A SURVEY OF WATER POWERED PROPULSION SYSTEMS

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Summary

Water is fast becoming a lucrative resource for development as a propellant due to its stable nature and potential for extraplanetary acquisition. **We have evaluated a thorough cross-section of water-fueled propulsion systems that are currently in development in academia and in the commercial space markets.** Resistojets have demonstrated to be successful in satellite attitude adjustment and are the most common technology within commercial expressions. Other electrothermal systems, especially Microwave Electrothermal Thrusters, are also promising, where **the non-hazardous nature of water makes it desirable for payloads on rideshare-style launch vehicles**. There is considerable commercial and academic interest in electrolysis based systems and various hybridized architectures. **Water's versatility lends itself to broad operational capabilities, and is likely to drive the in-situ resource utilization technology development.** A performance comparison shows that water powered systems compare favorably with adjacent technologies.

Highlight 1

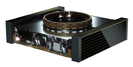
It is difficult to assess the **maturity of satellite propulsion architectures** based on publicly available information. As such, NASA has introduced a new metric based on their **Progress towards Mission Infusion score (PMI)**. This metric does not replace the Technology Readiness Level (TRL) evaluation tool, but rather provides a tool for evaluating propulsion technologies in a **market that is motivated equally by commercial interests as much as academic endeavors**.

- Some Resistojets are on the market now

TunaCan *Steamjet*

Comet *Bradford Space*

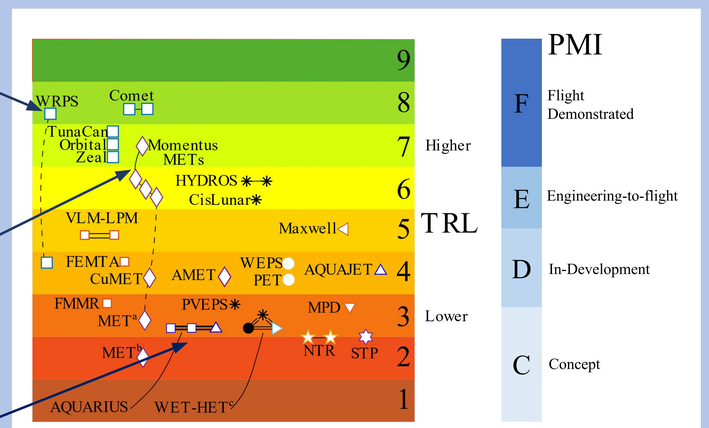
- ◊ Microwave Thermal and ✳ Electrolysis based thrusters are being flight tested soon



Vigor *Momentus*

HYDROS *Tethers*

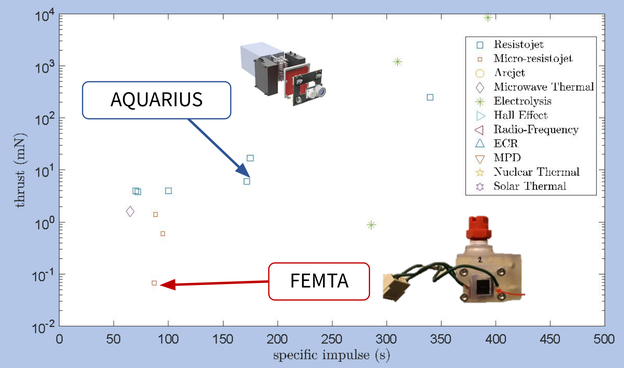
- Hybrid Systems represent the holy grail of flexible, water based propulsion systems



Technological Maturity of Different Architectures

Highlight 2

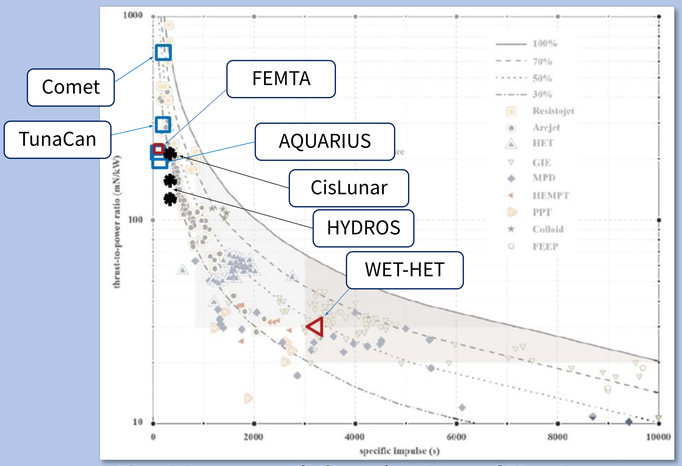
There is a wide variety in performance capability across the market. The **lowest thust micro-resistojets**; FEMTA (*Purdue*) and VLM/LPM (*TU Delft*) are **used for attitude control**, while the **higher thrust systems such as the electrolysis based** Cislunar Thrusters (Cornell) and the Vigor **microwave electrothermal thrusters** (Momentus) are **designed for orbital transfer**. Hybrid systems such as AQUARIUS (*Blue Dot*) combine **multiple capabilities from a single fuel source**.



Highlight 3

Several thrusters with demonstrated and published performance are comparable to adjacent architectures. **Five thrusters have been flown in space on published missions**, including the Microresistojet that was used on the UK Disaster Monitoring Constellation, and Comet (*Bradford Space*) that is currently in-service on 8 satellites.

The figure to the right shows **data from a recent state-of-the-art review by Holste et al , compared with water-based alternatives.** So far, water-based thruster generally favour lower-specific impulse performance.



Thrust-to-power ratio for various types of EP systems

Takeaways

- Ridesharing of small satellites on larger launch vehicles necessitates the use of **non-hazardous fuel sources.** Water is an attractive candidate for small satellites with short program cycles.
- In the future, **in-situ resource utilization** of water means that spacecraft can minimize their fuel payload at launch, and potentially become self sustaining
- The technology is far from fully matured, and water's flexibility means that there are many opportunities for development and mission capacity.

Reference Holste et al. 2020. *Ion thrusters for electric propulsion: …* Rev. Sci. Instrum. 91, 061101 (2020);

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