Beyond SFNP

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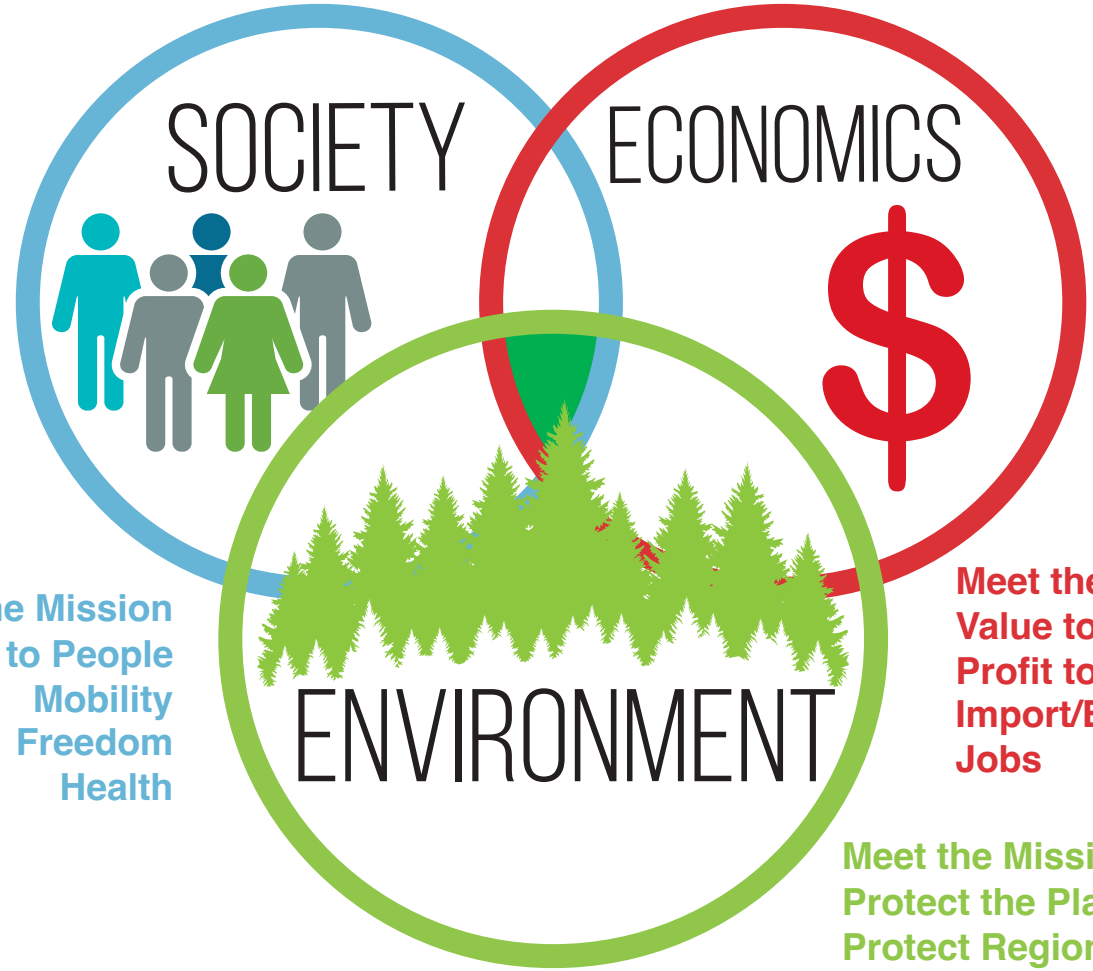
NASA Aeronautics Mission Directorate
ARTR Meeting, Washington, D.C., July 19, 2024

Agenda

- Background and Context
- Beyond SFNP Strategy Development
- Ongoing Discovery and Innovation Activities
- Thoughts on a National Partnership
- Questions and Reflections

