National Aeronautics and Space Administration

Cryogenic Electrified Aircraft Propulsion: Lessons Learned, Opportunities, and Needs

Justin J. Scheidler

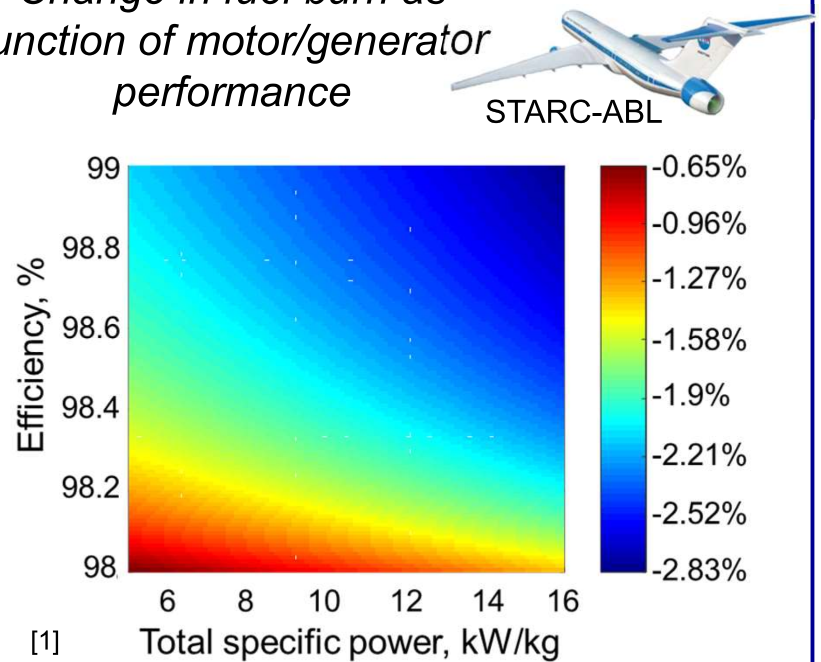
NASA Glenn Research Center, Cleveland, USA

ITEC-EATS 2026
June 10, 2026

Lessons Learned on Electric Machines

Efficiency often has a larger impact *on the aircraft* than specific power

Change in fuel burn as function of motor/generator performance



[1]

Rotors cooled via conduction by on-board cryocoolers are viable

Stationary demonstration of HEMM rotor in TVAC chamber [2]

