NASA Interests in Superconducting and Cryogenic Technology

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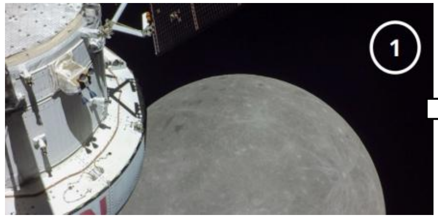
Space Applications

Space – Notable Applications

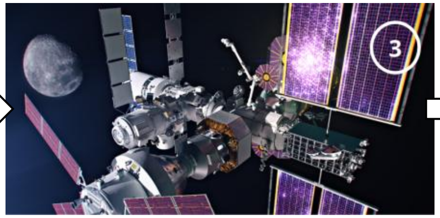
Moon to Mars (incl. Artemis and Moon Base)

- Architecture[1] & objectives[2]



Human Lunar Return

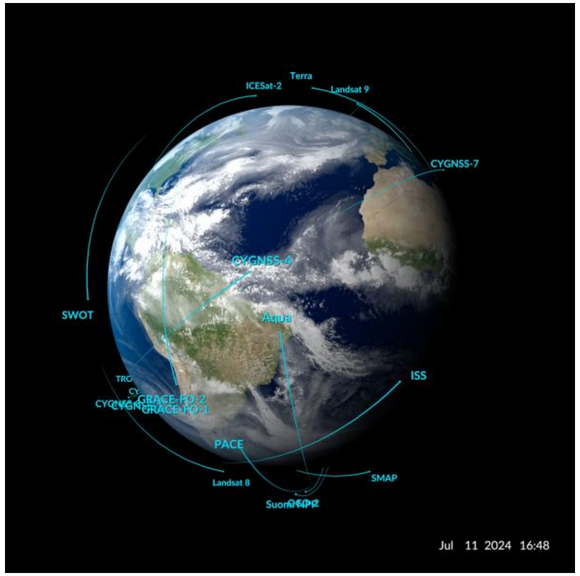
Foundational Exploration



Sustained Lunar Evolution

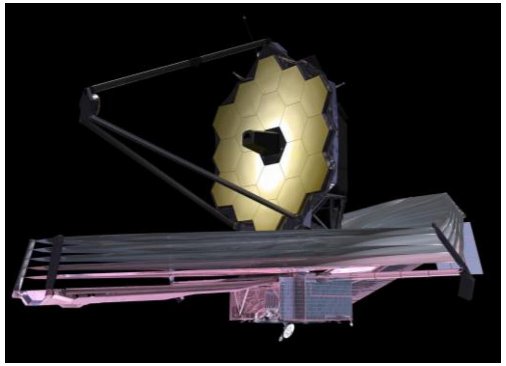
Humans to Mars

Earth science



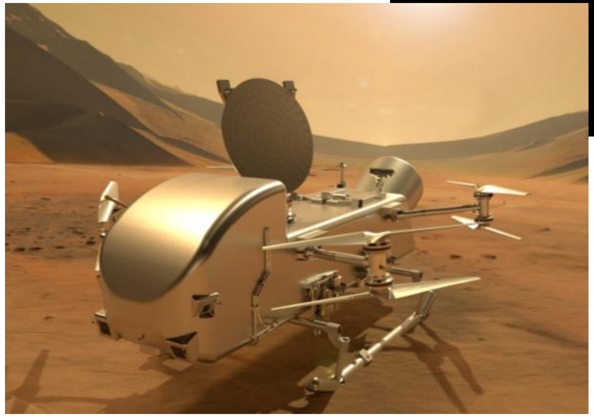
Credit: NASA's Scientific Visualization Studio

