National Aeronautics and Space Administration

POWER GENERATION FROM HYDROTHERMAL VENT ENERGY FOR ROBOTIC AND IN SITU SENSING OPERATIONS

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Program: Innovative Spontaneous Concept

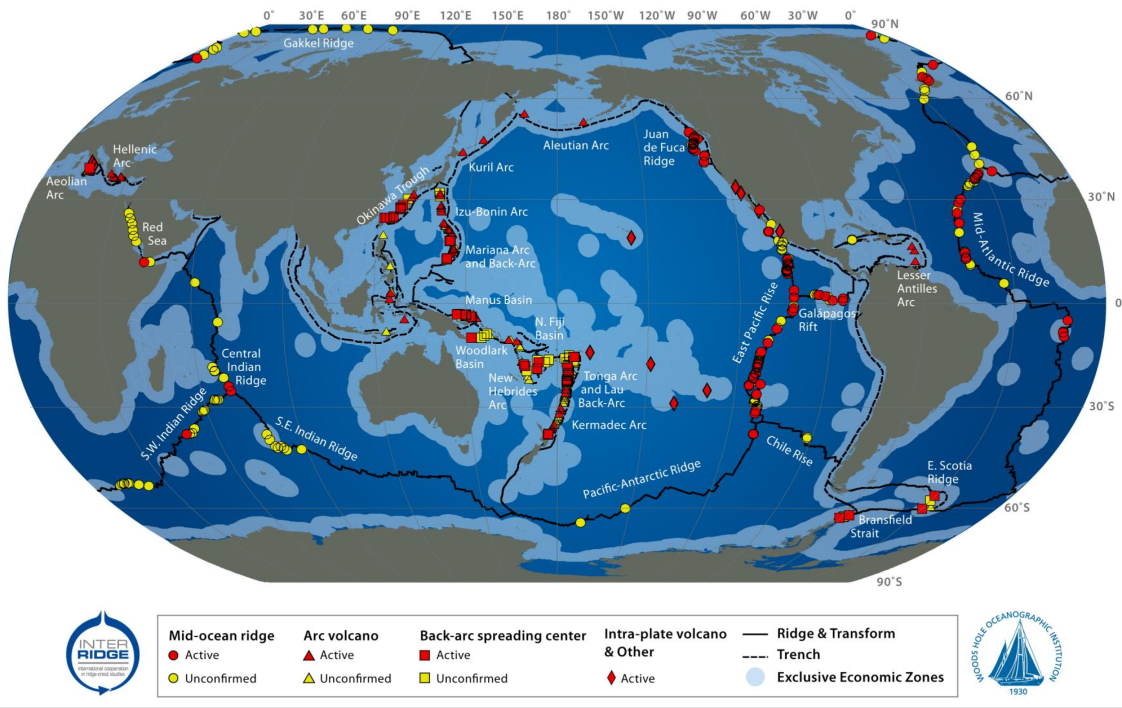
Science Objectives:

- **Define and design key components of a thermoelectric (TE)/energy storage-based power system to enable hydrothermal vent science on Earth**
- **Lay the foundations for hydrothermal vent exploration on Icy Moons and Ocean Worlds on moons of Jupiter, Saturn, and beyond**
- **Develop and understand extreme life Earth analogs crucial for Astrobiology investigations in hydrothermal vent systems around the Solar System**

Specific Design Objectives:

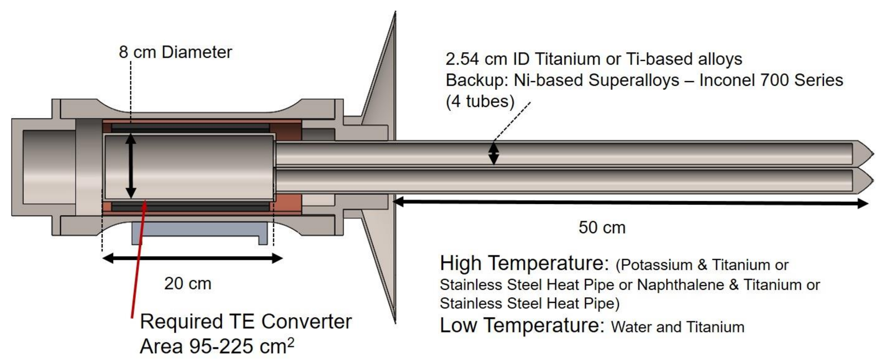
- **Investigate / design / characterize performance of a high-temperature integrated TE power generation/energy storage system for hydrothermal vent environments**
- **Predict performance under various TE generator/energy storage power system placement scenarios and operational concepts**
- **Establish and prioritize hydrothermal vent science enabled by such a power system**