Sustainability is Complex



Meet the Mission
Value to People
Mobility
Freedom
Health

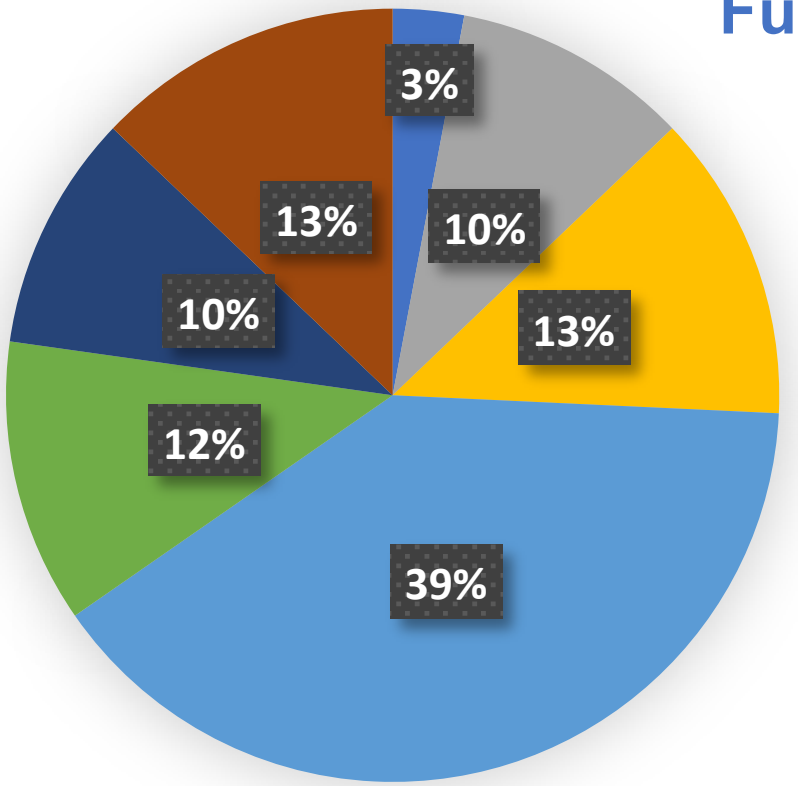
Meet the Mission
Value to Business
Profit to Shareholders
Import/Export Trade Balance
Jobs

Meet the Mission
Protect the Planet
Protect Regional & Local Ecosystems

Success requires meeting demand for mobility, connectivity, and improved quality of life with reduced energy/fossil fuel use, while remaining safe, quiet, economical and equitable.

