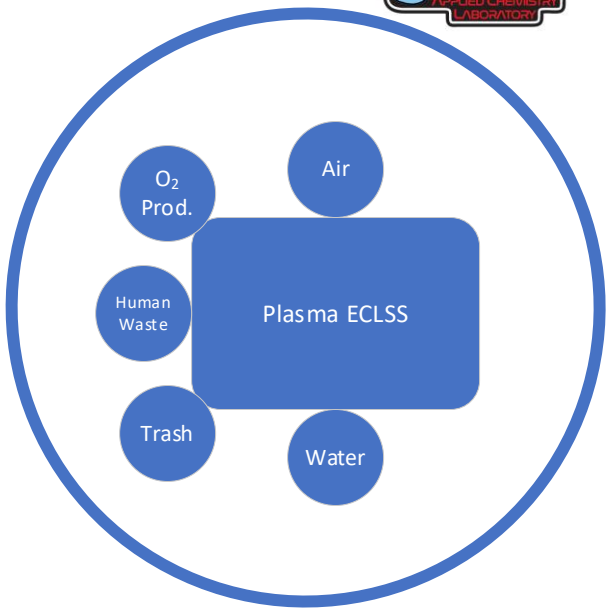


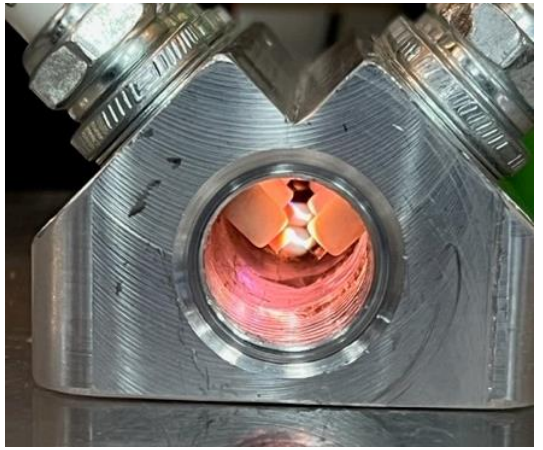
Life Support Systems Breakout

- **Water reclamation**
  - **Plasma treatment of water**
    - **Breakdown of PFAS, dioxane, dyes, medicines in water stream**
    - **Mitigates biohazards**
- **Air revitalization**
  - **VOC mitigation and abatement**
- **O_2 production**
  - **CO_2 splitting**
- **Human waste processing**
  - **Fecal – No current solution**
  - **Urine – Assists or alternative to Urine Processing Assembly (UPA)**
- **Trash**
  - **Waste gasification or pyrolysis**
    - **Different by-products per method**



