U.S. Department of Energy
Advanced Research Projects Agency-Energy (ARPA-E)

Request for Information
DE-FOA-0003359 on
Electrified Airplane Integration Retrofit Powertrains Learnings
And
Novel Electric Port & Operations Related Technologies
(E-AIRPLANE/PORT)

Introduction:

The purpose of this Request for Information (RFI) is to solicit input for a potential ARPA-E program focused on the feasibility and impact of retrofitting an existing aircraft with electric powertrains developed under ARPA-E's Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND) program for a full integration with the aircraft and to show full functionality of the electric powertrain. ARPA-E is interested in groundbreaking technologies needed for a full integration of an electric powertrain into the aircraft main electrical and propulsion systems, as well as opportunities in airport electrification. This RFI aims to identify potential participants and gather insights to inform the development of a future funding opportunity focused on this transformative technology.

Areas Not of Interest for Responses to this RFI:

Approaches not of interest include:

- Subcomponent (e.g., electric motors and power converters) development only
- Non-electric energy sources (e.g., hydrogen and sustainable aviation fuel)

RFI Guidelines:

PLEASE CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Please note that the information you provide will be used by ARPA-E solely for program planning without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential**.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on May 31, 2024.** Emails should conform to the following guidelines:

- Please insert "Response to E-AIRPLANE/PORT - <your organization name>" in email subject line.
- In the body of your email, include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center [FFRDC], government-owned/government-operated [GOGO]), email address, telephone number, and area of expertise.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their materials, designs, or processes.

Technical Background:

Transportation of people and goods is an important part of our economy and social structure. The electrification of transportation has been proven to lead to both more sustainable and more economical outcomes by greatly increasing the efficiency of propulsion systems.[1] This increased efficiency results in transportation options that require less energy for the same range and thus have the ability to lower operating cost.[2]

Ground transportation has seen growth in the adoption of electrified vehicles.[3] Rail, ship, and aerospace transportation modes have not yet experienced similar growth due to an absence of sufficiently power-dense energy storage and propulsion system options.[4]

ARPA-E has launched several programs focused on the development of transformational technologies needed for more efficient transportation. The recently announced Pioneering Railroad, Oceanic and Plane ELectrification with 1K energy storage systems (PROPEL-1K) program is focused on the advancement of energy storage systems with a target energy density of 1000 watt-hour per kilogram (Wh/kg) and a volumetric energy density of 1000 watt-hour per liter (Wh/L) at the pack level.[5] The ASCEND program has been supporting projects in the development of novel, lightweight (greater than 12 kilowatt per kilogram (kW/kg), less than approximately 22.9 Newton meter per kilogram (Nm/kg)), and ultra-efficient (as much as 93%) electric motors, drives, and thermal management systems, collectively referred to as the all-

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[1] Westbrook, Justin. "*Electric Vehicles Are Way, Way More Energy-Efficient than Internal Combustion Vehicles.*" MotorTrend, March 6, 2024. https://www.motortrend.com/news/evs-more-efficient-than-internal-combustion-engines/

[2] NREL media relations. "*News Release: Research Determines Financial Benefit from Driving Electric Vehicles.*" June 20, 2020. https://www.nrel.gov/news/press/2020/research-determines-financial-benefit-from-driving-electric-vehicles.html

[3] Muratori, M., Ledna, C., Gearhart, G., Farrell J., and Greene, D. "*Responding to "An Uphill Battle for EVs vs ICEs": setting the record straight on the status and future of EV adoption.*" In International Association for Energy Economics, Energy Forum, First Quarter, 2021. https://www.nrel.gov/news/program/2021/images/iaee-ev-adoption-article.pdf

[4] de Bock, H.P., Tew, D.E., Rahman, Z., Lecoustre, V. and Cox-Galhotra, R.A., 2023, June. Progress Toward Climate-Friendly Aviation in the ARPA-E ASCEND and REEACH Programs. In *Turbo Expo: Power for Land, Sea, and Air* (Vol. 86939, p. V001T01A039). American Society of Mechanical Engineers.