Following the Fuel Burn

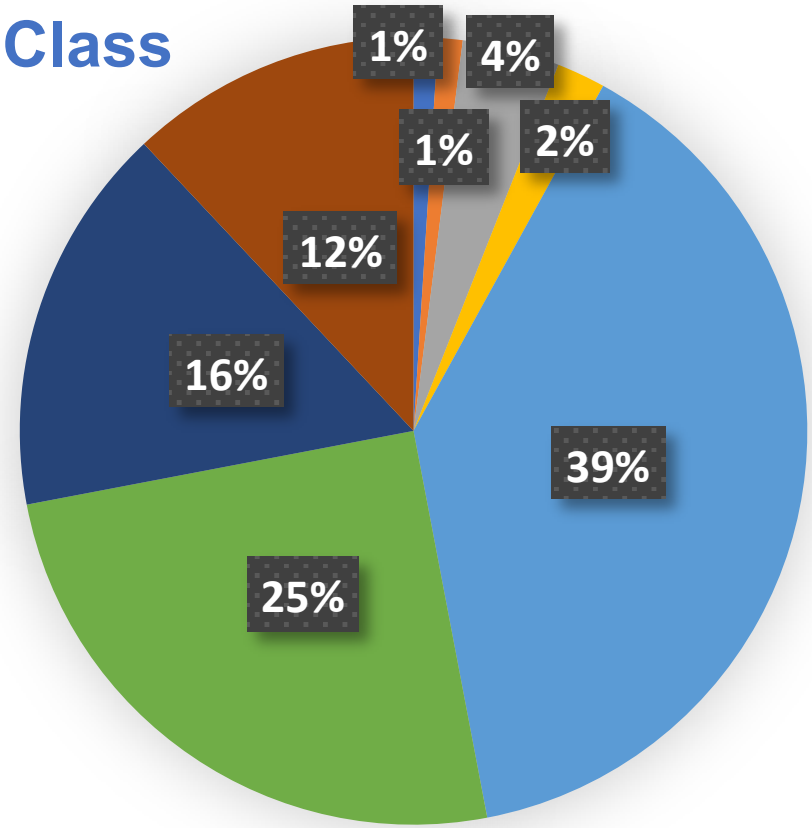
2012 Fuel Burn



Fuel Burn Contributions by Class

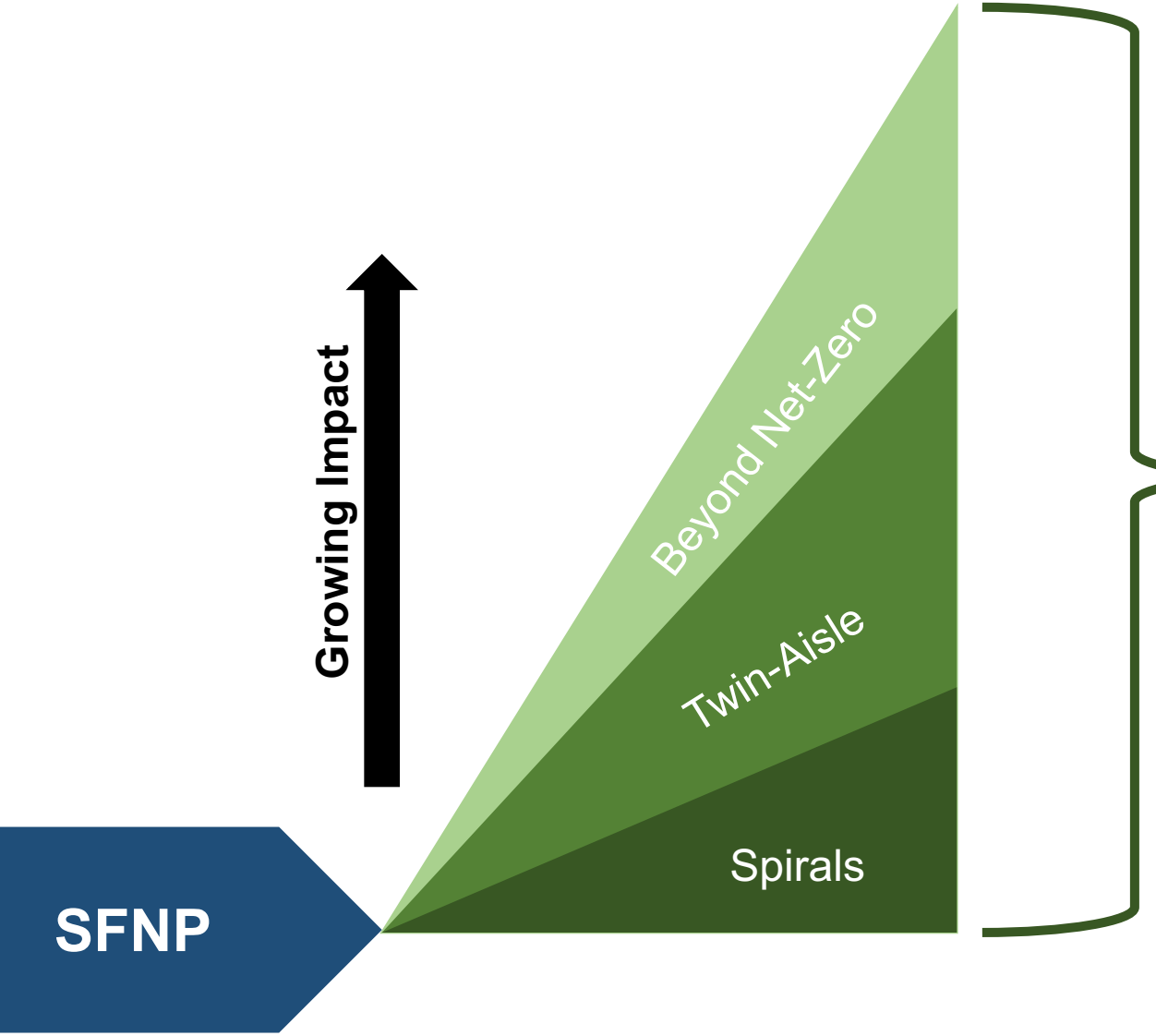
- Turboprop
- Business Jet
- Regional Jet
- Small Single Aisle
- Large Single Aisle
- Small Twin Aisle
- Large Twin Aisle
- Very Large Aircraft

2018 Fuel Burn



ARMD must prioritize technologies and solutions making biggest impact soonest.
Single and twin aisle comprise more than 80% of commercial aviation fuel burn.

A Balanced Beyond-SFNP Strategy



The Beyond-SFNP strategy must:

- Support the transformation area and express needs of the US aviation industry and flying public
- Build from ARMD's unique capabilities and national role in aviation
- Set aggressive, and realizable, vehicle technology and system concept goals
- Be subject to the realities of continued budget and schedule pressures

Striking this balance must be our priority.

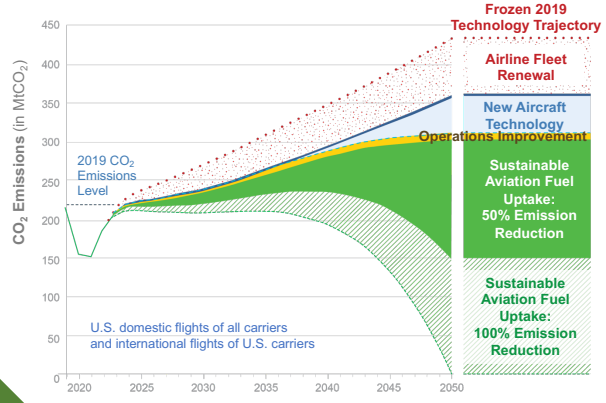
The Long Game: Aviation Eras on the Path Toward Sustainability