Global Distribution of Hydrothermal Vent Fields



FY19 Results:

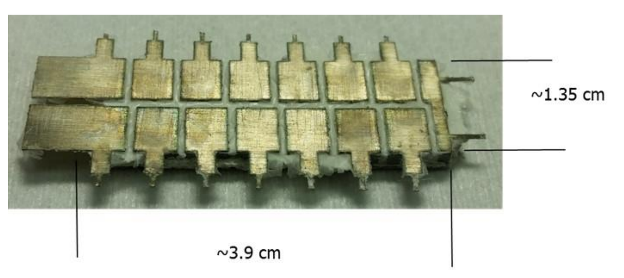
- **Developed high-temperature, high-pressure ocean hydrothermal vent power systems (HVD TPS) design as part of our earth science and ocean worlds thrusts**
- **HVD TPS can enable long-term AUV communications**, ocean seismometry, tsunami early warning, volcanism, ocean science (seafloor, sediments), oil detection
- **Power station for AUV (Autonomous Underwater Vehicle) charging**
  - Continuous ~75 W_e
  - Incorporates integrated energy storage to enable rapid recharge of underwater assets



Heat Pipes and Thermoelectric Power Converter

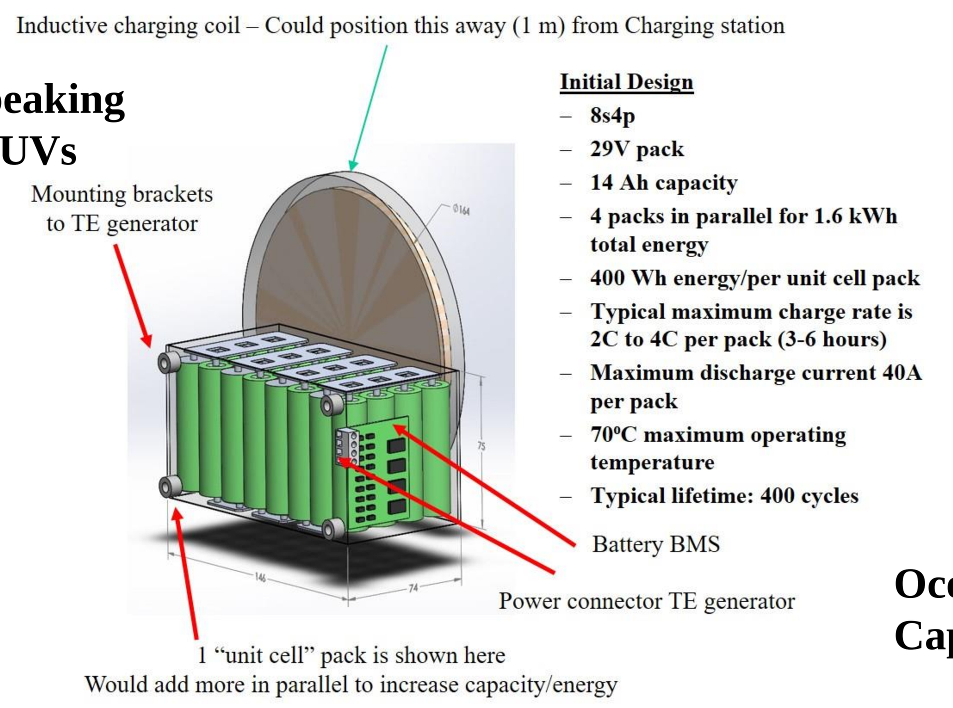
Hydrothermal Vent Example

Credit: https://oceanservice.noaa.gov/facts/vents.html

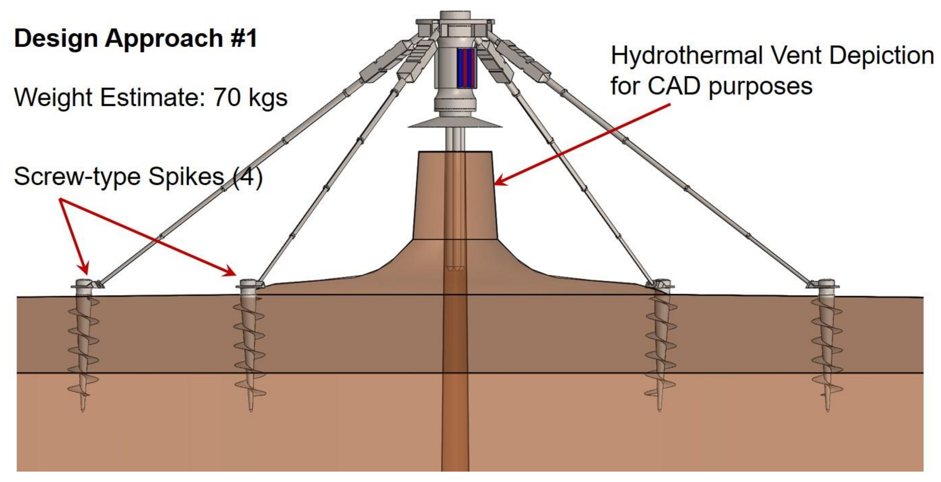


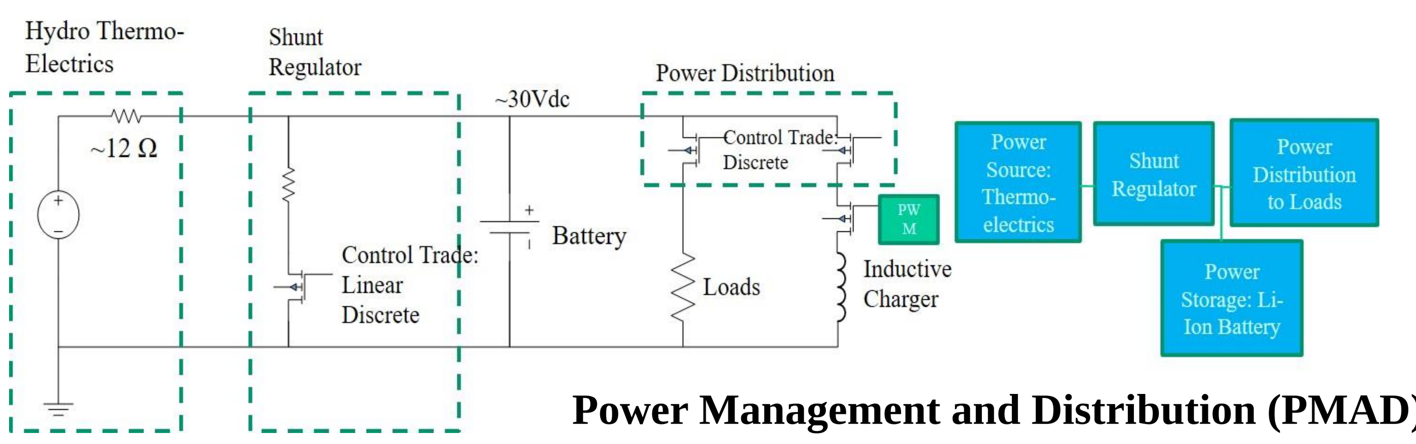
JPL's High-Performance Skutterudite Thermoelectric Module Technology and Design Creating the Electrical Power in the HVD TPS

Energy storage for power peaking and rapid recharge of AUVs



Anchoring Technique for HVD TPS Ocean Floor Attachment and Stabilization





Power Management and Distribution (PMAD) System Enabling HVD TPS Power Delivery, Control, and Safety

