NREL
Transforming ENERGY

Transforming Energy Through American Innovation

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NREL at-a-Glance

2,926

Workforce, including

219 postdoctoral researchers

60 graduate students

81 undergraduate students

World-class

facilities, renowned technology experts

More than **900**

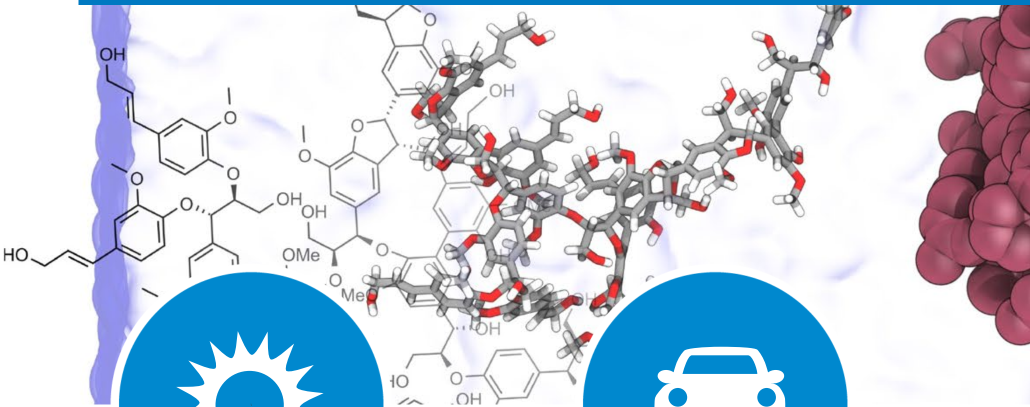
Partnerships

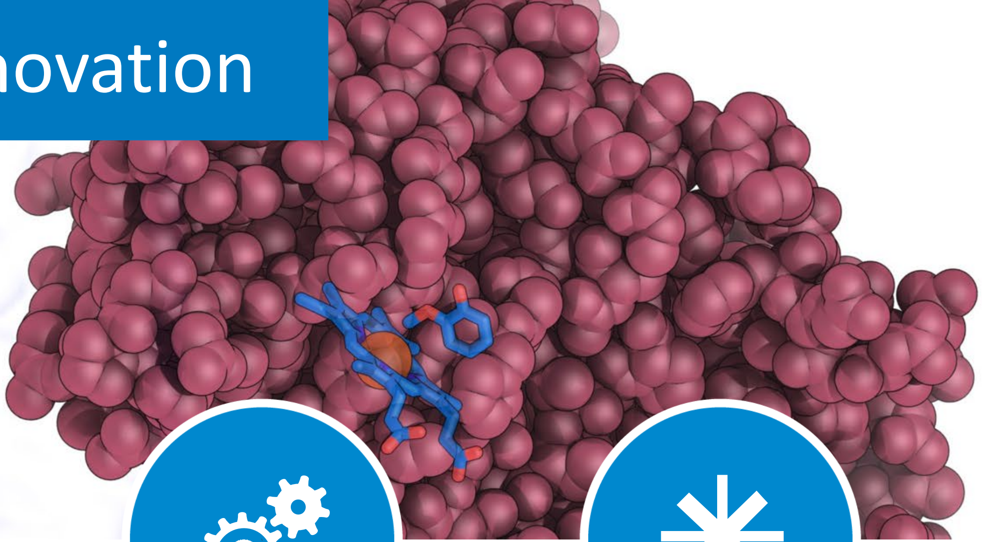
with industry, academia, and government

Campus

operates as a living laboratory

NREL Science Drives Innovation





Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

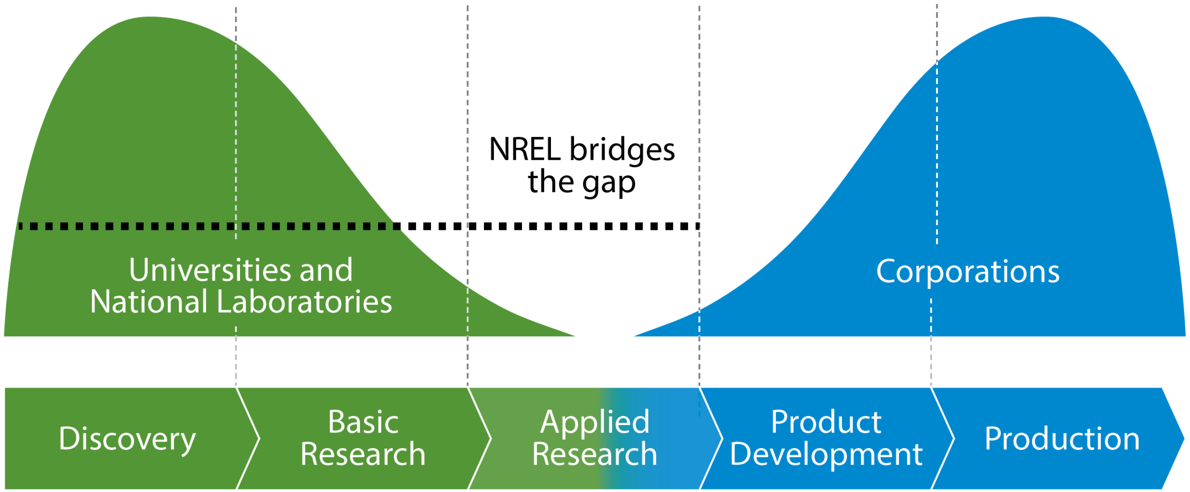
Grid Integration

Hybrid Systems

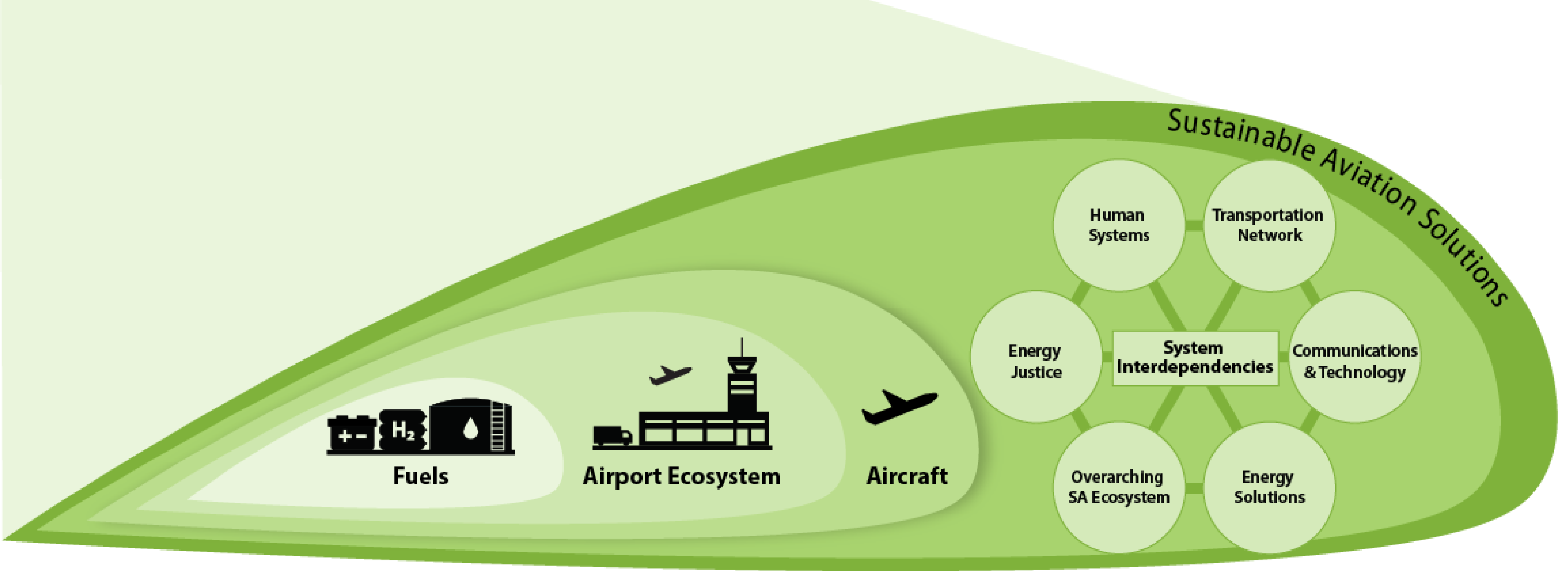
Security and Resilience

We Reduce Risk in Bringing Innovations to Market

- NREL helps bridge the gap from basic science to commercial application
- Forward-thinking innovation yields disruptive and impactful results to benefit the entire U.S. economy
- Accelerated time to market delivers advantages to American businesses and consumers