ΔT = 10.9-12.3 K from cold head to superconducting coil

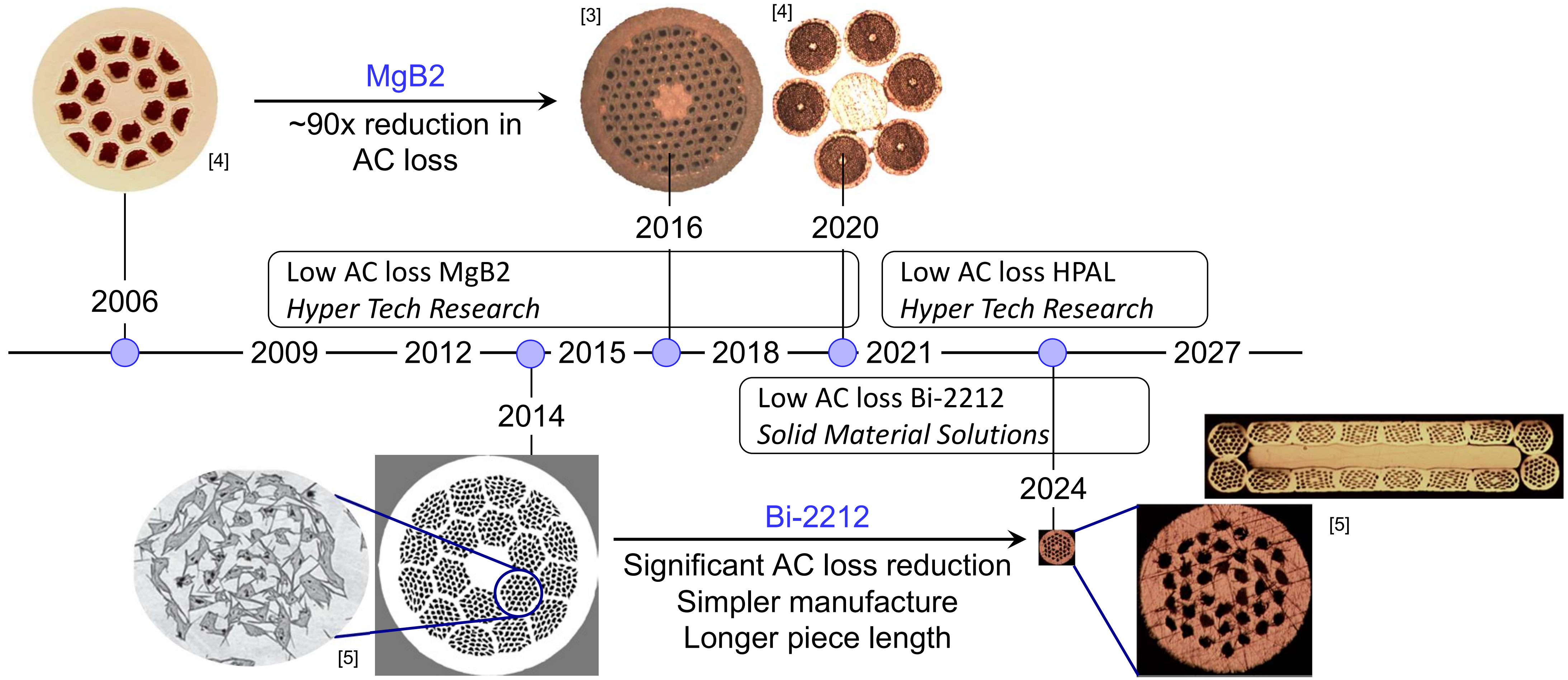
Fully assembled HEMM cryocooler

[1] J.J. Scheidler & T. Tallerico, "Methodology for electromagnetic optimization…," Applied Superconductivity Conference, 2022. https://ntrs.nasa.gov/citations/20220015722

[2] J.J. Scheidler et al., IOP Conf. Ser.: Mater. Sci. Eng. 1302 012020, 2024. https://ntrs.nasa.gov/citations/20230009864

Lessons Learned on Electric Machines

Significant progress has been made in the manufacture of low AC loss superconductors via NASA-funded SBIRs



[3] G.V. Brown et al., “Status of Analysis and Manufacturability of Superconducting Wires with Low AC Losses,” NASA/TM-20205005815, 2020. https://ntrs.nasa.gov/citations/20205005815