Telescopes



Other solar system exploration

Europa Clipper

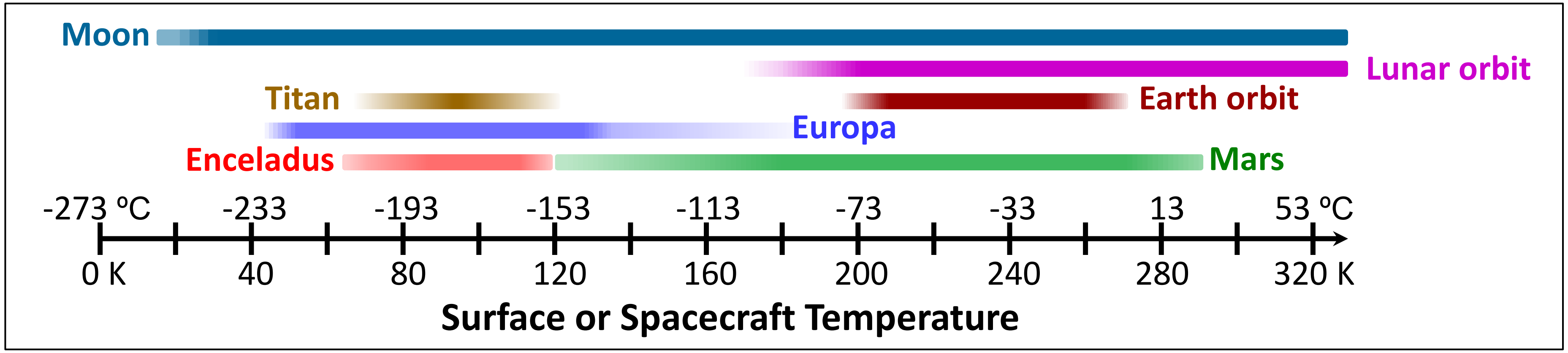


Dragonfly

1. https://www.nasa.gov/moontomarsarchitecture/
2. https://www.nasa.gov/moontomarsarchitecture-strategyandobjectives/

Space – Environments

- Temperature



- Atmosphere
  - Pressure ranges from hard vacuum (e.g., Moon) to thin (e.g., Mars) to thick (Titan)
- Radiation[4]
  - <u>Persistent</u>: solar radiation and galactic cosmic rays
  - <u>Erratic</u>: single event effects

4. SLS-SPEC-159 Cross-Program Design Specification for Natural Environment (DSNE) Rev G

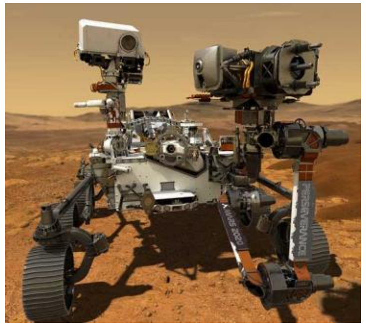
Space – Technology Needs

Past

(robotic missions)

Typical space motors & electronics

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

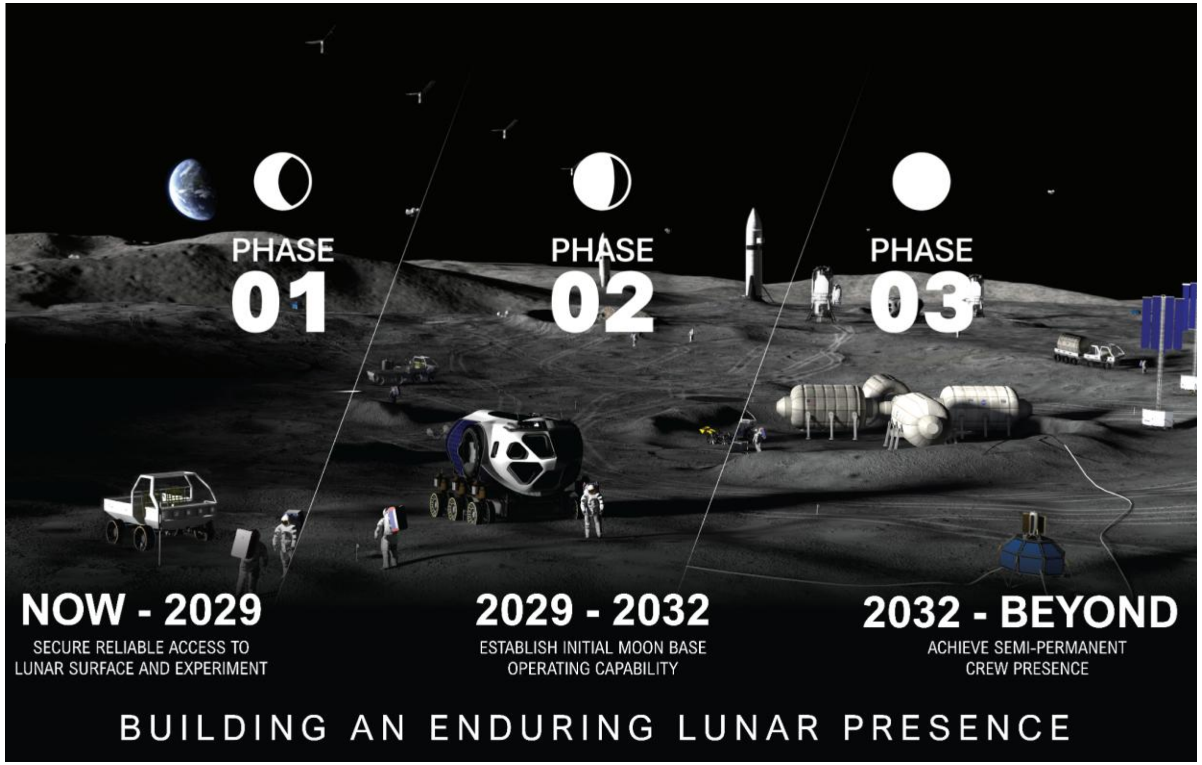


Technology needs [6,7] shifting

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.