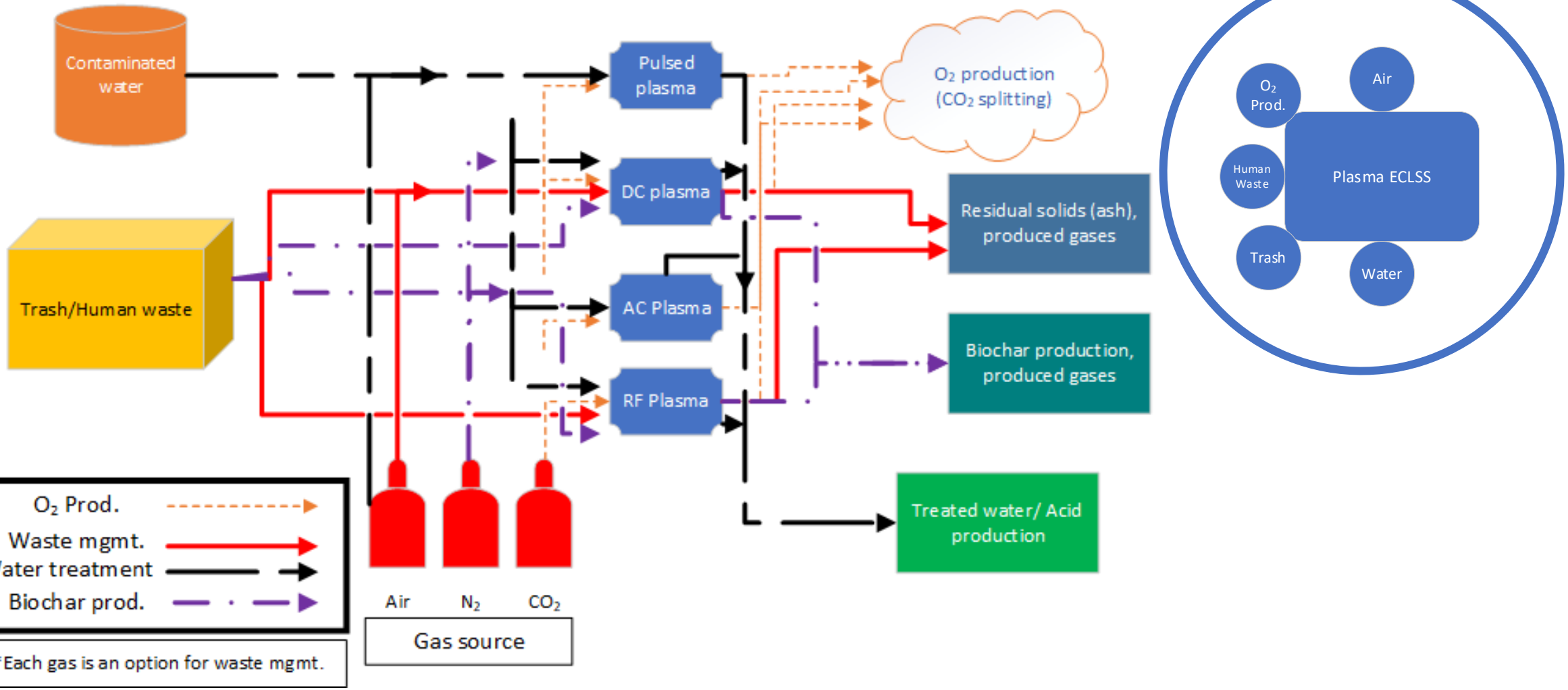
DC, Plasma 'V8' for VOC treatments.





DC, Plasma 'V8' for VOC treatments.

Environmental Controls and Life Support Systems

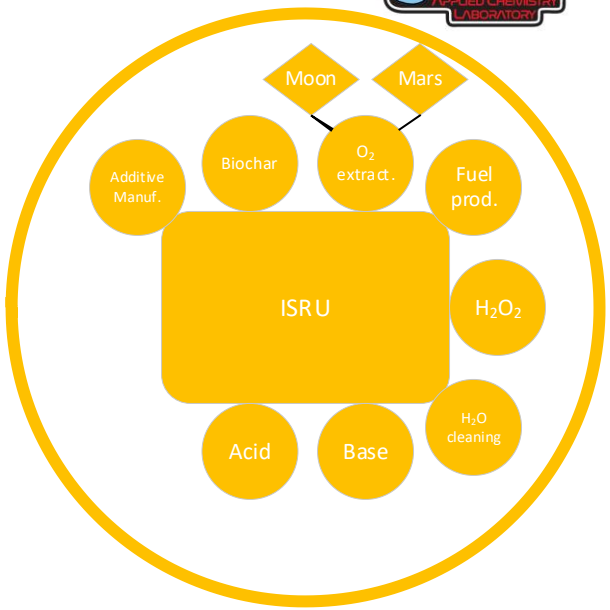


Production of Resources

- **Additive Manufacturing**
- **Biochar**
  - Carbon filters, graphite
- **O_2 production**
  - H_2 plasma reduction of lunar regolith
  - CO_2 splitting of Martian atmosphere
- **Fuel production**
  - O_2 or methane production
  - Plasma electrolysis of water for H_2/O_2
- **H_2O_2 – Hydrogen Peroxide production**
- **Acid-base production**
  - Observed pH changes from 2.7-11.5