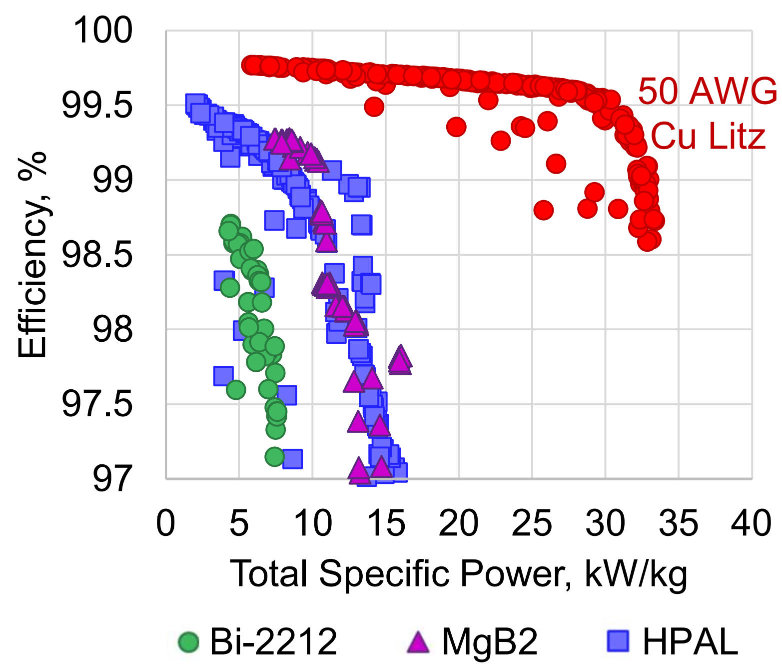
[4] https://hypertechresearch.com/

[5] courtesy of A. Otto, Solid Material Solutions

Lessons Learned on Electric Machines

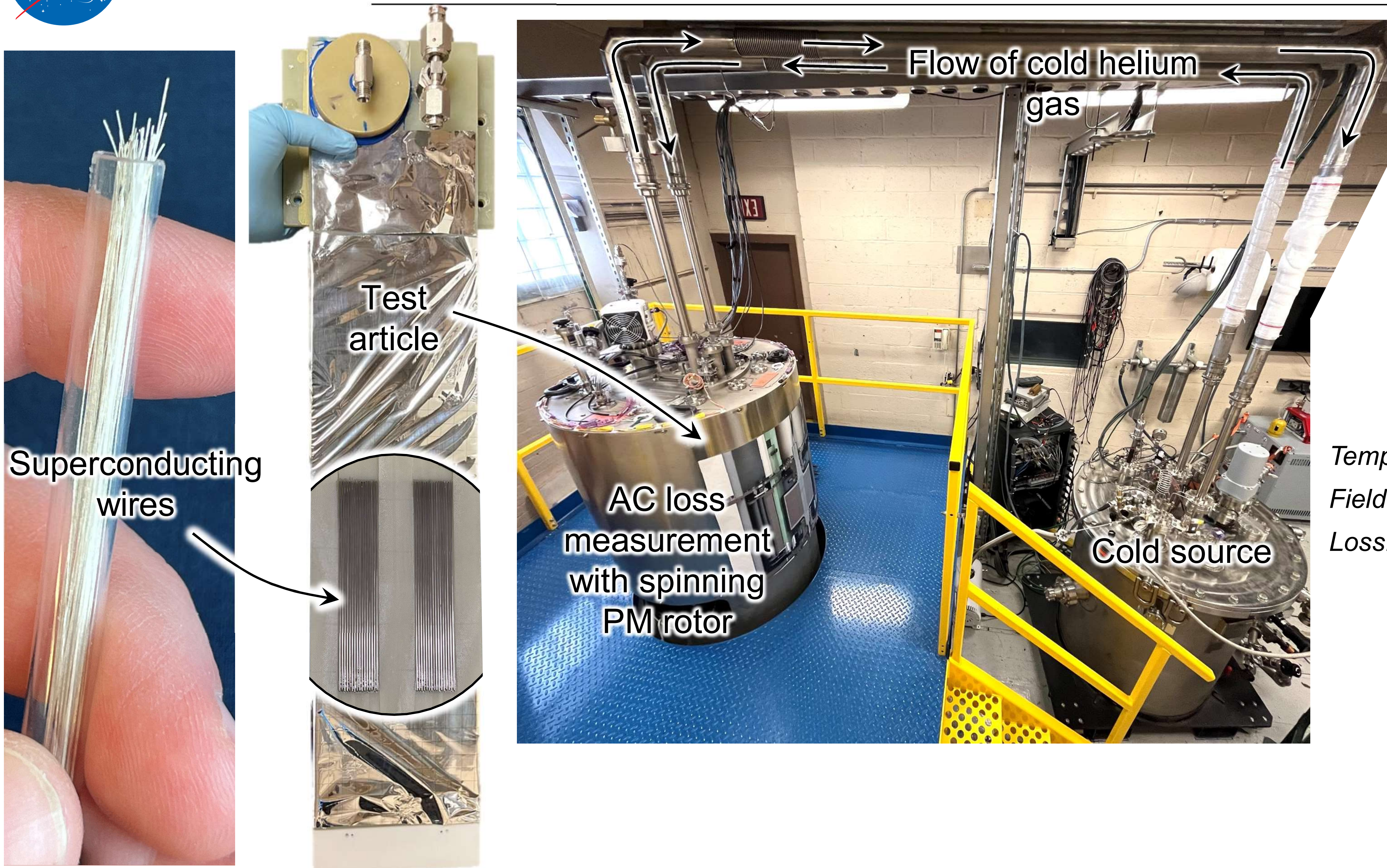
Don’t neglect traditional conductors for use in armature windings

Preliminary results under 1 set of conditions (don’t draw broad conclusions)



Results shown for 3,000 rpm and Liquid Ne coolant @ 25 K

Conductor AC Loss Test Rig Operational



Temperature:	*≥ ~25 K*
Field:	*~0.5 T at 0 – 400 Hz*
Loss:	*~0.2 – ~20 W via 1 of 4 methods*