Space – Technology Needs

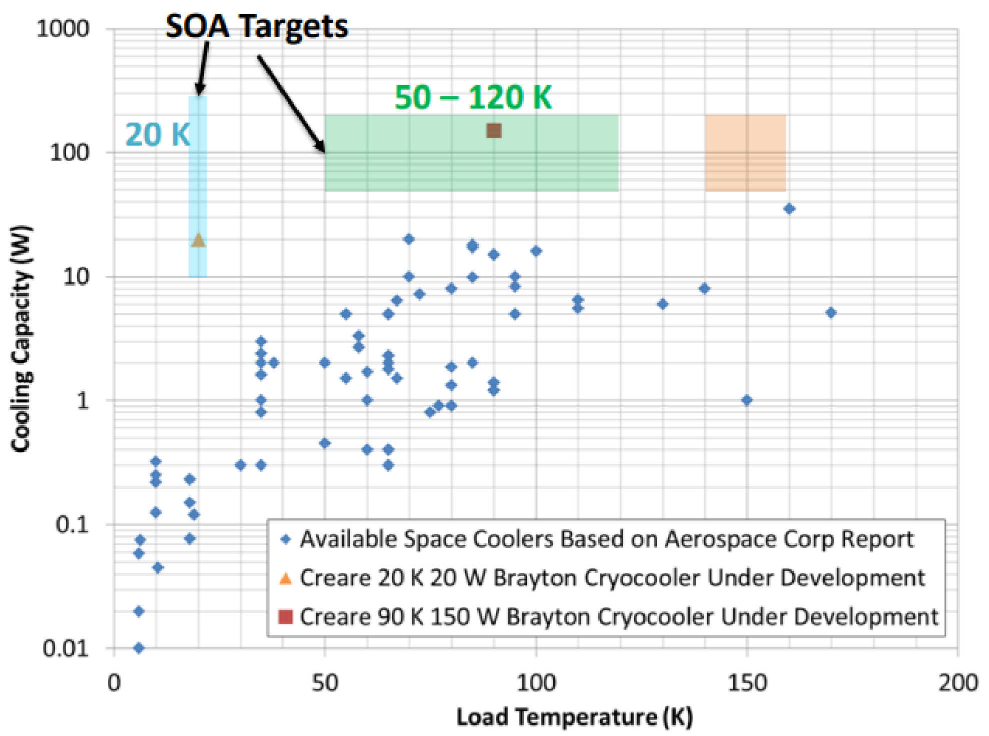
- Updated Civil Space Shortfall Prioritization for FY26[3]
  - 32 shortfalls and 40 top focus areas

Relevant shortfalls	Rank	ID	Relevant critical technology gaps
Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment	2	2.0	Transmission Cable Systems up to 10 kWe Increment, AC and DC at > 1 kV Surface Power Transfer Cables/Connectors/Dust Compliant Cabled Power Transmission in Permanently Shadowed Regions
In-space and On-surface, Long-duration Storage and Transfer of Cryogenic Propellant	10, 11	16.04, 16.05	Active cooling systems such as cryocoolers High vacuum, soft vacuum, and load bearing insulation Cryogenic thermal coatings and low conductivity structures Propellant transfer

3. https://www.nasa.gov/spacetechpriorities/

Space – Perennial Interests

- Active cryocooler systems for storage, liquefaction, or science instruments; Passive thermal control (used w/ or w/o active cooling)
  - LH_2 (20 K), LO_2 (91 K), and LCH_4 (112 K) for ascent/descent stages, nuclear thermal propulsion, IRSU on Moon/Mars, etc.
  - Helium (mK to ~10 K) generally used for science instruments
  - Active cooling needs: high lift, low specific mass (kg/W), low specific power (W/W), low vibration
  - Passive cooling needs: reduced overall mass, low conductivity structures, high heat rejection, store prop weeks to 4+ year
  - Recent efforts: 20K and 90K cryocoolers, composite, additive manufactured, & inflatable tanks, advancements in thermal coatings
- In-space propellent transfer & mass gauging in low-g
  - Prop transfer needs: minimize residuals in supply tank, minimize losses during transfer
  - Mass gauging needs: gauge supply tank, receiver tank, and transferred mass to within 2%



SOA & As-tested Creare cryocooler performance[5,6]