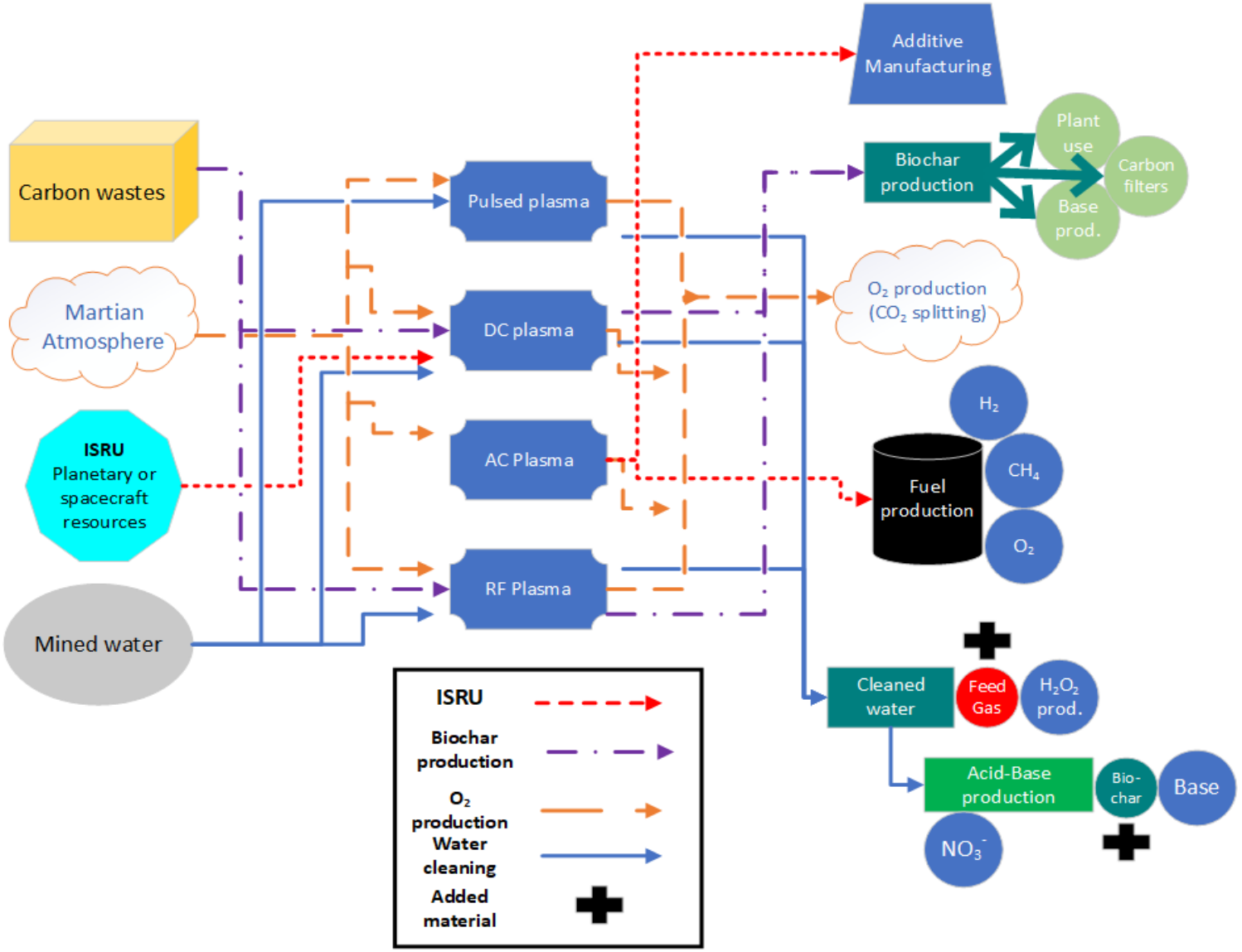
DC, nitrogen plasma torch in a quartz cell.