Sustainable Aviation Ecosystem



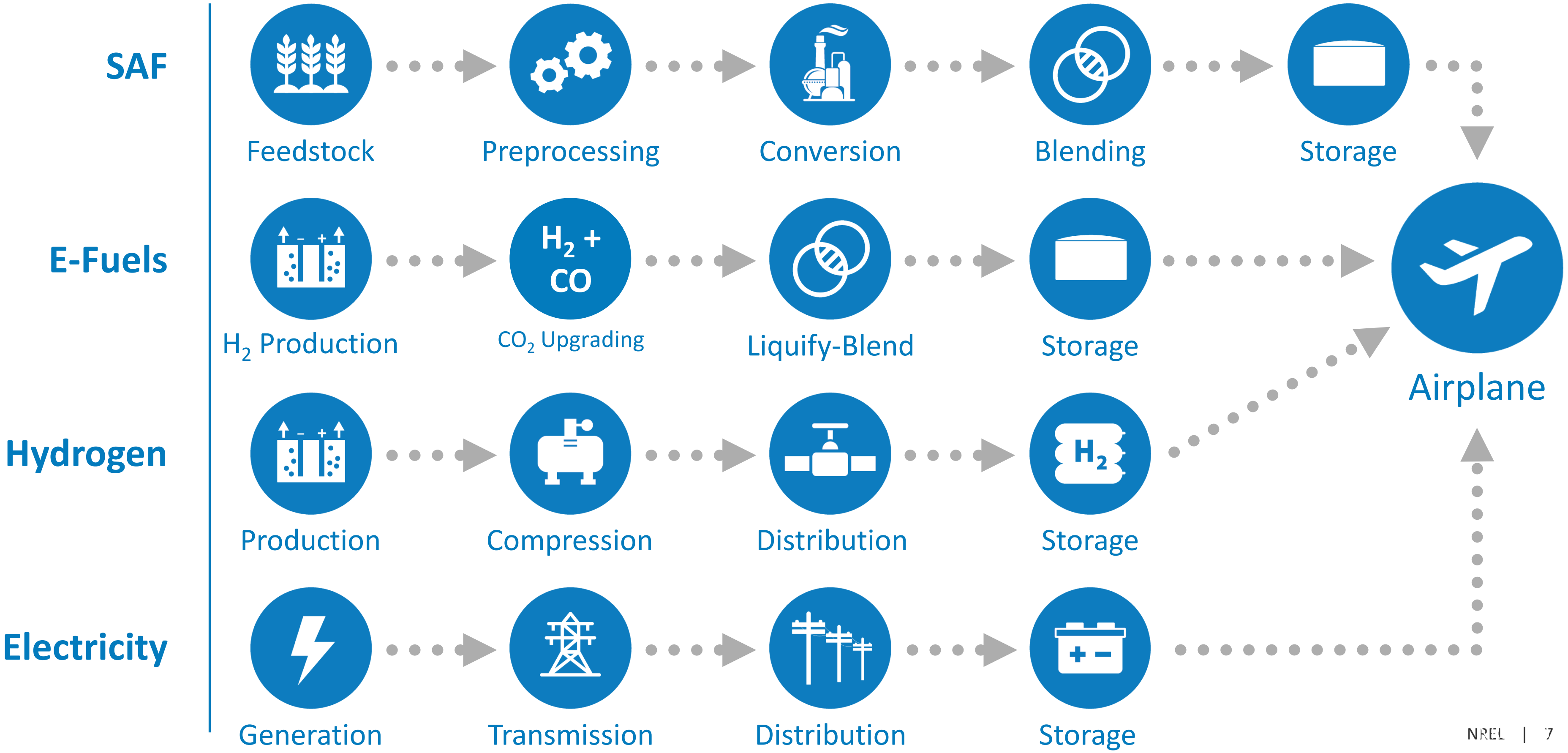
NREL Capabilities: Research, Analysis, Modeling, Validation/Deployment