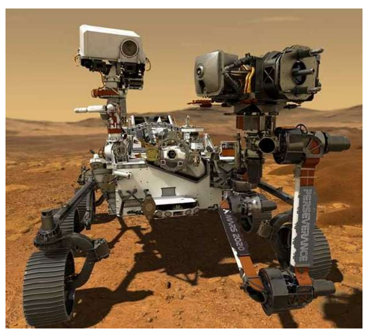
What Can be Learned from Space Technology – *Motors, Electronics*

Past

(robotic missions)

Typical space motors & electronics

- Low power (< 1 kW)
- Relatively short life
- Heated to avoid cryogenic temperatures

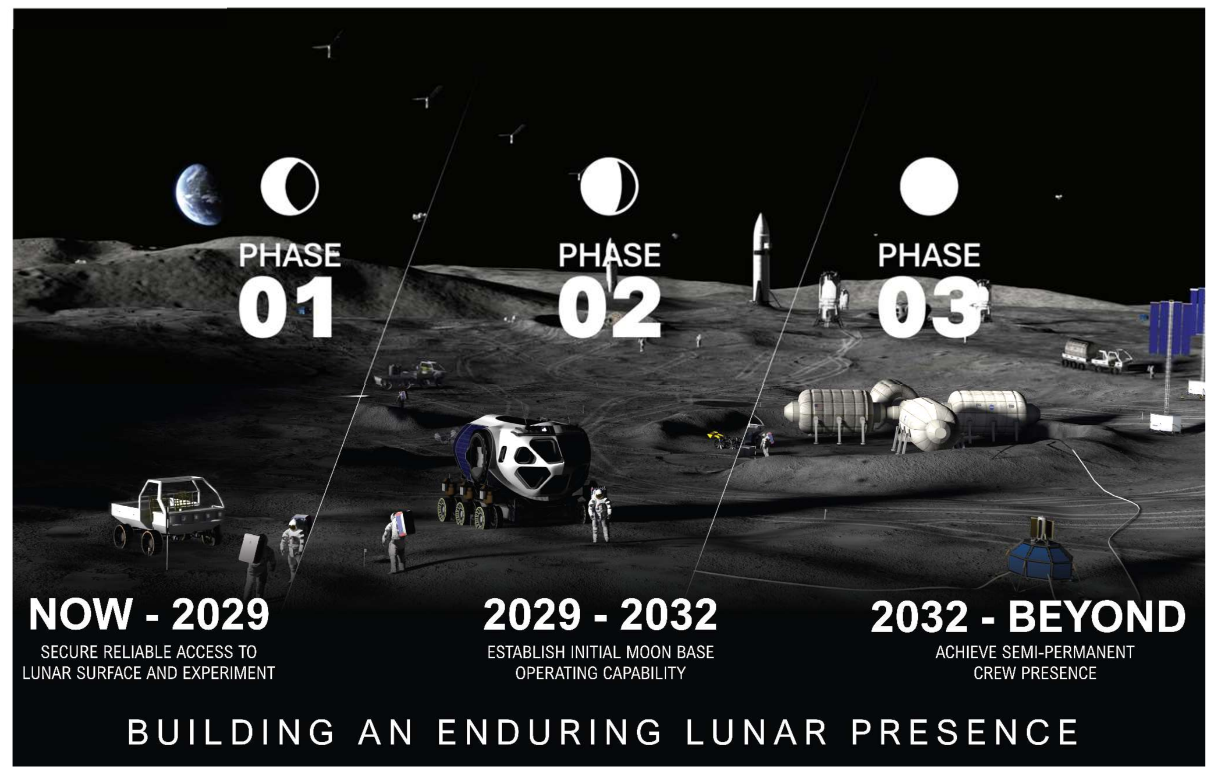


Technology needs [6,7] shifting towards aircraft application

Future

(Sustained lunar presence & manned missions)

- Higher power
- Longer life / higher reliability
- Cryo operation (e.g., cryogenic electronics components [8,9])