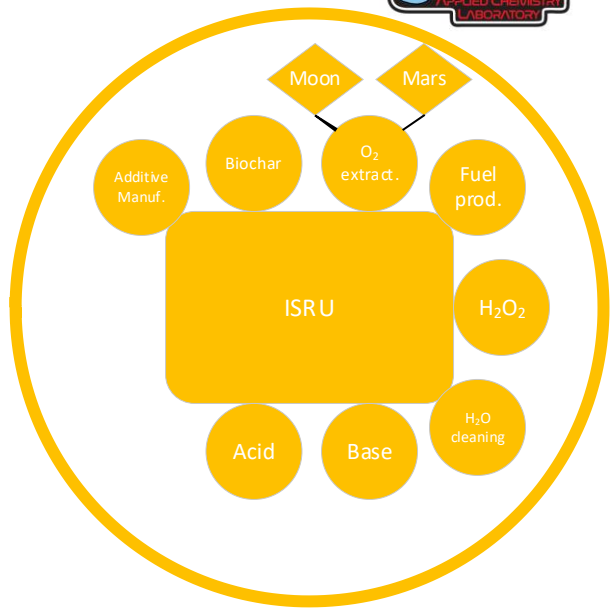




Inedible biomass pellet treated with nitrogen plasma torch.

Production of Resources



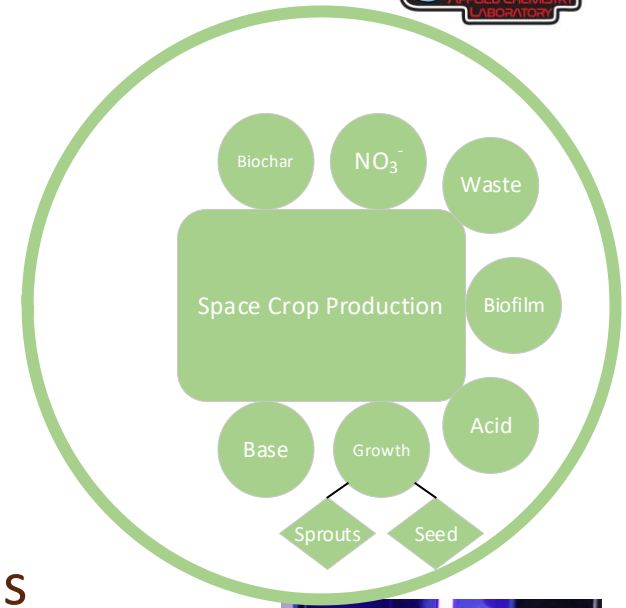


Space Crop Production

- Biochar
- NO_3^- for plant use
- Plant waste reutilization
- Biofilm sanitization
- Acids/Bases for hydroponic solution balancing
- Growth
  - Seed treatments
  - Sprout Treatments
    - Rhizomes
    - Venus Fly Traps