Aviation Low and Zero-carbon energy sources

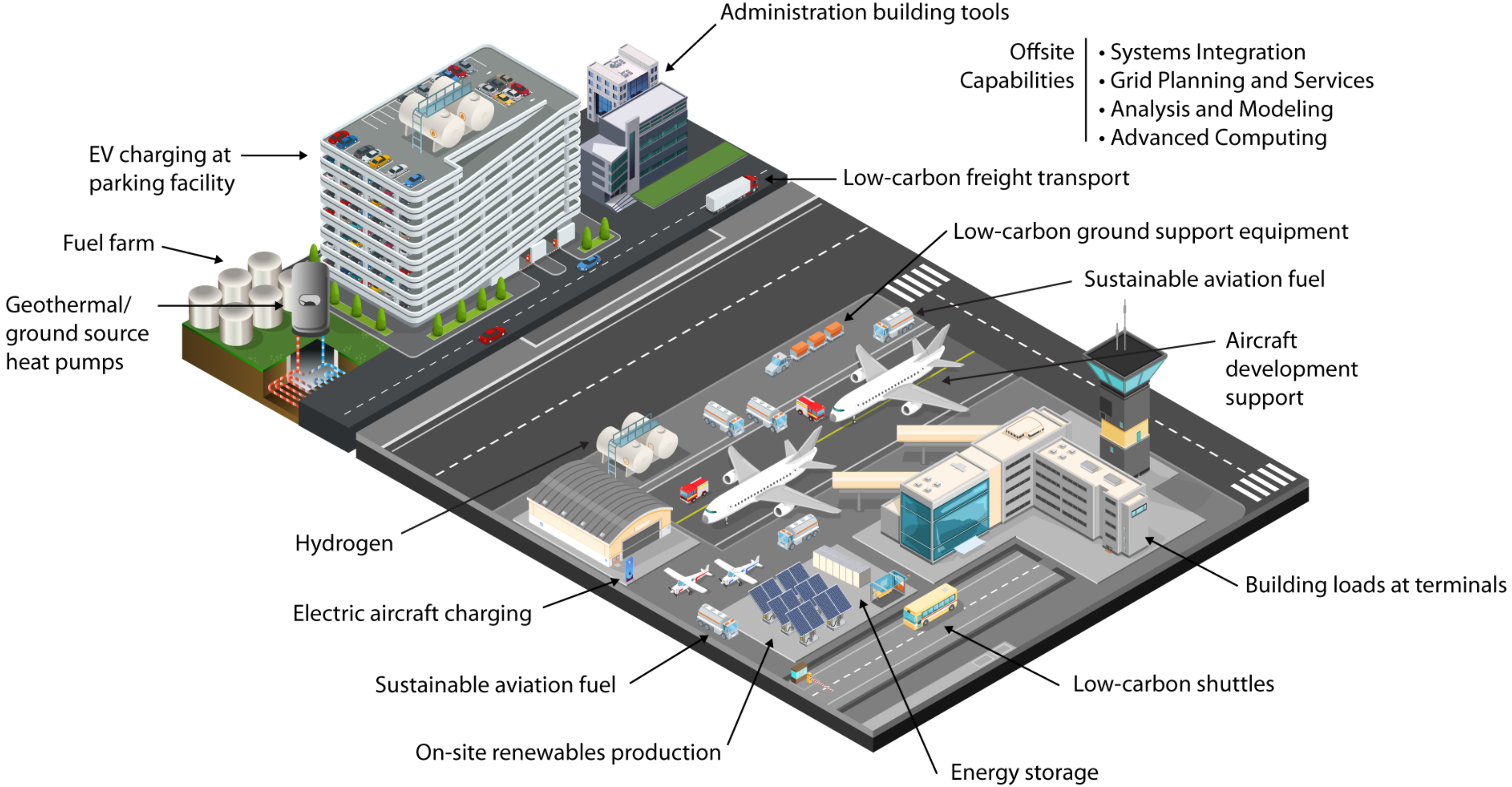
					2040	2045	2050
Commuter » 9-50 seats » <60 minute flights » <1% of industry CO2	SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO2	SAF	SAF	SAF	SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF
Medium haul » 100-150 seats » 60-150 minute flights » ~43% of industry CO2	SAF	SAF	SAF	SAF	SAF	SAF	SAF Potentially some Hydrogen
Long haul » 250+ seats » 150+ minute flights » ~30% of industry CO2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