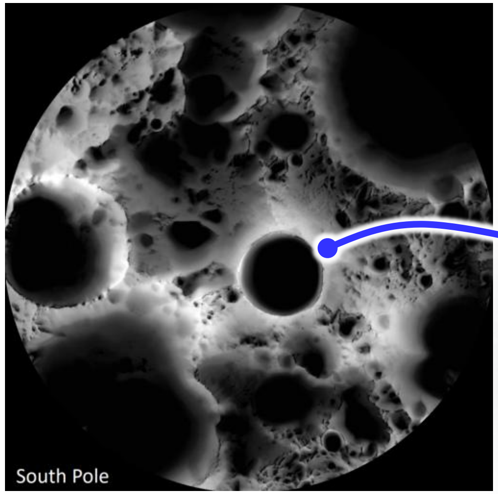
Carbon composite tank

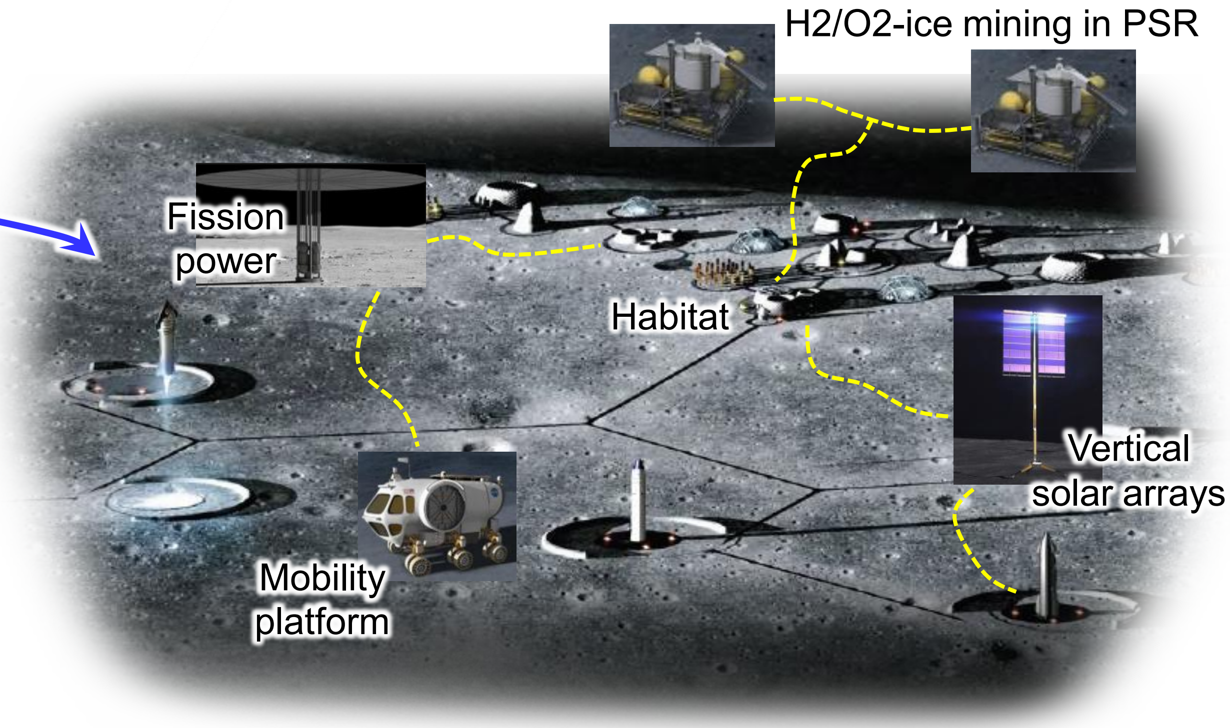
credit: Gloyer-Taylor Laboratories Inc.

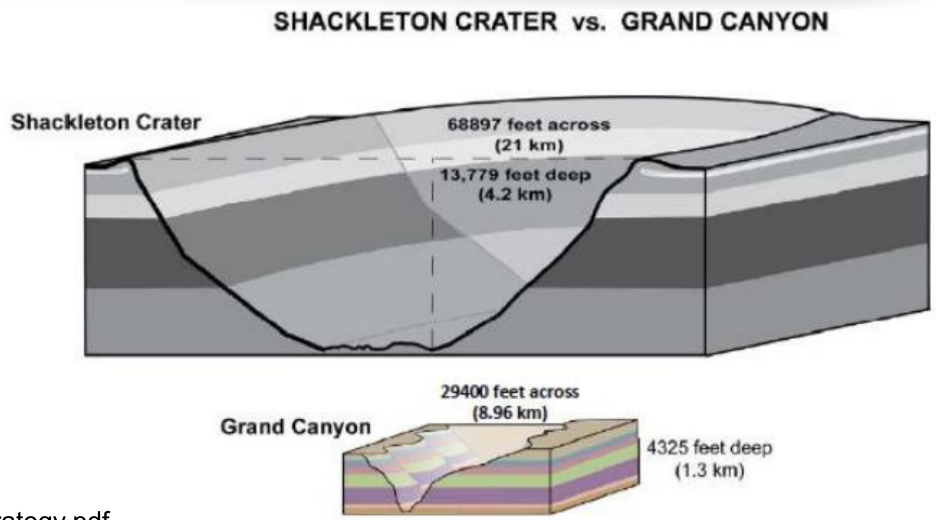
5. Nugent, et, al. “Characterization Testing of a 20 Kelvin Cryocooler for Space Applications” 22nd ICC, 2022.
6. Cragin, et al. “Testing of a High Capacity 90K Turbo Brayton Cryocooler” Cryocoolers 23, 297-306. 2024