Ocean-Floor-to-Surface Communication Modem Capability

- 6000 meter depth rating
- Power required: 20W maximum in transmission, 600 mW in receiving, and 10 mW idle

Benefits to NASA and JPL:

- **HVD TPS technology enables long-term stable-station monitoring of hydrothermal vents on Earth**
  - **Crucial for Astrobiology investigations in hydrothermal vent systems, e.g. to understand ocean world analogs and extreme life**
- **Continuous long-term monitoring is necessary to understand how they function and evolve over time**
- **Continuous, long-term monitoring of vents is extremely challenging. Only two sites in the world implementing long-term monitoring solutions:**
  - **Ocean Observatories Institute Cabled Array in the Pacific (~2km depth, uses a >200km underwater power cable from shore to vent instruments)**
  - **National Institute of Geophysics and Volcanology (INGV) near Palermo, uses solar powered cables for instruments monitoring seismically active shallow vent region**
- **HVD TPS can continuously power suite of most vent science instruments, except mass spectrometer, in long-term stable-station studies of vents worldwide**
  - **Provides crucial data for oceanography, astrobiology, monitoring of temperature / chemistry changes to detect volcanoes / earthquakes, & current / vent flow dynamics**
- **Provides a recharging capability for extended-range ROVs operating far from shore at operating depth or when there is limited ability to surface**
- **Directly supports the JPL Quest "Understand how life emerged on Earth and possibly elsewhere in our Solar System"**
  - **Enabling sustained measurements in regions where it is postulated life on Earth and elsewhere may have originated**
- **Technology also supports the JPL Quest "Understand how Earth works as a system and how it is changing"**
  - **Enabling recharging of remote science AUVs far from shore**
- **NASA and JPL Leadership**
  - **Enables sustained and uninterrupted science measurements to be performed across the world's oceans**
    - **Capability is very rare due to lack of appropriate power solutions**
  - **Leadership in Life Detection and Astrobiology, Autonomous Systems and In Situ Science**
- **Supports the 2018 JPL Strategic Implementation Plan**
  - **"More frequent and detailed observations of surface movements associated with earthquakes and volcanoes"**
    - **Near and upon Earth's mid-ocean ridges where hydrothermal vents predominate**
  - **"Novel approaches for measuring ocean currents" in these remote, under-explored locations where new power system approaches are required**
  - **Exploration of the Ocean Worlds of the Solar System, including Europa and Enceladus**
    - **Ultimately provides hydrothermal vent power design pathways and systems to study postulated vent environments in these Icy and Ocean Worlds**

Instrument	Vendor	Voltage (V)	Power (W)	Comments
Communication Modem	Teledyne	27	20	Power delivered in intermittent spikes during operation
Mass Spectrometer	Harvard	24	72 to 192	24VDC@8A on startup; 24VDC@3A nominal
Camera	Rayfin	16.5 to 32.5	7.5 idle 8.5 recording 13.5 peak	
Camera	Sculpin	12-32	2.8	
Seismometer	Orcus		7.5 to 8	
Seismometer	Aquarius		0.190 to 0.200	
Doppler Profiler	TBD	13.5	20	
Oxygen & CO_2 Optode	TBD	5 to 14	0.5 to 1.4 (100 mA max)	
Spectrophotometer	TBD	10 to 35	8.3 to 28	
Hydrophone	TBD	24	2	
Temperature	Omega	-	-	Power need is very small
Acoustic Current Meter	ACM	5 to 12	0.2-20	

Earth Science Instruments Potentially Powered by the HVD TPS Enable Substantial Science Station Capability for Long-Term Deep-Ocean Exploration

Publications:

Jet Propulsion Laboratory New Technology Report #51213, "Energy Harvesting from Hydrothermal Vents to Support Remote and Autonomous Operations", Provisional Patent Filed, May 2019.

Terry J. Hendricks, Erik J. Brandon, Jean-Pierre Fleurial, Laura M. Barge, "New Thermoelectric Energy Harvesting Opportunities: Ocean Robotic Exploration Enabled by Ocean Hydrothermal Vents", European Materials Research Society 2019 Spring Meeting, Materials for Energy Symposium, Paper Io-6.8, Nice, FR, May 2019.

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