[5] ARPA-E/DOE, Funding Opportunity No. DE-FOA-0003162 and DE-FOA-0003163, *Pioneering Railroad, Oceanic and Plane Electrification with 1K Energy Storage Systems (PROPEL-1K)*, September 1, 2023. https://arpa-e.energy.gov/technologies/programs/propel-1k

electric integrated powertrain (IPT).[6] The Range Extenders for Electric Aviation with low Carbon and High efficiency (REEACH) program aims to develop a disruptive system to convert chemical energy contained in energy-dense carbon neutral liquid fuels into electric power for aircraft propulsion via electric powertrains and other key systems. Together, these programs could deliver a path to single-aisle regional aircraft electrified missions of 100 passengers up to 1000 km and beyond.

Launched in 2020, the ASCEND program has supported world class teams to develop and test high density aerospace IPTs with power ratings ranging from 250 kW to 5 megawatts (MW). These systems are planned to be tested under simulated altitude conditions at NASA facilities in late 2024 and early 2025. Information on the teams participating in ASCEND can be found on the ARPA-E website.[7]

For more information about ARPA-E's ASCEND projects and PROPEL-1K program, see Appendix A and B on ARPA-E Exchange at https://arpa-e-foa.energy.gov/.

RFI Interest

ASCEND powertrains represent a significant step towards aviation decarbonization via electrification. However, integrating these new powertrains into aircraft clean sheet designs presents significant challenges and may take several years and efforts far exceeding ARPA-E's typical modest project scope focused on transformational technology risk reduction. Retrofitting an existing aircraft with at least one of the developed ASCEND IPTs or evaluating IPTs for aircraft planned for imminent release offer faster pathways to develop and validate the disruptive technologies required to integrate an IPT with an aircraft for electrified flight. Another approach is to evaluate an ASCEND IPT and test as a drop-in research option, referred to as a "shadow" option, for a more mature propulsion alternative that is nearly ready for electric flight. ARPA-E is interested to learn what missions such an aircraft could fly with ASCEND and PROPEL-1K technologies, and what the cost per average seat mile (CASM) difference an electrified aircraft could have versus a conventional aircraft for the same type of mission.[8]

Commercial aircraft are commonly classified by their maximum take-off weight (MTOW). Although electrified aircraft demonstrations have been successful for smaller aircraft, larger aircraft with MTOW more than 19,000 lbs (transport aircraft)[9] represent a more substantial category of aerospace's environmental footprint. Possible aircraft platforms of interest could be regional commercial aircraft, cargo platforms, and crewed or autonomous aerospace vehicles. ARPA-E is interested to learn which aircraft are, or could be, considered for electrification and how integration of one or more ASCEND IPTs could further accelerate the path for electrified aircraft to commercialization and technology maturation.

ARPA-E seeks to learn what transformational technologies are needed to integrate one or more ASCEND IPTs on an aircraft platform. Anticipated technical challenges could include but are not limited to aircraft electrical system architecture, fault management, advanced dynamic controls, electromagnetic interference (EMI) mitigation, structural integration, heat rejection integration, propellor and/or fan

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[6] ARPA-E/DOE, Funding Opportunity No. DE-FOA-0002238 and DE-FOA-0002239, *Aviation-class Synergistically Cooled Electric-Motors with INtegrated Drives (ASCEND)*, December 16, 2019. https://www.arpa-e.energy.gov/technologies/programs/ascend

[7] https://www.arpa-e.energy.gov/technologies/programs/ascend

[8] "*Technology Dashboard*." L.E.A.D.S. https://www.leadsresearchgroup.com/technology-dashboard .

[9] "*Standard Airworthiness Certification.*" Standard Airworthiness Certification | Federal Aviation Administration. https://www.faa.gov/aircraft/air_cert/airworthiness_certification/std_awcert/std_awcert_regs/regs .

integration, or propulsion system efficiency at high cruise speed. In addition, ARPA-E aims to understand if such a platform could also be used afterward as a testbed for other active and future relevant ARPA-E technology programs, such as REEACH, PROPEL-1K, and CIRCUITS (Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors).

Novel aircraft propulsion maturation takes time and effort that significantly exceeds ARPA-E's traditional scope. Although fully safe and certified flight is the aspirational goal, many sub-steps in a retrofit approach can serve as stepping stones to better fit a modest budget. Possible operations could be:

- Integration into the aircraft
- In-hangar testing
- Aircraft roll-out
- Airport taxiing
- Simulated and aborted take-off
- Limited flight under experimental certification

ARPA-E is interested to learn what sequence of sub-steps should be considered relevant to maturation of an innovative novel powertrain. It would be helpful to understand what quantitative achievements and aerospace standards, regarding both performance and safety, would be used to describe and characterize such sub-steps. For example, if roll-out and airport taxiing are considered significant, what standard of airport maneuvers would need to be met for an IPT-integrated aircraft to have capabilities matching existing aircraft today? Are any of these steps considered relevant and meaningful on a path to further commercial investment and commercialization?