Space – Newer Interests

- Lunar infrastructure for sustained human presence on Moon is of high interest
  - Power distribution within PSRs (extreme cold) and between PSRs and sunlit areas
  - Be compatible with power source (e.g., NASA nuclear fission systems) & evolving power standards [1,2]
- Superconducting cables of 10 kW capacity and 5 km length may be needed for use in permanently shadowed regions (PSR)
- Surface temperature in PSRs is roughly 20 K to 90 K, but superconducting won't be a 'free lunch'







[1] https://internationaldeepspacestandards.com/wp-content/uploads/2024/02/ISPSIS-RevA-20220727-2.pdf
[2] https://ntrs.nasa.gov/api/citations/20250010948/downloads/ACR25%20-%20WP%20-%20Lunar%20Power%20Strategy.pdf

Aeronautics Applications

Aero – NASA's Direction

- Prior to 2026: largely focused on tech for 2035 EIS ▪ various energy carriers, but emphasis on SAF ▪ few cryo efforts (notably HEMM [1], CH_2ARGE [2])
- As of April 2026: ~2050 EIS ▪ **LNG fueled** ▪ several cryo efforts
  - Decision influenced by NASA-funded AACES 2050 studies (4 industry, 1 academic) to develop transformative aircraft designs, propulsion technologies, and sustainability solutions [3] & US Department of Energy study on aviation energy carriers [4]
- LNG not unanimous winner, but cheap, available, cryogenic
- LH2 still viewed as potential long-term solution
  - Challenges: electrolysis energy requirement, cryo tanks (manufacturing rate & safety, weight fraction, packing within airframe)

Enable an American aviation ecosystem powered by domestic LNG and advanced electrification