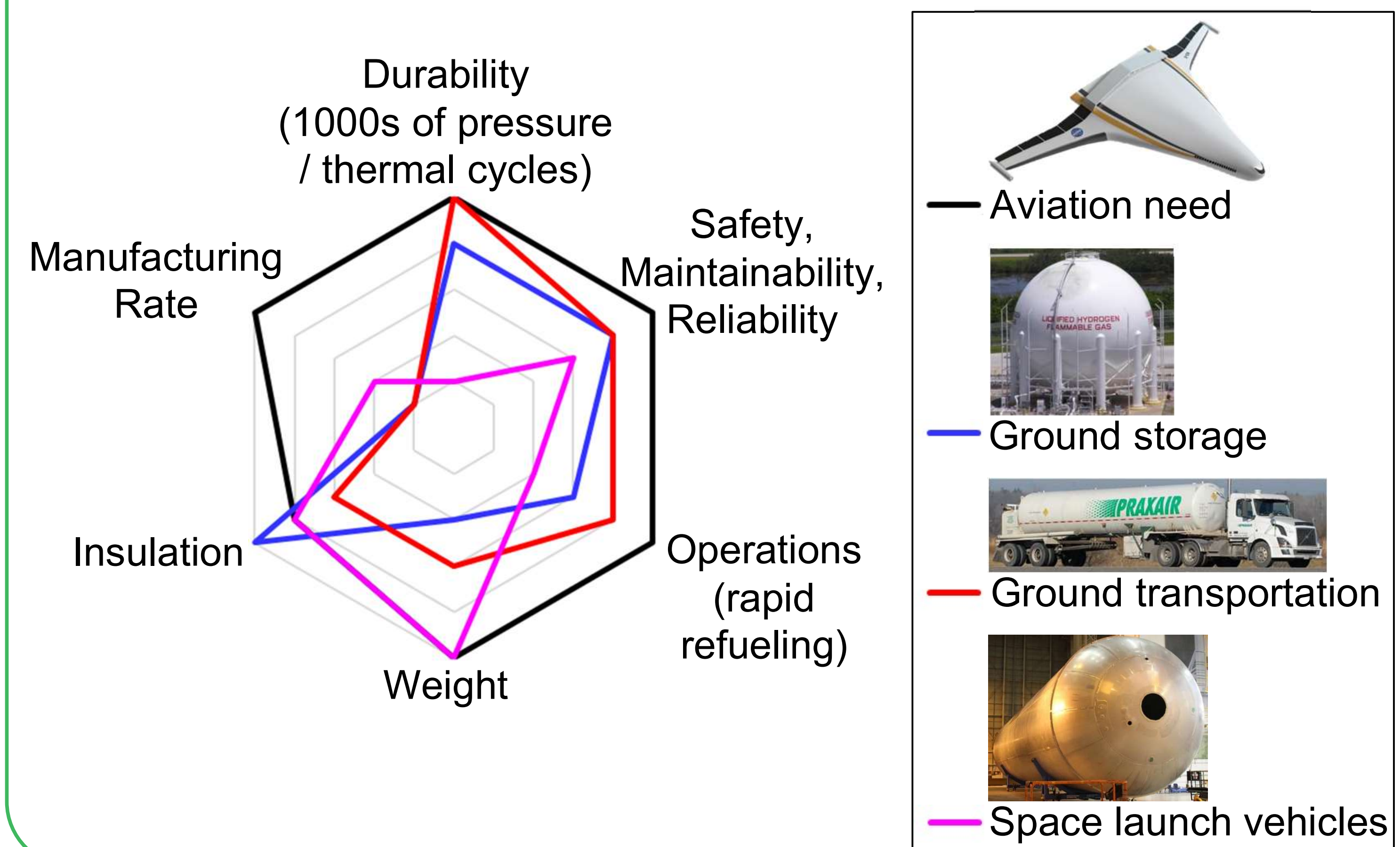


[6] https://www.nasa.gov/wp-content/uploads/2026/04/moon-base-architecture-users-guide.pdf
[7] https://www.nasa.gov/spacetechpriorities/
[8] N.R. Uguccini et al., "Cryogenically-Operable Electronics for Surviving the Lunar Night," Space Power Workshop, 2024. https://ntrs.nasa.gov/citations/20240004406
[9] M. Ashtijou et al., "Select Electronic Parts Operation at Extreme Low Temperature," IEEE Aerospace Conference, 2020.