Source: ATAG Waypoint 2050 Report

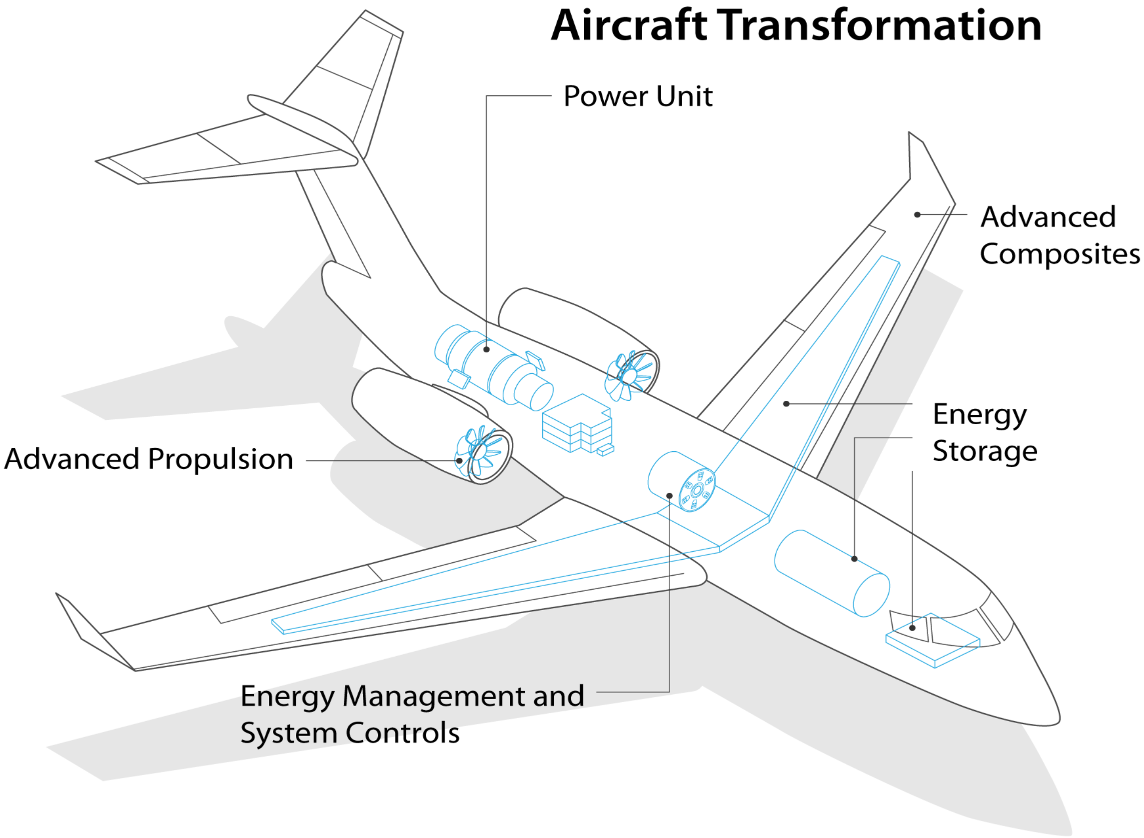
Next-Gen Aviation Energy Supply Chain



Airport/Base System



Aircraft



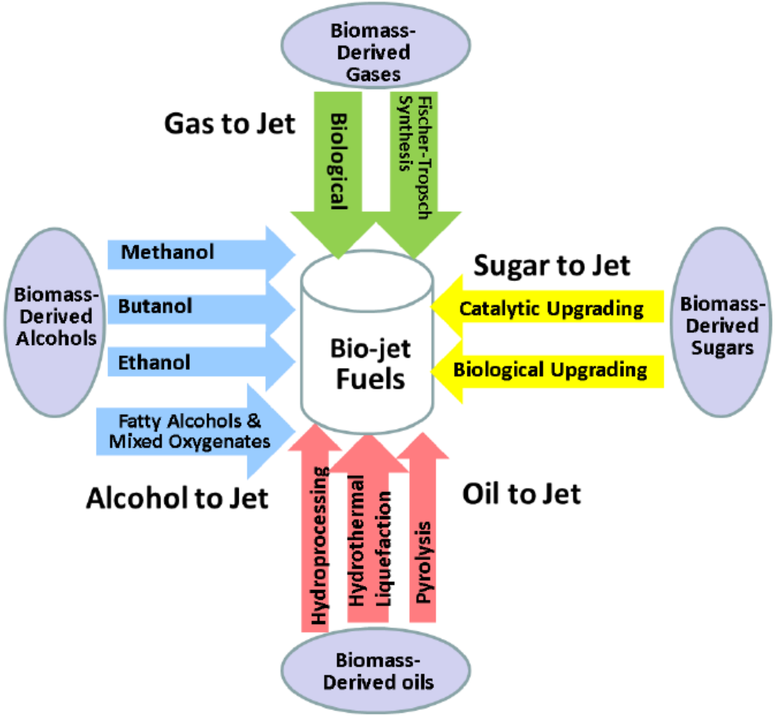
eVTOL

Regional Air Mobility

Turbine Aircraft

Sustainable Aviation Fuel (SAF) Development

- Agencies Engaged
  - Department of Commerce
  - Department of Defense
  - Department of Energy
  - Department of Transportation
  - FAA
  - EPA
  - NASA
  - NSF
  - USDA



More information from: http://www.nrel.gov/docs/fy16osti/66291.pdf

What about Electrified Aviation?

- Case Study – Essential Air Service – Denver
  - Four routes served by Pilatus PC-12