Credit: Boeing/Aurora

Credit: Electra

Credit: Georgia Tech

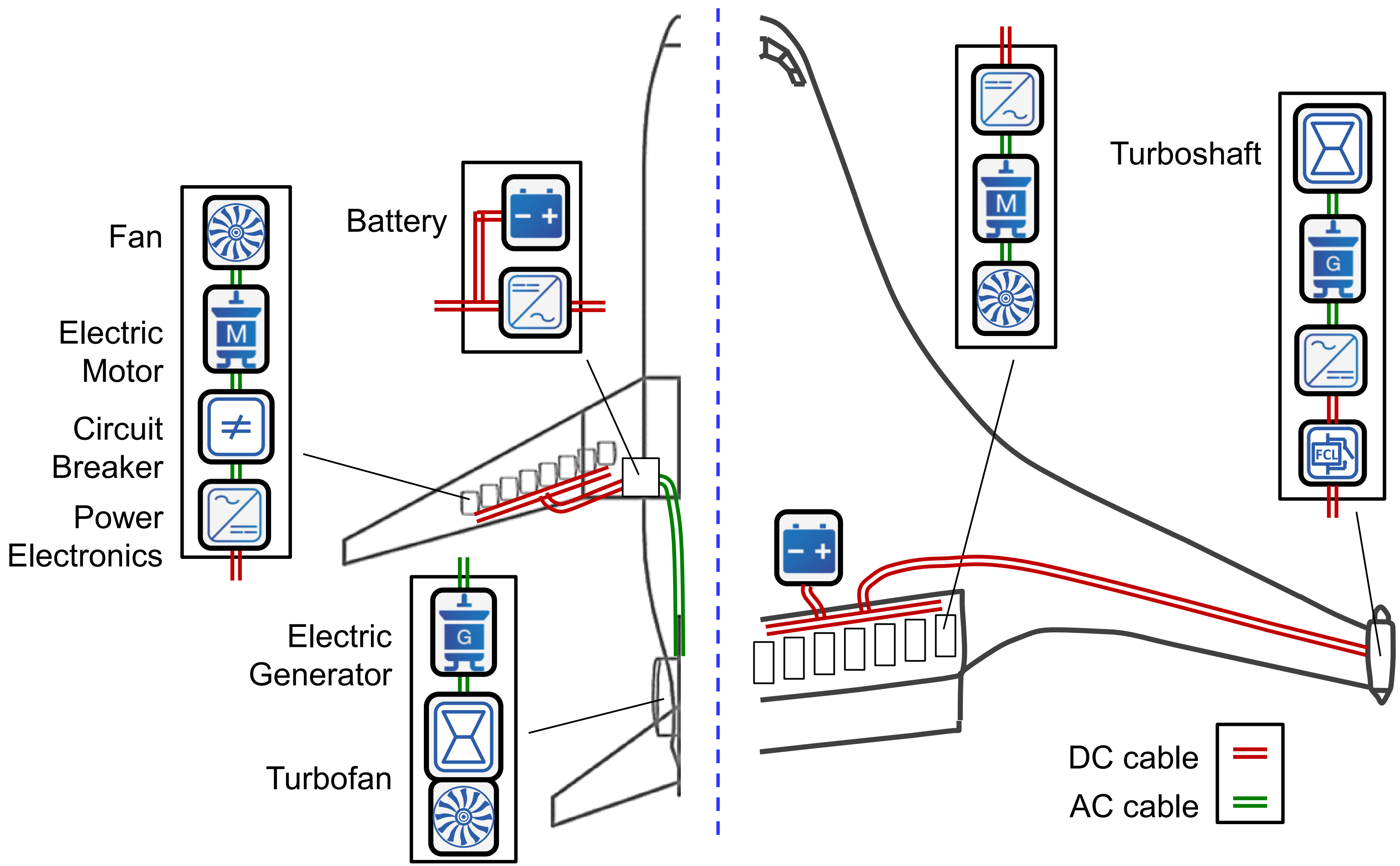
Credit: JetZero

AACES 2050 concepts [5]
(Pratt & Whitney HySIITE concept not depicted)

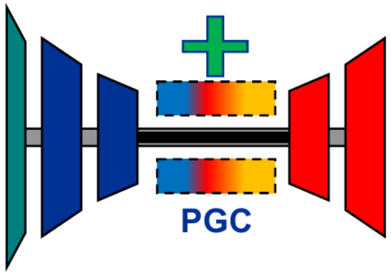
1. https://www.nasa.gov/eap-resources/publications/technology-development/#hemm
2. https://ntrs.nasa.gov/citations/20250002550
3. https://www.nasa.gov/reference/advanced-aircraft-concepts-for-environmental-sustainability-2050/
4. K. Moriarty et al., An Overview of Potential Future Aviation Energy Carriers, NLR/TP-5400-100028, 2026, https://docs.nlr.gov/docs/fy26osti/100028.pdf
5. https://www.nasa.gov/reference/advanced-aircraft-concepts-for-environmental-sustainability-2050/