What Can be Learned from Space Technology – *Cryogen Storage*

- Lessons learned by NASA via 60+ years of liquid hydrogen system storage and testing:
  - Instrumentation [11]
  - Hydrogen storage (insulation, stratification, boil off) [12]
- No existing cryogen tank meets aviation needs
  - Largest gap – manufacturing rate
  - Launch vehicle tanks lacking in durability, manufacturing & refueling rates

Characteristics of existing cryogen tanks relative to aviation needs (based on [10])



[10] V. Lvovich et al, “Commercially-viable Hydrogen Aircraft…,” 26th International Society for Air Breathing Engines (ISABE) Conference, 2024. https://ntrs.nasa.gov/citations/20240008370
[11] W. Johnson, “Liquid Hydrogen and other Cryogenic Instrumentation Experience at NASA Glenn,” Energy and Mobility Conference, 2023. https://ntrs.nasa.gov/citations/20230012808
[12] W. Johnson and A. Swanger, “Lessons Learned in Hydrogen System Operation,” Mission Hydrogen Webinar, 2026. https://ntrs.nasa.gov/citations/20260001336

Needs – *Electrified Propulsion System*

General comments

- Component technologies need to reach TRL 6 approximately 10 years prior to aircraft entry into service
- Address 'ilities' during technology development to the extent feasible
  - Industry anecdote: "I would rather have a 97% efficient motor with 10,000 hour maintenance interval than one with >99% efficiency and 1,000 hour interval"

Needs – *Electrified Propulsion System*

Systems Engineering

1. Aircraft study on breakeven points for cryo powertrains for various fuels & powertrain operating temperatures
2. Fault analysis of cryo powertrain

Materials & Manufacturing

1. Lightweight composite and non-metallic structures, including manufacturing
2. Superconductor development (AC loss reduction, Je increase, coil fabrication)
3. Material property data at cryo temperatures
4. Improved understanding of partial discharge at cryo temperatures

Components

1. Flight / flight-like designs & demos (e.g., emulated flight profiles, off-nominal response, fault tolerance / safe shut down)
2. Efficient, lightweight cryocooling methods (including lifting from 20-70 K to 112 K)
3. Maturation of cryo power electronics
   - Lighter, smaller, more efficient means to reduce output THD
4. Lightweight cryofans with high volume flow
5. Maturation of machine configurations that operate warmer
6. Maturation of cable cryostats & connectors that meet weight, flexibility/installation, and high voltage safety

Needs – *Cryogenics*

Credit: Wes Johnson, Stephanie Vivod, Vadim Lvovich et al., adapted from [13]

- NASA RFI (Feb ‘25) on liquid hydrogen testing capability and needs
  - 16 questions covering testing, facilities, materials, and collaboration
  - 25 responses from vehicle, component, government, test facility, and university entities