Net-Zero GHG, 2050

2020s → 2030s → 2040s → 2050s → 2060s

Era One: Evolution *(Change is Coming)*

Tube-and-Wing, Existing Infrastructure, Transition to Drop-In SAF, Increasing Electrification



Era Two: Revolution *(SFNP Realized)*

Vehicle Architecture Change, Major SAF Adoption, Mild Hybrid EAP, Minor Infrastructure Change

Era Three: Transformation *(Paradigm Shift)*

Major Vehicle Architecture Change, Non-Drop-In Fuel Adoption, Many-MW EAP, Major Infrastructure Change

Growing Risk ↓

Growing Potential Impact →

ARMD must make deliberate, long-term investment in broad-ranging technologies outside industry's risk tolerance

Beyond SFNP: Long-Term Transport Technology and Innovation

Generational studies to inform future technology investments

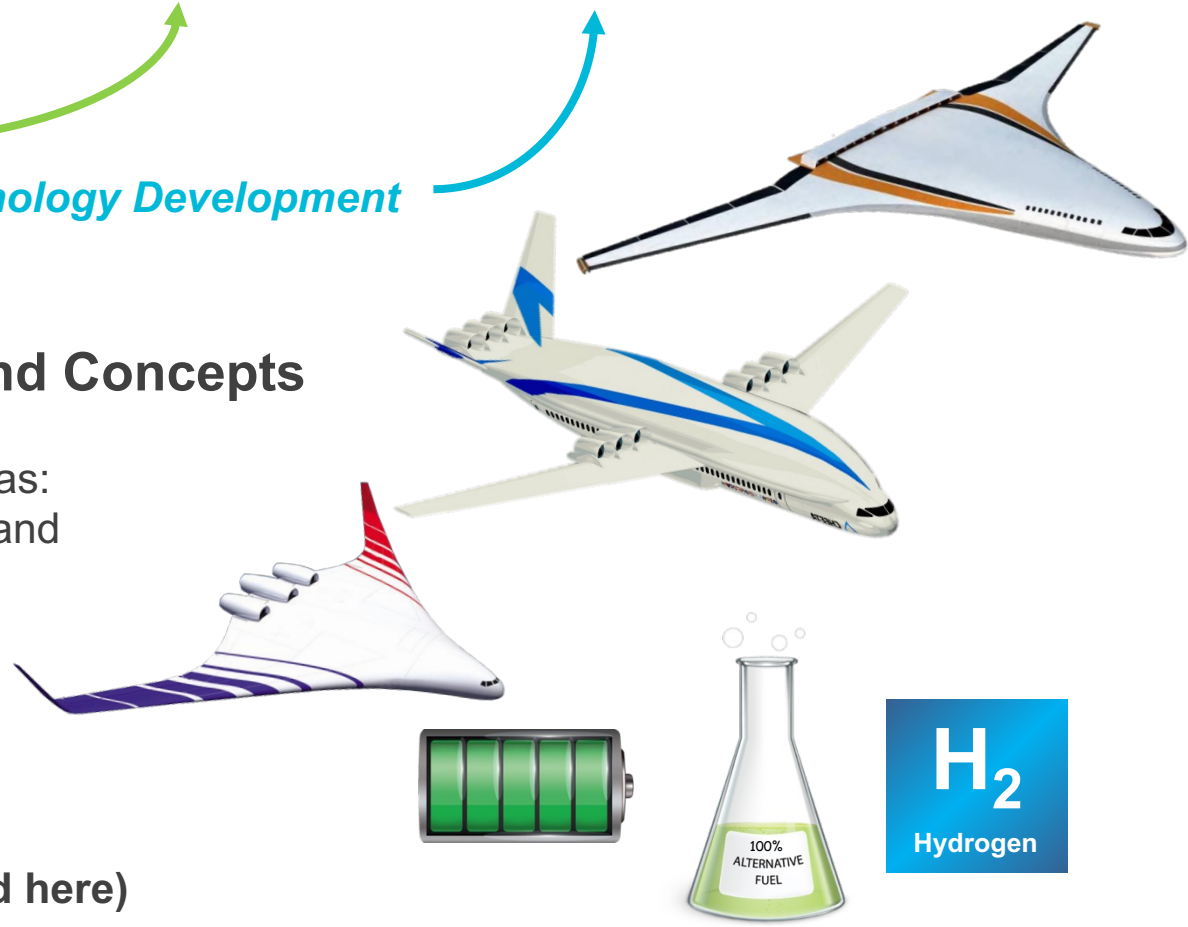
2008-2019 | 2020-2029 | 2030 - 2039 | 2040 - 2050