Soybeans

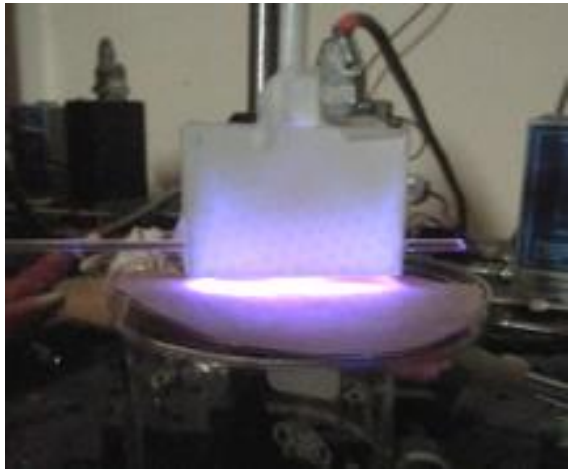


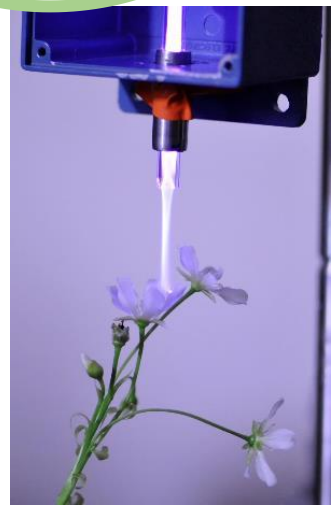


Rhizomes

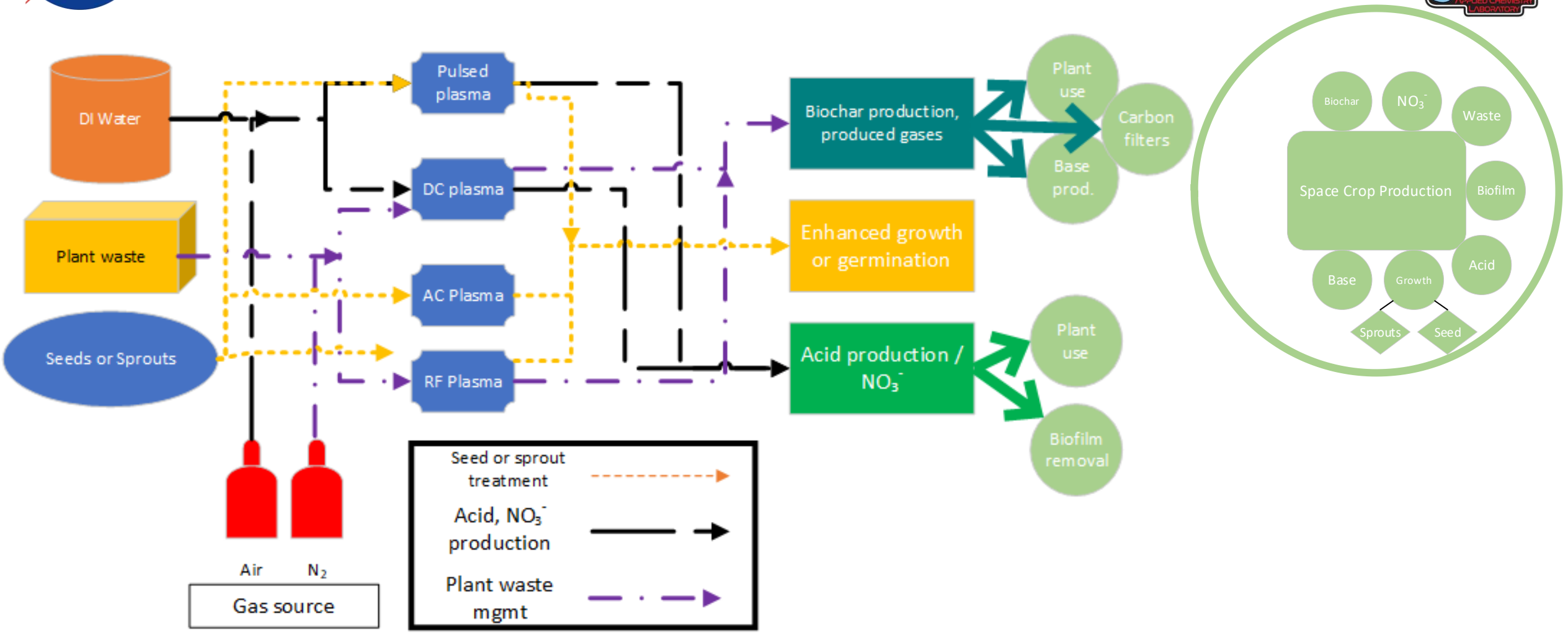


Seeds





Plasma Assisted Space Crop Production

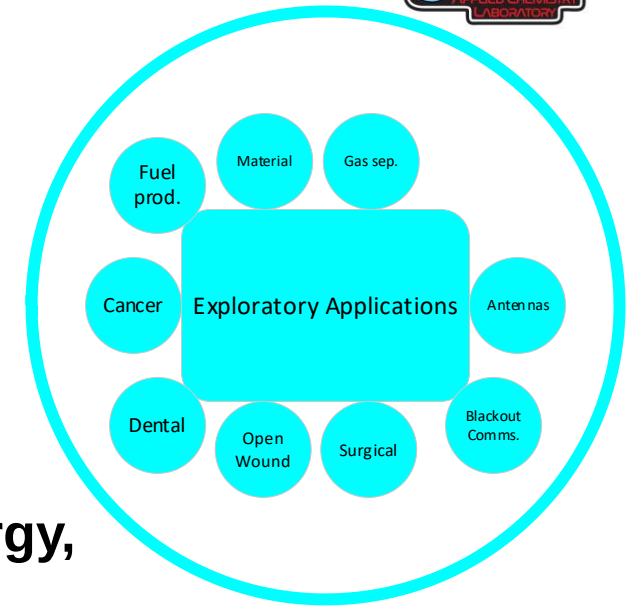


Exploratory Plasma

- **Plasma Medicine**
- **Tissue Sterilization**
- **Blood Coagulation**
- **Surgical**
  - **Increase wettability of grafts**
- **Dental**
- **Cancer**
- **Tissue Engineering**
- **Tissue Regeneration**
  - **Open wounds**

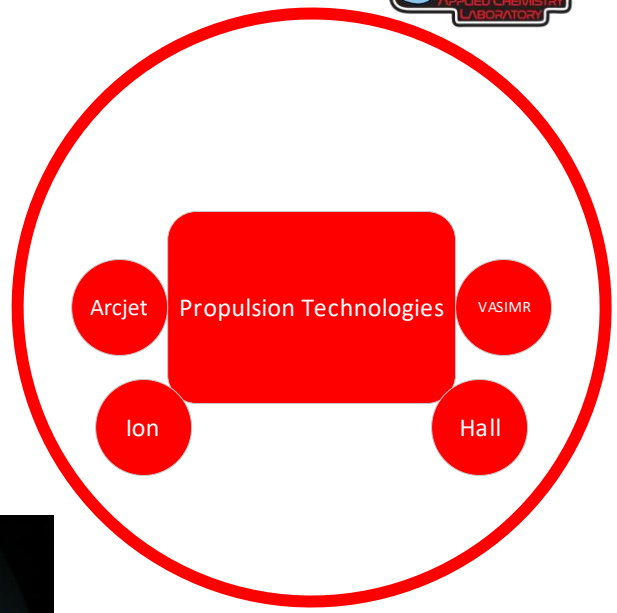
Other Applications

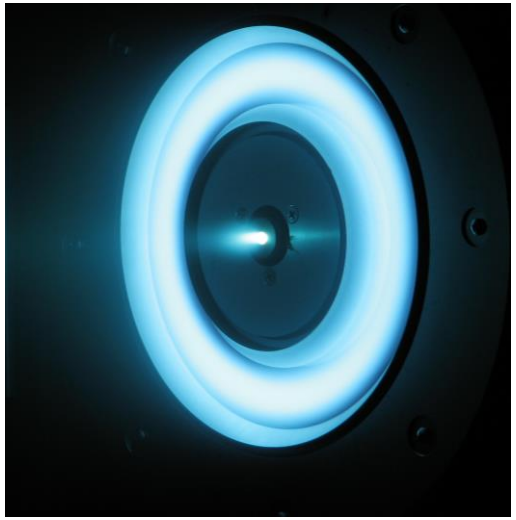
- **Blackout communications**
- **Antennas**
- **Gas separation**
- **Materials**
  - **Modifications: Surface energy, ion implantation**
  - **Construction**
- **Fuel Production**
  - **H_2, O_2, CH_4, etc.**



Electric Propulsion

- **Ion and Hall Thrusters**
  - Accelerate ions outward to produce thrust
  - Both use cathodes (plasma-based electron sources) to neutralize
  - High efficiency station keeping (NSTAR)
- **Arcjet**
  - Plasma heats and ionizes propellant
  - Can use hydrazine for satellite keeping (Aerojet MR510)
- **VASIMR**
  - Variable thrust/ISP using superconductors
  - Potential for rapid transport to Mars