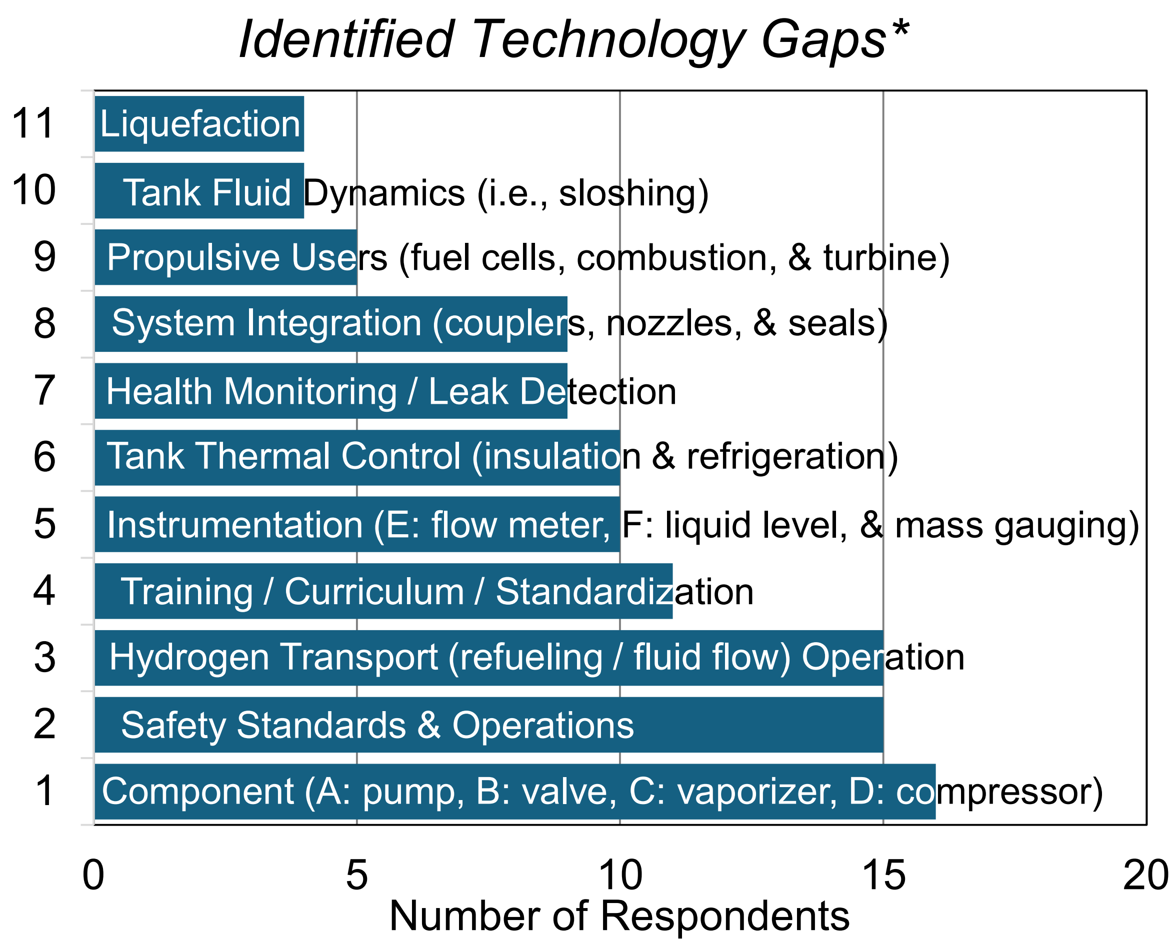
Takeaway

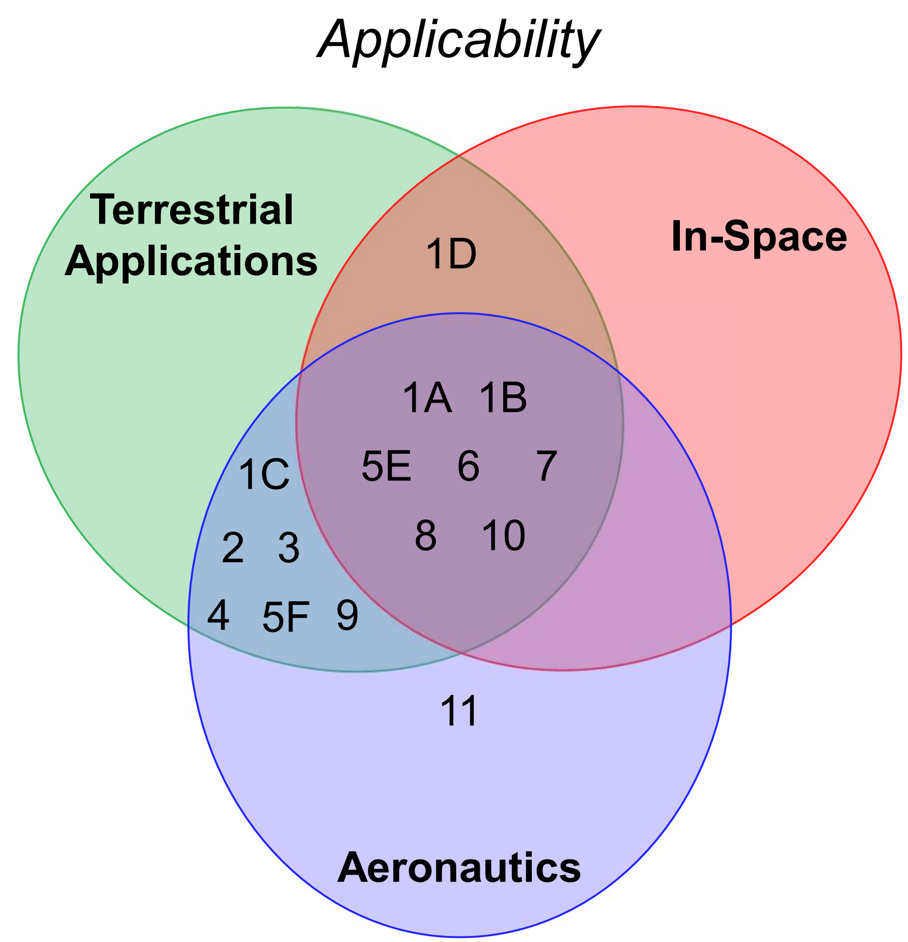
There is a significant need for hydrogen testing capabilities within the US at all levels of integration

[13] W.L. Johnson, S.L. Vivod, V.F. Lvovich, et. al. “The Development of a Liquid Hydrogen Test Capability for Aviation and Beyond as a US National Asset”, Internal NASA report, 9/15/2025.