Subsonic Fixed Wing

N+2 Studies, ERA for the 2020s Impact

N+3 Advanced Concept Studies for 2030s Impact

Concept Studies and Technology Development Needed for 2040s Impact



Opportunities to Define Future Aviation Systems and Concepts

- ARMD-commissioned strategic assessments across multiple areas: Propulsion; Electrified Aircraft Propulsion; Materials, Structures, and Manufacturing; Future Flight Demonstrations
- AACES Advanced Concept Studies for 2040+ EIS
- Net-Zero Emissions Concepts
- Promising Technologies and Architectures
- Support Aviation Community with NASA-unique Contributions

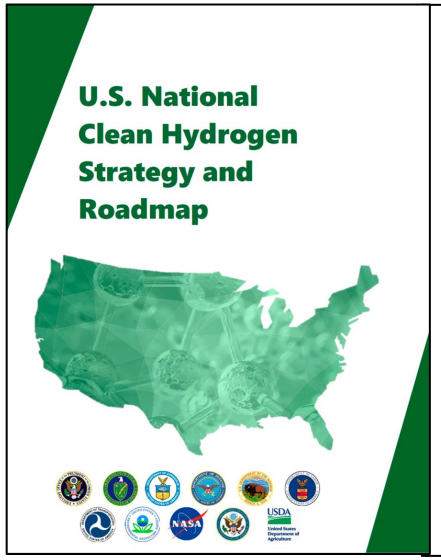
Note: Advanced Airspace Operations is also key (not discussed here)

Beyond SFNP as Part of a National Strategy

FAA

Net-Zero GHG emissions from aviation by 2050

Assumption of SAF-dominated aviation fuels landscape



DOC/DOD/DOE/DOI/DOL/ DOT/EPA/NASA/USDA+

National clean H2 production and infrastructure strategy

National H2 production goals:

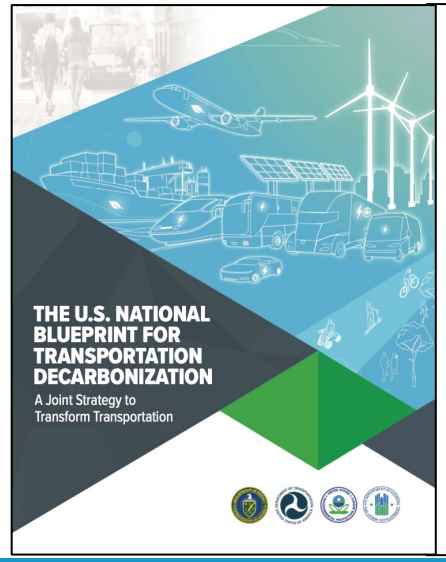
- 10MMT/year by 2030
- 20MMT/year by 2040
- 50MMT/year by 2050

DOE/DOT/FAA/USDA/EPA

References US Aviation Climate Action Plan goals

Establishes national goals for SAF production of:

- 3B gal/year by 2030
- 35B gal/year by 2050



DOE/DOT/EPA/DOH

Transportation sector wide decarbonization strategy

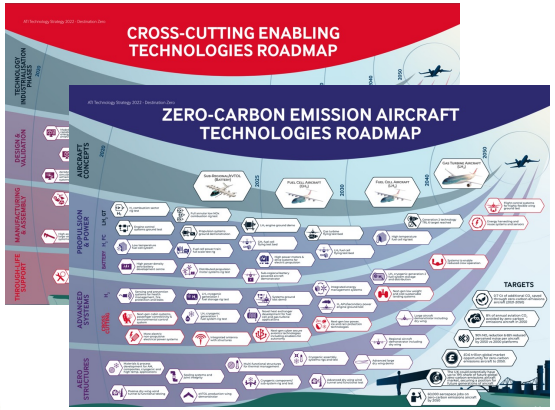
Three strategic pillars:

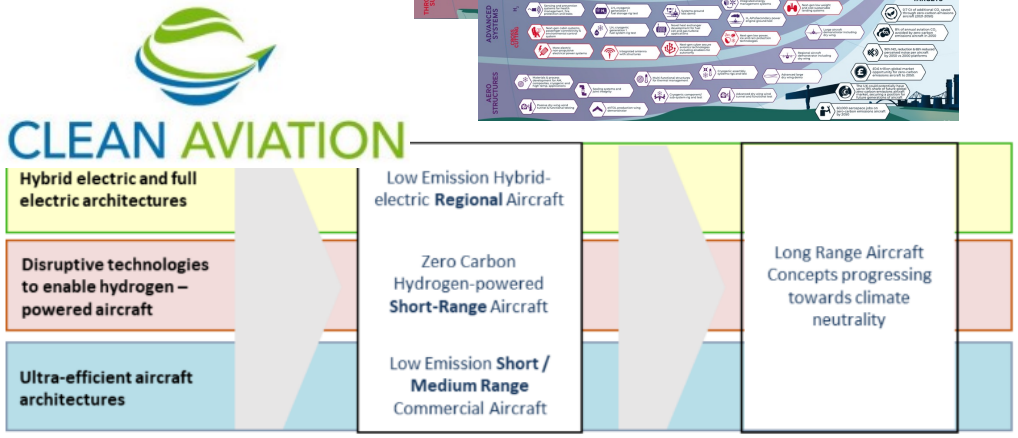
1. Community redesign
2. Improved efficiency
3. Transition to clean fuels

Metrics and goals are important. We can look to other government agencies for guidance but must keep in mind the unique role that ARMD plays in the aviation community when setting our own.