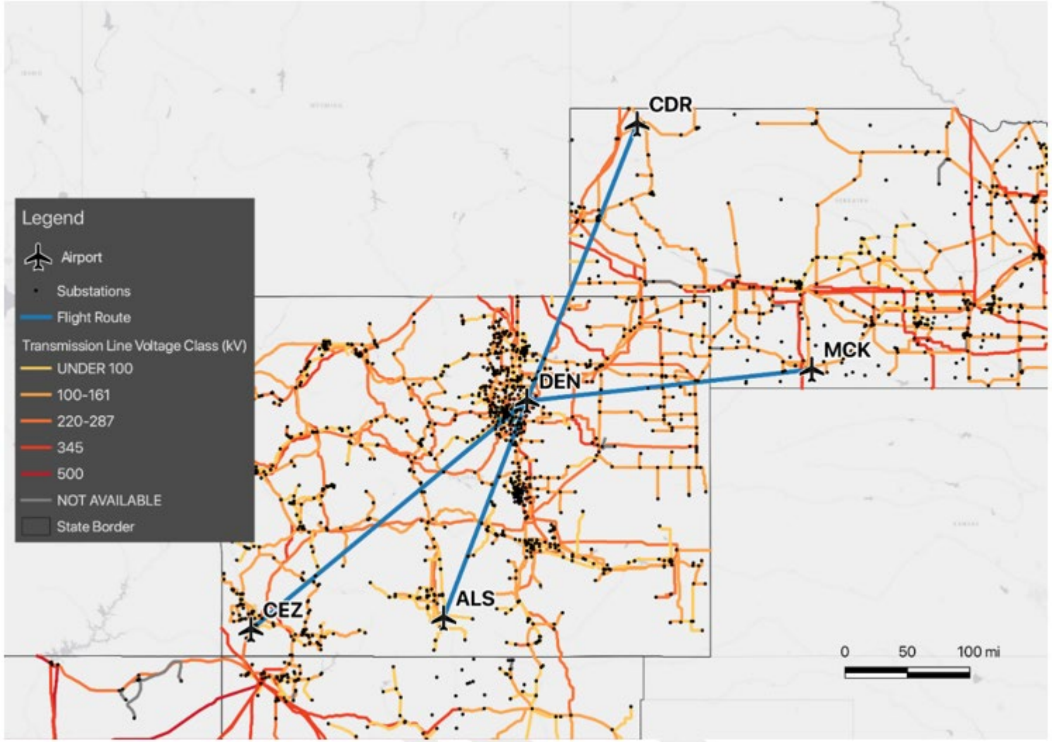


Figure 2. Case study area

Illustration by Emma Robertson, NREL

Essential Air Service Subsidies

Table 2. Essential Air Service Subsidies (2019–2022)[a] and 2020 Enplanements for Markets Served within 280 Miles of Denver International Airport

Airport[b]	2019	2020	2021	2022	2020 Enplanements[c]
MCK	$2,462,456	$2,511,705	$2,561,939	$2,613,178	1,269
CDR	$2,456.787	$2,518,208	$2,737,716	$2,808,159	2,462
ALS	$2,891,307	$2,949,133	$3,505,574	$3,505,574	4.742
CEZ	$3,579,703	$3,669,195	$3,760,925	$3,854,948	5,603

[a] "Essential Air Service," Department of Transportation Accessed August 2021. https://www.transportation.gov/policy/aviation-policy/small-community-rural-air-service/essential-air-service, accessed August 2021. Data for 2022:, MCK: USDOT 2018-5-10 Order Re-Selecting Air Carrier and Establishing Subsidy Rates; CDR: USDOT Order 2021-4-6 Selecting Air Carrier: file:///Users/aschwab/Downloads/DOT-OST-2000-8322-0160_attachment_2.pdf, ALS: USDOT 2020-9-17 Order Extending Contract, https://www.regulations.gov/document/DOT-OST-1997-2960-0193; CEZ: 2018-8-1 Order Re-Selecting Carrier and Establishing Subsidy Rates, https://www.regulations.gov/document/DOT-OST-1998-3508-0062

[b] MCK = McCook Ben Nelson Regional Airport; CDR = Chadron Municipal Airport, ALS = San Luis Valley Regional Airport; CEZ = Cortez Municipal Airport

[c] "Passenger Boarding (Enplanement) and All-Cargo Data for U.S. Airports," FAA, last modified August 12, 2021, https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/.

Essential Air Service Subsidies

Table 3. Information for Select Flights from Denver (DEN) for Liquid-Fueled and Electric Aircraft

Destination	Flights /day	Miles	Flight Time (mins)	Fuel Use (gals)	Fuel Costs[a]	$kgCO_2$ /PAX[b]	kWh (approx.)	Electricity Cost[c]	$kgCO_2$ /PAX Coal[c,d]	$kgCO_2$ /PAX Solar[c,d]
ALS	4	179	80	88	$440	36	334	$43	34	2
CEZ	3	277	80	88	$440	56	516	$66	53	3
MCK	2	217	65	72	$358	44	404	$52	41	2
CDR	2	222	70	77	$385	44	414	$53	42	2

[a] Assuming a $5/gallon fuel cost [14]

[b] PAX= number of passengers carried by an airline, assuming eight passengers.

[c] Based on commercial electricity costs for Cortez, Colorado; these values provide a conservative estimate of the electricity costs. Industrial electricity cost pricing could provide a 50% reduction in these costs.

[d] kg CO2 calculated from the use of coal and utility scale solar to produce the needed amount of energy ("IPCC Working Group III – Mitigation of Climate Change, Annex II Metrics and Methodology" IPCC https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-ii.pdf#page=26).

Initial finding – high subsidies in place where a new technology can reduce operating cost, emissions, and potentially noise. Infrastructure cost, energy demand models needs more analysis.