Needs – *Cryogenics*

Credit: Wes Johnson, Stephanie Vivod, Vadim Lvovich et al., adapted from [13]





* Definition of technology gaps shown in appendix

[13] W.L. Johnson, S.L. Vivod, V.F. Lvovich, et. al. "The Development of a Liquid Hydrogen Test Capability for Aviation and Beyond as a US National Asset", Internal NASA report, 9/15/2025.

Acknowledgements

Wes Johnson and Jason Hartwig for insight on cryogenic fluid management & handling

This work was funded by:

Advanced Air Vehicles Program

Subsonic Vehicle Technologies and Tools Project – Transformative Propulsion and Energy

Contact Info

justin.j.scheidler@nasa.gov

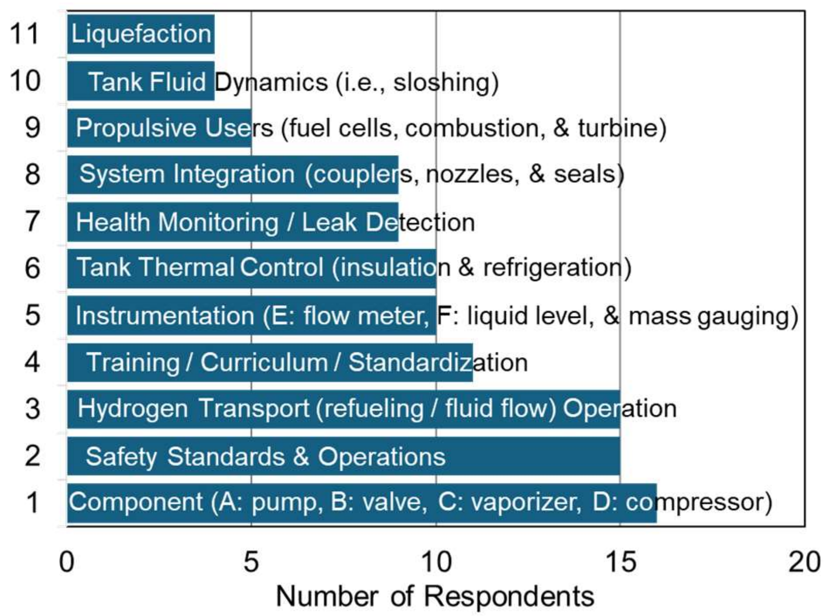
THANK YOU


Glenn Research Center
Lewis Field
RESEARCH AND TECHNOLOGY
Glenn Research Center
FOR THE BENEFIT OF ALL
NASA

Appendix

Definition of Grouped Technology Gaps

Credit: Wes Johnson, Stephanie Vivod, Vadim Lvovich et al., adapted from [13]



- Tank Fluid Dynamics – occurrences within the tank such as sloshing and ullage pressure collapse and mechanisms to mitigate them.
- Tank Thermal Control – Insulation and refrigeration systems that minimize or prevent boil-off
- Hydrogen Transport – Refueling, fluid flow dynamics in lines, and associated operations
- Components – Pumps, Valves, Vaporizers, Compressors
- Instrumentation – Flow meters, Liquid Level sensors, and Mass gauging
- Safety Standards and Operations – Ways to perform testing operations in a safe manner and safety standards for design / operations of aircraft and airports.
- System Integrators – Couplers, Nozzles, Fittings, Seals
- Health Monitoring – Leak Detection, Tank
- Propulsive Uses – Fuel Cells, Turbines, Combustion Devices, other propulsive / users of hydrogen
- Training /Standardization / curriculum – Providing training and standardization with associate curriculum to inform users how to interact with hydrogen.
- Liquefaction – conversion of gaseous hydrogen to liquid hydrogen

[13] W.L. Johnson, S.L. Vivod, V.F. Lvovich, et. al. “The Development of a Liquid Hydrogen Test Capability for Aviation and Beyond as a US National Asset”, Internal NASA report, 9/15/2025.