Aero – Relevant Applications

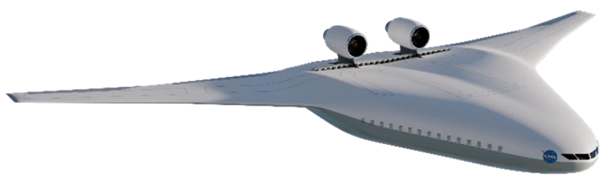
Electrified aircraft propulsion



Advanced engine cycles for cryo fuel



Radical airframe technology & propulsion airframe integration



Aero – Interests

- 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"
- Propulsion system components (5-20 MW powertrain)

Superconducting

- Electric machines[9]
- DC cables (multi-kA)
- Fault current limiters

Cryogenic

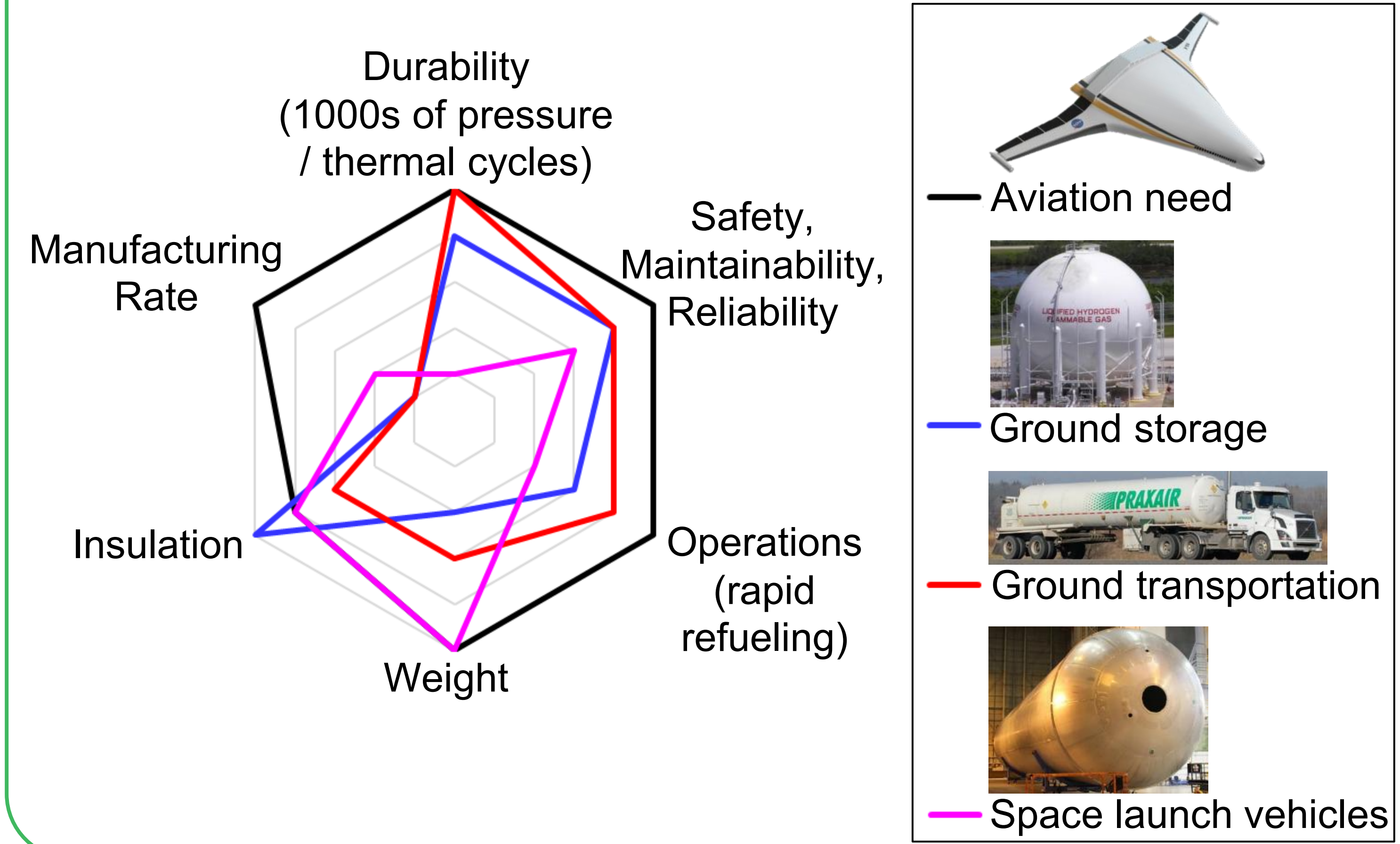
- MW-class power electronics
- Lightweight, high cycle cryogen tanks
- Fluid loop components (e.g., cryofans, pumps, valves, HXs)
- Thermal management (< 1 kg/kW)
- Cryocooling