Beyond SFNP as Part of an International Strategy

AIRBUS ZEROe Program



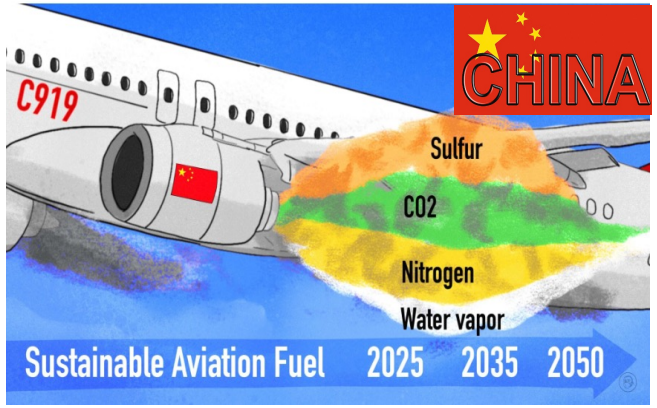


INSAT
Initiative for sustainable aviation technology

JAXA Aviation Technology Directorate

Sky Green+ →

Contributing to environment- and user-friendly sustainable air transport



"Green Aviation Manufacturing Development Outline (2023-2035)." Focus on SAF production.

Carbon neutrality is a global objective.
Countries around the world are implementing aviation sustainability strategies to achieve this goal.

The Importance of a Balanced Portfolio

- Far-term projections are fraught with uncertainty
- In the face of uncertainty, diversification and hedging is a critical element of strategy
- Value in broad applicability (future scenario, future vehicle product, stakeholder interest, transformation area, etc.)

What will the energy carrier of the future be?

- SAF production capability is increasing
- Biomass pathway SAF production faces scalability challenges (water, land, feedstock)
- PtL SAF: The US is leading, and forecast to lead, in production through 2030

Latest forecasts show the US missing its 2030 SAF production goals by ~30% (0.9-1.4 bn gal)

- A green hydrogen economy is developing around the world – US, EU, China, +
- The US is leading, and forecast to lead, in green hydrogen capacity through 2030
- H2 production does not necessarily equate to availability for aviation applications

Latest forecasts show the US will miss its 2030 clean H2 production goal by ~40% (3.9 MMT)

Key Findings from ARMD Strategy Assessment Studies

Considered information from multiple sources… and still collecting more

- ARMD strategy studies; Gov/Industry Workshops; Internal Studies; AACES; OGA/Industry Engagement

Key themes emerging

- Likelihood of multiple fuels availability
- Heightened opportunities around vehicle integration
- Leveraging Computational Materials and Structures
- Increased need to consider market dynamics and implications beyond the vehicle

Initial assessment identified multiple research and technology opportunities:

- Power and Energy: Superconducting EAP; High-Perf Heat Exchange and TMS; Advanced Cycles
- Aircraft Integration Technologies: Distributed Propulsors; Cryo Fuels; Advanced CFD and MDAO for PAI
- Materials and Structures: Computational Materials; Cryo Tanks and Integrated Structures; Next Gen Manufacturing – Qual/Cert for Additive Manufacturing, and Digital Engineering

- Critical gaps requiring further study (Integrated cryogenic fuels strategy and vision concepts, high-power EAP vision concepts, multi-domain, sector-level systems assessment capability, strategy development within computational materials and structures sub-domain)

The time is now for ensuring the future ARMD portfolio reflects complexity of achieving sustainability. Balanced investment in light of significant uncertainty beyond SFNP is critical to making impact.

Ongoing Beyond-SFNP Zero Emissions Activities

Transformational Tools and Technologies Project
Innovative solutions through foundational research and cross-cutting tools

Call for Proposals: Green Aviation Seedling Research – Due Oct 13

Summary: The T³ project is soliciting research proposals for innovation in green aviation. Review the criteria below and submit your proposals electronically by Oct 13, 2023.