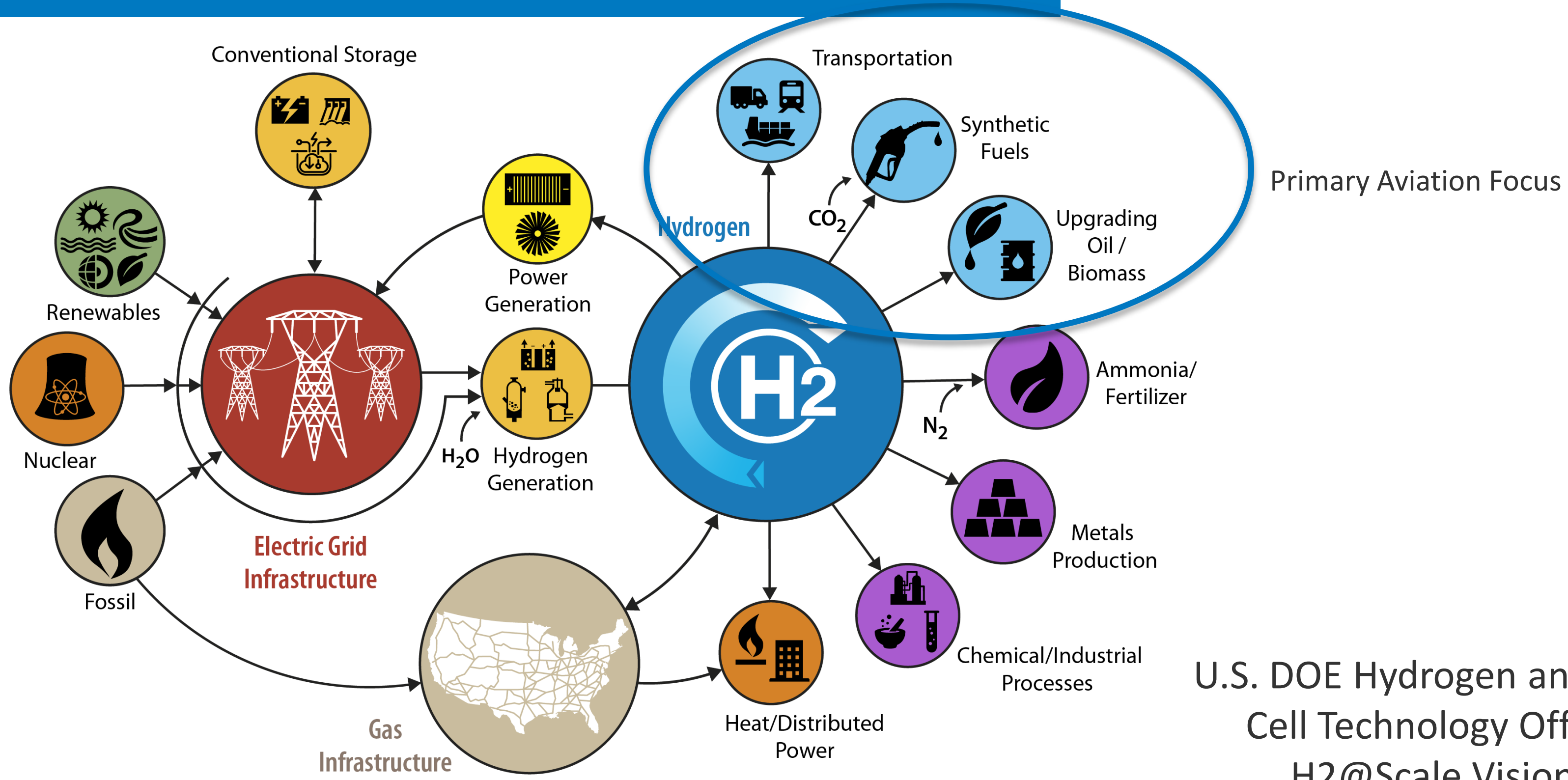
Infrastructure Peak Loads

Potential load impacts of 2019 flight schedule between DEN and ALS, CDR, CEZ, and MCK

Initial indications of charging implications

- Charging capabilities
  - Current High power charging – maxes at 350kW
  - Class 8 Truck – 1MW Charging Analysis underway
  - CHARin- Testing 3.75MW testing standard
  - Initial deployments possible
  - Scale and battery improvements are focus area
- No Standard currently exists in Aviation
  - eVTOL – appears focusing on existing technologies with potentially cooling of cables, batteries, etc.
  - RAM – appears targeting 1MW level and higher to meet ops pace