  - Assume cryo fuel will not be allowed to directly cool electrical components
- Fault management
- Aircraft requirements (e.g., DO-160[10])

9. https://ntrs.nasa.gov/citations/20230010027.
10. RTCA standard DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, 2010.

Aero – Interests

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

Aero – Interests

Authors' opinions

Systems Engineering

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

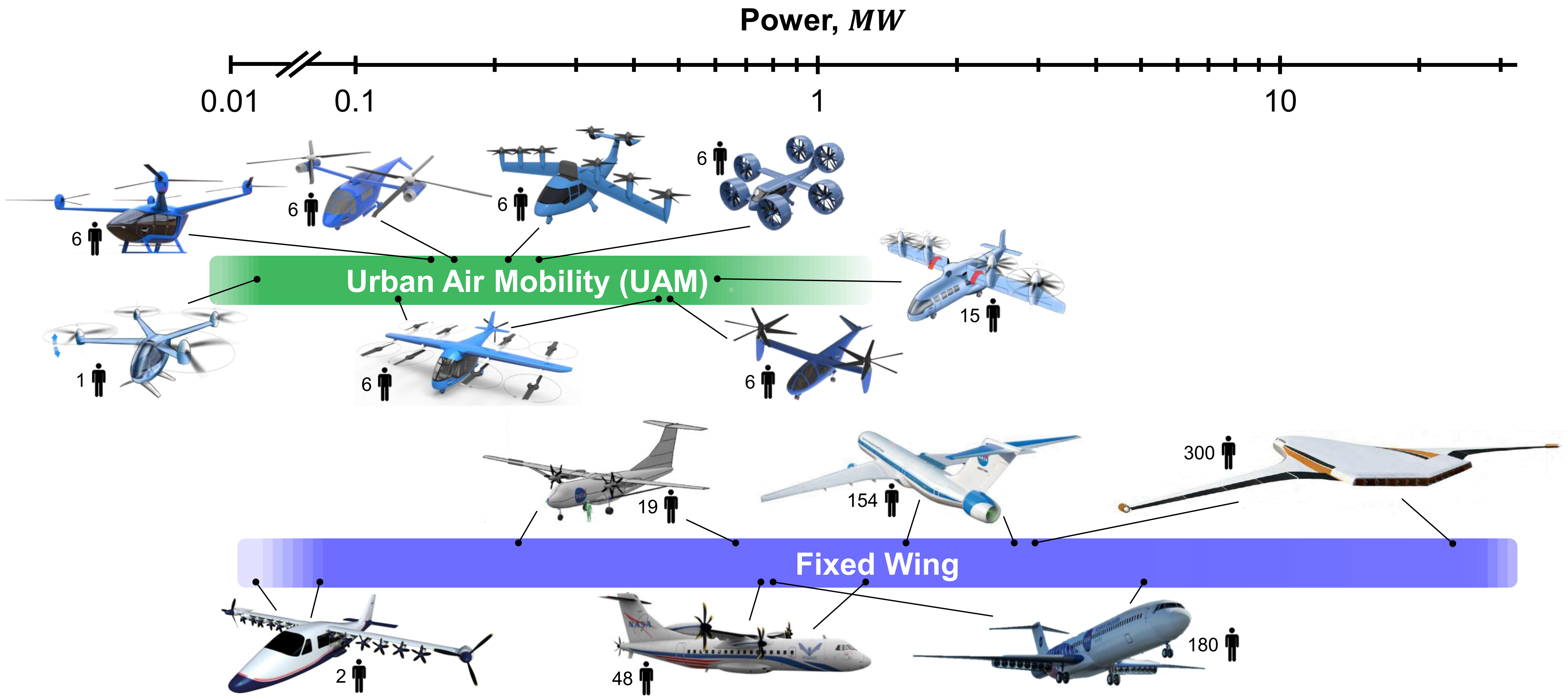
Materials & Manufacturing

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

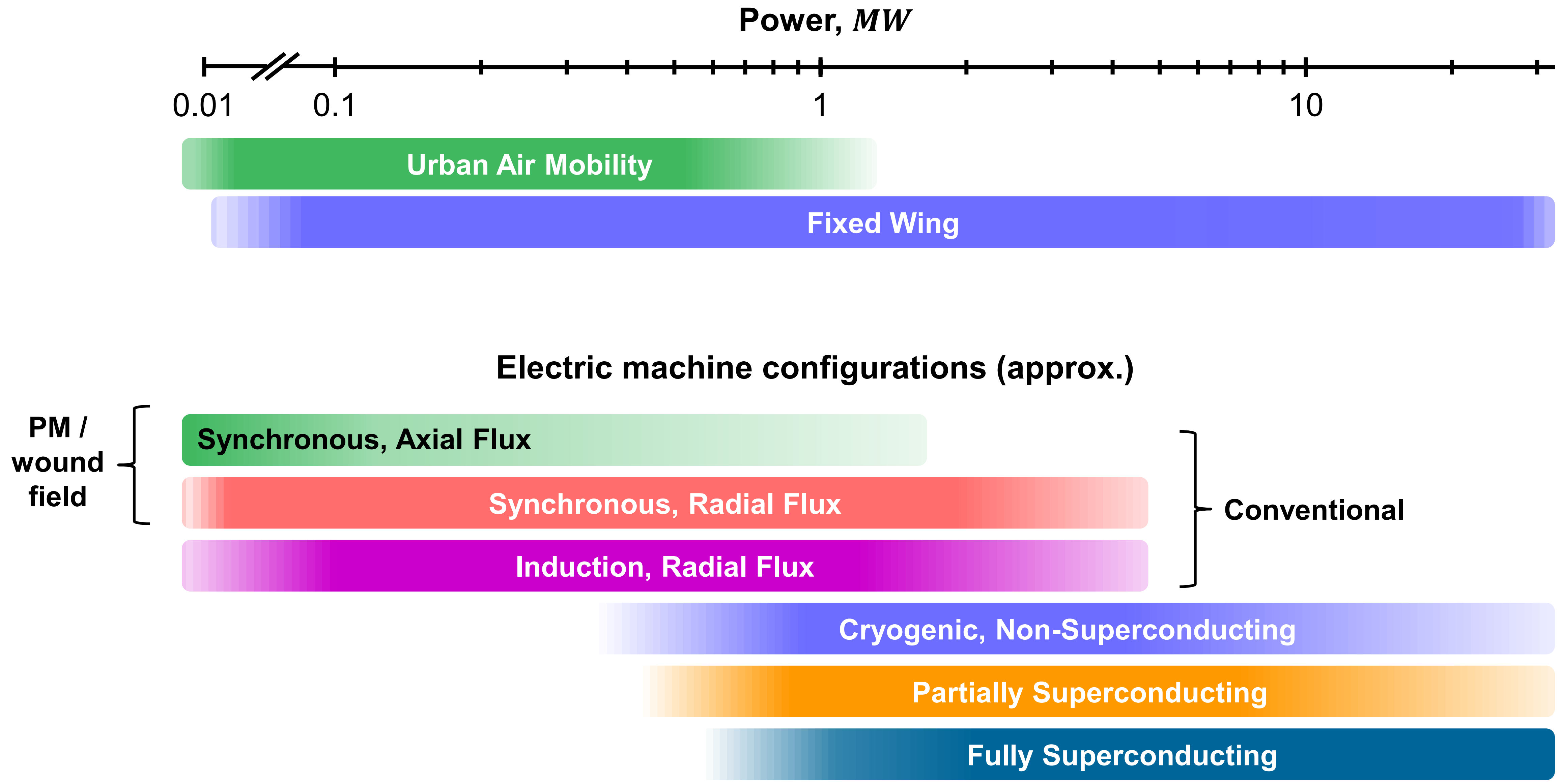
Components

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

Aero – What Scale of Electric Machine is Relevant?



Aero – What Types of Electric Machines are Relevant?



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