Introduction

Transformational Tools and Technologies Project

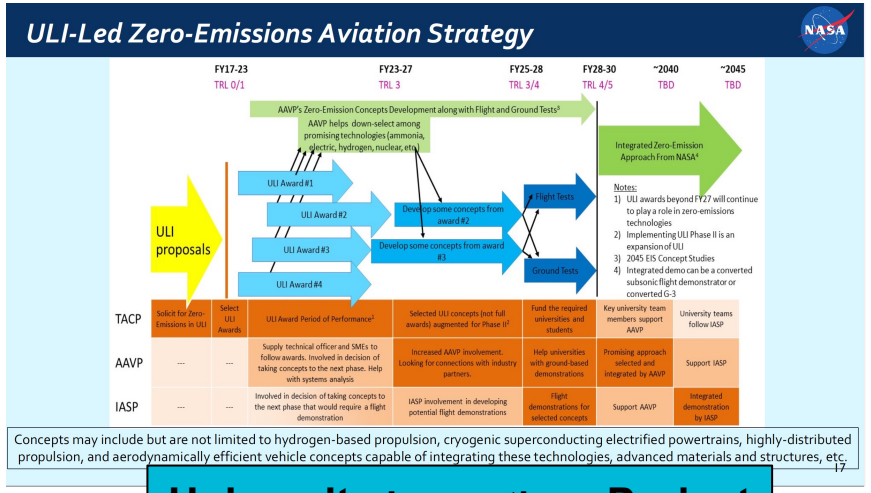
- Green aviation exploratory investments
- Battery systems and prognostic safety
- Advanced materials
- MDAO tools for advance vehicle configuration design

w/ OSTEM

Gateways to Blue Skies Competition

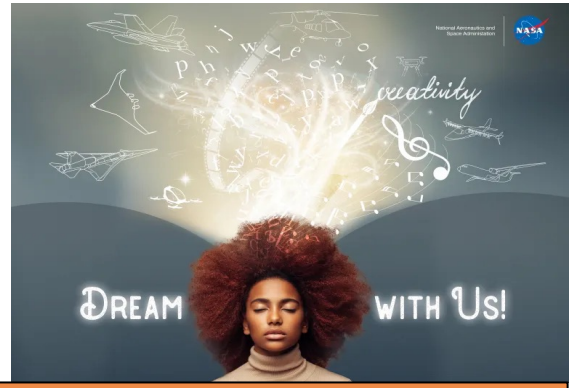
Convergent Aeronautics Solutions Project

- Green aviation future system concepts
- Power beaming
- AI discovery tools for transformative future states



University Innovations Project

TACP serves as the ARMD Innovation Ecosystem evolving an opportunity roadmap



w/ OSTEM

Dream with Us Design Competition

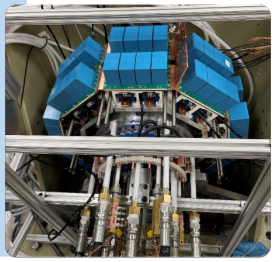
TACP's Zero Emissions portfolio is a fertile breeding ground for low-TRL concepts and technologies. Strong ties between AAVP and TACP are foundational to this transformation area.

Ongoing Beyond-SFNP University Innovation Project Investments

Electric Propulsion

Ohio State University (1 MW motor)

- Developed 9 kW/kg, 95.8% efficient integrated modular motor drive
- No partial discharge observed at 50,000 ft in NASA NEAT facility



Hydrogen

University of Illinois, Urbana-Champaign
(Cryogenic hydrogen electric aircraft)

- Superconducting motors and power transfer, Liquid hydrogen tanks
- Hydrogen fuel cell, Cryogenically-cooled power electronics

Florida State University
(Hydrogen powered hybrid electric aircraft)

- Combination of turboelectric generators and fuel cells
- Develop power electronics, power distribution, and manage thermal loads

Ammonia

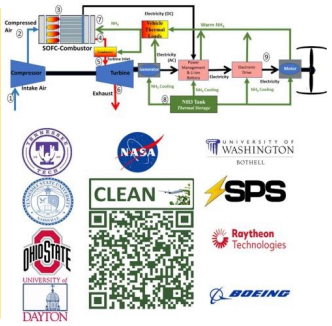
University of Central Florida
(Cracking ammonia for hydrogen propulsion)

- Ammonia as a hydrogen carrier, NOx control, and thermal management
- Supercritical carbon dioxide waste heat recovery system

Ammonia as a Liquid for the Future of Aviation

Tennessee Technological University
(Ammonia based power generation)

- Integrate an ammonia-based Solid Oxide Fuel Cell-Combustor and a turbogenerator
- Distributed electric propulsion



From Student Competition:
Aluminum Powder, Energy Beaming, Nuclear

Measuring Progress: Updated Subsonic Transport Metrics

Approach for updating table:

- Move toward current standards
- Timeframes reflect current strategy
- Goals traceable to studies
- Balanced goals - aspirational and technically feasible

- Mid Term goals reflect latest SFNP strategy and sync with FAA CLEEN Phase IV goals for the same metrics (see next chart)