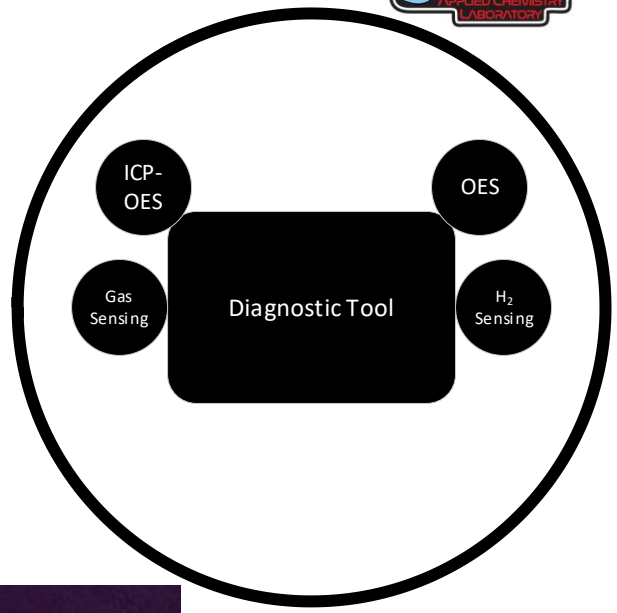


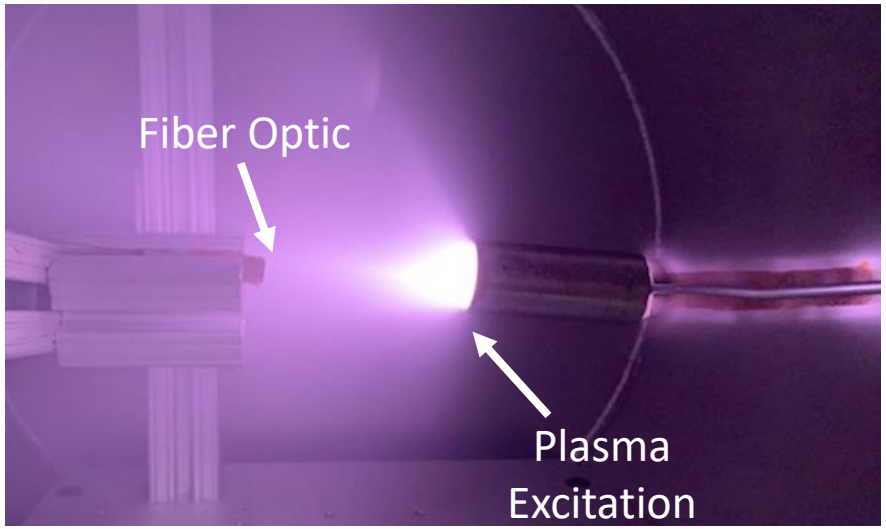


Taken from nasa.gov

Plasma as a Diagnostic Tool

- **General gas sensing**
  - **Atmospheric monitoring**
- **Inductively-coupled plasma optical emission spectroscopy**
  - **Identification of unknown substances**
  - **Plasma breaks down and excites materials to identify components**
- **Optical emission spectroscopy**
  - **Identification of unknown substances**
  - **Plasma excites gases to identify species**
- **Hydrogen gas sensing**
  - **Plasma excitation**
  - **Detection of small quantities**