To complete the picture, ARPA-E seeks to understand the anticipated cost and duration of such sub-steps. In addition, it is important to note that any IPTs developed under ARPA-E ASCEND are built for research purposes and are not anticipated to be designed or budgeted to the standard of aerospace certifiable commercial production parts.

Finally, electrified aircraft might require novel electric infrastructure at an airport to operate. This could include electrified charging infrastructure and other systems. Are airport electrification studies needed, and are transformational technologies needed to be developed in this area?

ARPA-E encourages responses from a broad range of stakeholders, including:

- Aircraft manufacturers and operators
- Powertrain developers and integrators
- Certification authorities
- Research institutions
- Airport operators and developers
- Other relevant stakeholders

RFI Questions:

The questions posed in this section are classified into several different groups as appropriate. Provide responses and information about any of the following. ARPA-E does not expect any one respondent to answer all, or even many, of the prompts in this RFI. In your response, indicate the group and question number. Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies that are not outlined below except for those that fall under the "Areas Not of Interest" described above. Specifically, ARPA-E is interested in understanding:

A. Possible aircraft that could be considered for integration of one or more ASCEND IPTs

1) Can existing aircraft structures and systems be safely and effectively modified to accommodate the weight, size, and power requirements of an ASCEND powertrain?
2) What are relevant aircraft to consider for integration of one or more ASCEND IPTs?
3) Would an aircraft with a MTOW greater than 19,000 lbs (CFR 14 Part 25 or equivalent) be more relevant for a transformational future study?
4) What would be the mission capability of such an aircraft (high-level Breguet-style analysis sufficient) with an ASCEND propulsion system and PROPEL-1K energy system?
5) Could such an aircraft become a test platform for future ARPA-E technologies such as PROPEL-1K?
6) What would be the approximate changes in operational cost (e.g., CASM for passenger aircraft or cost per ton-mile for cargo aircraft) and maintenance cost for an electrified version of this platform compared to the baseline for a feasible mission? (Assume $50/MWh electricity available).
7) Are you aware of similar active endeavors, in commercial development or in research, to establish in a relevant environment the functionality of a fully integrated electric powertrain at ASCEND power ratings (250 kW – 5 MW)? Why is ARPA-E's disruptive high-risk approach/high reward project support needed?

B. Transformational technologies for integration

1) What innovations are needed to address the technical challenges in the electrical domain on a retrofitted aircraft (e.g., EMI mitigation and fault management, and especially high voltage challenges at altitude)?
2) What control technologies are needed to operate an IPT-retrofitted aircraft?
3) Most of the ASCEND powertrains rely on a closed-loop cooling system that uses ambient air as the ultimate heat sink. From a heat management perspective, would the integration/retrofit of these IPTs be challenging? What heat management challenges would the retrofit face?
4) What other innovations are needed to realize an IPT integration?
5) What is a meaningful integration validation test?
6) Are there any additional challenges you foresee in IPT integration into an aircraft? What are the innovations needed to overcome these challenges?

C. Technology integration maturation steps

Add and/or remove rows in Table 1 below to identify steps that would be needed for propulsion system integration (research purposes, not production flight). Fill out additional columns based on the following questions:

1) What would be the time associated with each of these steps?
2) What would be a rough order estimate (ROM) cost of such a step?
3) What are relevant aerospace metrics or standards that could define such a step?
4) What facility or facilities upgrades would be needed?
5) What are the key regulatory steps needed to perform experimental test flights of the retrofitted electric aircraft?

Table 1. Technology integration maturation steps.

Step	Duration	ROM cost (research purposes, not production)	Relevant metric or standard	Facility requirements
1. Aircraft procurement				
2. Integration of IPT onto aircraft				
3. Testing of IPT on aircraft				
4. Roll-out				
5. Limited airport operations/taxiing				
6. Take-off and minimal flight under experimental certification				

D. Electrified Aircraft airport support systems and Relevant Technologies

1) What innovative technologies are needed to build up airport infrastructure required for future electrified aircraft?
2) What are the possible impacts of airport electrification?
3) What other transformational infrastructure innovations might be needed for electrified aircraft support?