- Far Term goals reflect the uncertainty in the fuel/energy landscape beyond 2040 (i.e., SAF-dominant vs. beyond-SAF)

Draft currently undergoing final internal review

AIRCRAFT TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)	
	Mid Term By 2030	**Far Term** By 2040-2045
Energy Consumption[1,2] (below CAEP 10)	35%	50% 35% w/ zero operational GHG emissions
LTO NO_x Emissions[2,3] (below CAEP 8)	75%	>75%
LTO nvPM Emissions (below CAEP 11)	50%	75%
Noise (cum below Stage 5)	25 dB	35 dB

1) CAEP 10 CO_2 metric is energy-use based; energy use per available seat-mile also tracked
2) Life-Cycle GHG emission benefit from sustainable aviation fuels (SAFs) is additional, with possible trades between energy efficiency and non-drop-in fuels recognized in the Far Term
3) CAEP standards for Cruise NO_x are not yet established
4) Aircraft operations improvements may yield significant system-level efficiencies and reduced atmospheric impacts in time at the fleet and vehicle levels

The updated metrics table represents a move toward standards-based metrics and traceable goals, while acknowledging uncertainty of Far Term energy futures in the Beyond-SFNP timeframe.

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SUBSONIC AIRCRAFT TECHNOLOGY BENEFITS[1]	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Mid Term By 2030	**FAA CLEEN IV** EIS 2035	**Far Term** By 2040-2045
Energy Consumption[2,3] (below CAEP 10)	35%	35%	50% 35% w/ zero operational GHG emissions
LTO NO_x Emissions[3,4] (below CAEP 8)	75%	70%	>75%
LTO nvPM Emissions (below CAEP 11)	50%	50%	75%
Noise (cum below Stage 5)	25 dB	25 dB	35 dB

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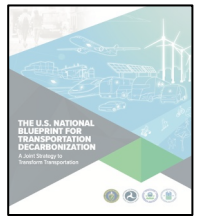
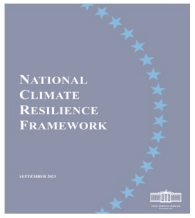
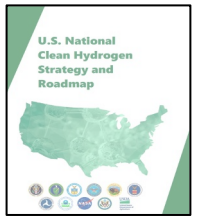
Thoughts on a Beyond SFNP National Partnership

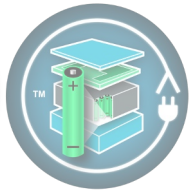


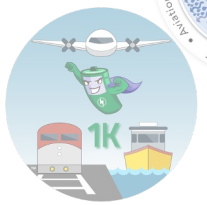


Joint Office of Energy and Transportation



U.S. Department of Transportation





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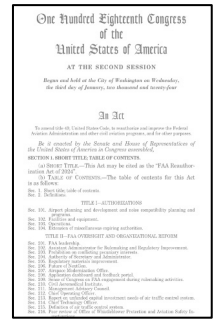
U.S. DEPARTMENT OF ENERGY

U.S. Department *of* Defense

Federal Aviation Administration



DEFENSE INNOVATION UNIT

AFRL
AIR FORCE RESEARCH LABORATORY

ROLLS ROYCE

PRATT & WHITNEY DEPENDABLE ENGINES

GT

STATE

VT

UNIVERSITY of VIRGINIA

UCONN

O

Academic CoEs + UTCs

The next National Partnership will require us to think broadly - *beyond the OML*.
Strong cross-government and academic partnership will be critical to enabling an alternative fuels future for aviation.

Path to Refining Beyond-SNFP Strategy

Phase 1

Phase 2

Define goals by understanding strategic needs

- Engage industry, academia, and OGA
  - Component, engine, airframe manufacturers
  - Other government agencies (FAA, DoD, DoE, etc.)
- Identify major technical challenges

Identify how NASA can support

- Assess the broad range of ongoing NASA activity
- Leverage past studies
- Coordinate between strategy teams to ensure complementary activities with minimal overlap/gaps

Develop paths to reach defined goals

- Select/evaluate system-level technology that is ready for maturation
- Develop technology timeline for future demonstration / technology maturation

Questions and Reflections

To maintain perspective on Beyond SFNP investment opportunities, we expect to remain engaged with a similar stakeholder community as today. Not wrong, but perhaps insufficient.

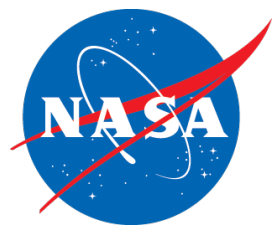
- Who are the most important communities to engage? Industry, Venture Capitalists, OGA, Academia, International Market Players?

We've just discussed numerous approaches and examples of potential opportunities

- Do you see a roadmap evolving?

What do you see as future trend lines that we should explore?

- Are we missing anything?


NASA