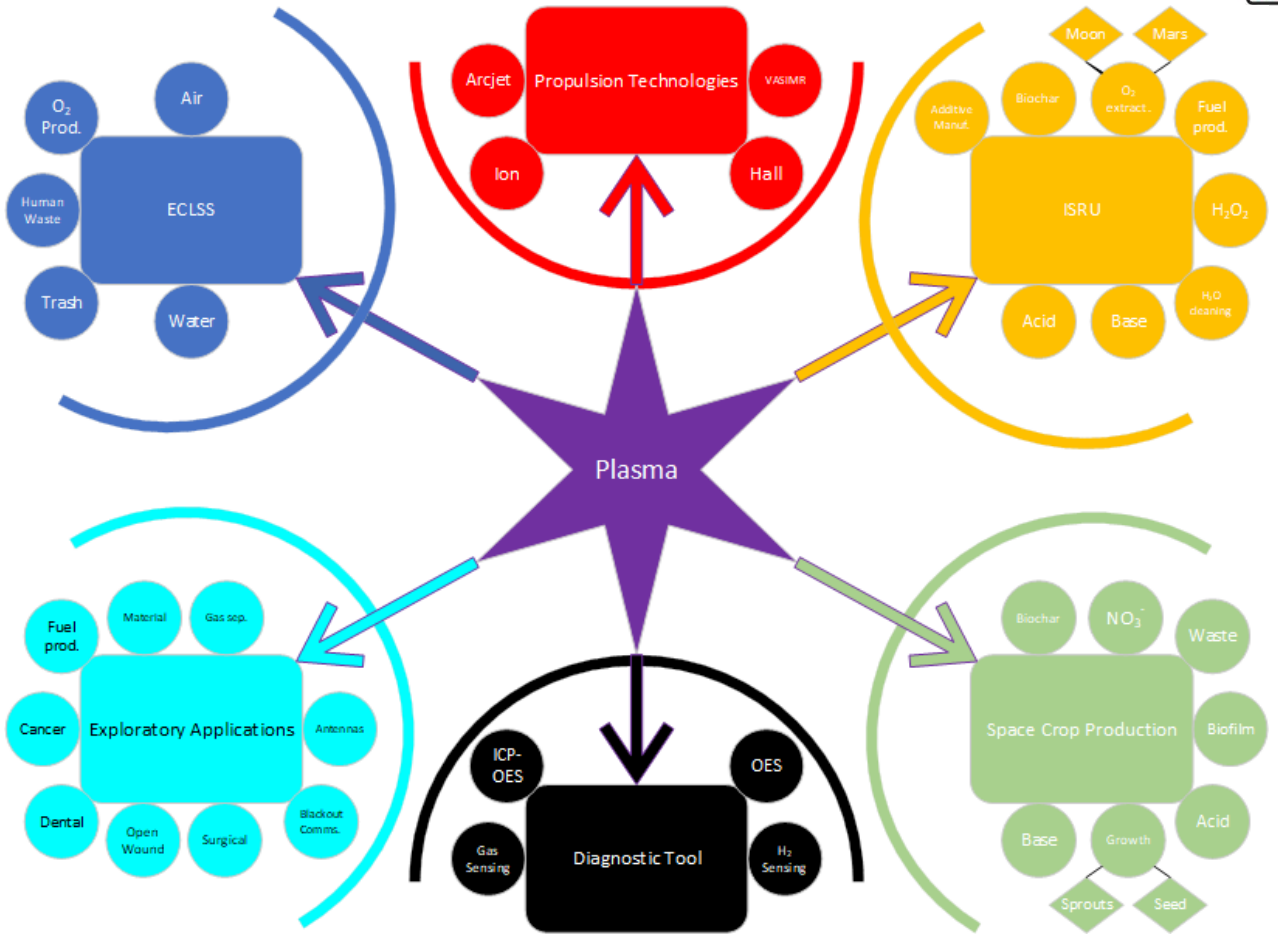




DC, hydrogen plasma glow discharge in a vacuum chamber.

Economics of Logistical Impacts

- Trash management
- Human waste management
- Production of resources
- Reduction of resupply
- Versatility of a single system



Current Capabilities Under Investigation at NASA's Kennedy Space Center



Space Crop Production

- Enabling of crop nutrient production
- Further close the space crop loop
- Nitrogen fixation (Mars*)
- Nutrient recovery of inedible biomass
- Hydroponic pH stability

Water Processing

- Treatment of contaminants in water
- Oxidative reactions
- pH stability
- Breakdown of chemicals
- Conductivity control

Logistics Reduction

- Fertilizer resupply reduction
- Acid-base production
- Soap for sanitation
- Mitigation of inedible biomass waste handling

In-Space Manufacturing

- Acid-base production
- Ash generation for potential additives

ISRU

- NO_3 in-situ on Mars
- Oxygen extraction from regolith
- On-Demand, point-of-use fuel production
- Electricity and air as consumables

Questions?

NASA Space Technology Graduate Research Opportunities (NSTGRO) Now open (Due Nov. 1st)

Master's & Ph.D. Students Applicable

$84k per year, Visiting Technologist Experience @ NASA Centers