Hydrogen



U.S. DOE Hydrogen and Fuel Cell Technology Office H2@Scale Vision

Hydrogen

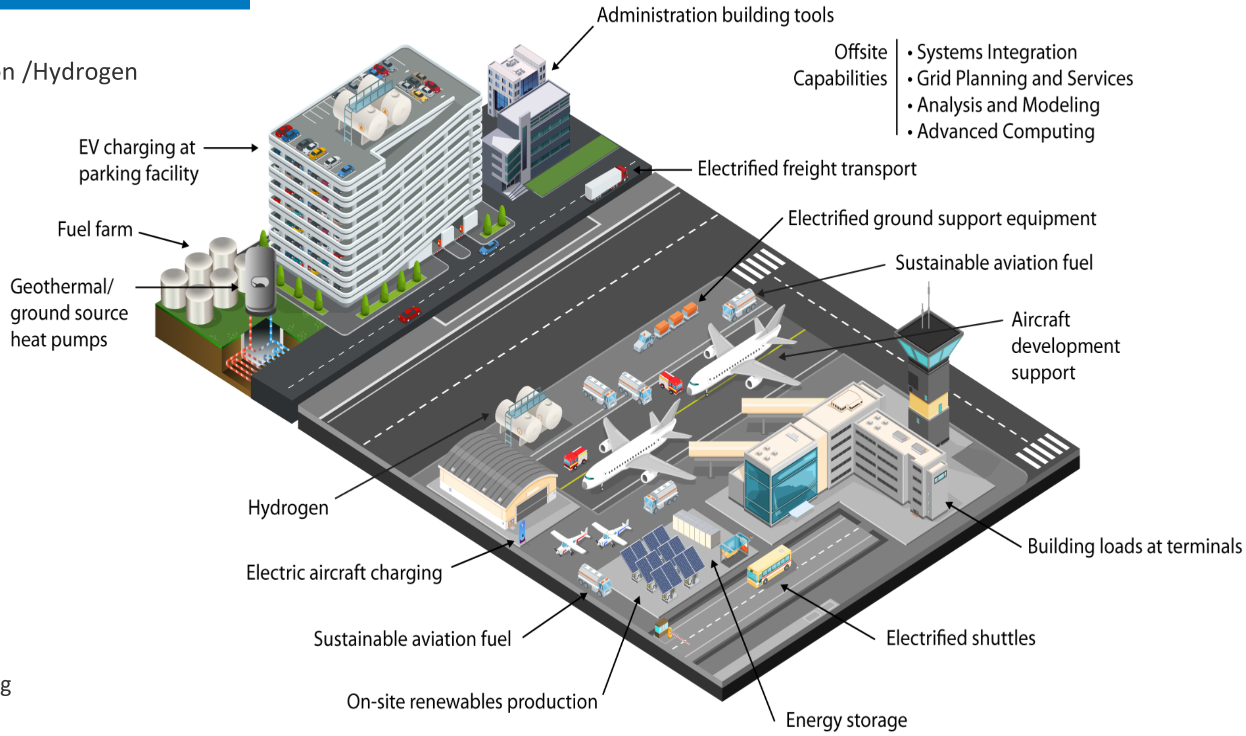
- Department of Energy announced Earth Shot – 2021

- Multiple OEM's moving forward
  - Airbus/Universal Hydrogen/ZeroAvia/Cranfield Aerospace
- FAA – currently focusing upon SAF- H2 contributes to some pathways
- Growing interest and energy delivery models growing

- https://www.energy.gov/eere/fuelcells/hydrogen-shot

Who is working on solutions to assist industry?

- FAA
  - Sustainable Aviation Fuel/Electrification /Hydrogen
- Department of Defense
  - AFWERX – Agility Prime
  - AFRL
- Department of Energy
  - Sustainable Aviation Fuel
  - Grid Modernization
  - Onsite energy solutions
  - Charging system fundamentals
  - Cybersecurity/Energy Resilience
  - Battery technologies
- NASA
  - Prototype aircraft
  - Regional Air Mobility –
    - Regional Energy Analysis – Pending
  - Grand Challenge
- State DOT/Cities



Resources

- A sampling of resources/activities:
  - NASA RAM study https://sacd.larc.nasa.gov/ram/
  - WSDOT electrification study https://wsdot.wa.gov/sites/default/files/2020/11/18/Electric-Aircraft-Feasibility-Study-Nov2020.pdf
  - NREL
    - SAF Delivery https://www.osti.gov/biblio/1768316-airport-infrastructure-sustainable-aviation-fuel- Partner with PANYNJ
    - SAF Production https://www.nrel.gov/news/program/2021/from-wet-waste-to-flight-scientists-announce-fast-track-solution-for-net-zero-carbon-sustainable-aviation-fuel.html – Partners with Alder Energy, Southwest, etc.
    - Extreme Fast Charging – Lessons underway in Class 8 trucking https://www.nrel.gov/docs/fy20osti/75705.pdf – Partner with multiple OEM's
    - FAA/NASA/DoD – recurring Aviation efforts – Batteries, SAF, H2, Electric, Power Electronics
    - State/Local – assisting early adopters accelerate adoption
    - OEM's – Component, Infrastructure and Life Cycle Support
  - DOE
    - SAF Grand Challenge - https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge
    - Grid Modernization Initiative - https://www.energy.gov/gmi/grid-modernization-initiative
    - H2 @ Airports - https://www.energy.gov/eere/fuelcells/h2airports-workshop

CAMI - https://www.communityairmobility.org/resources

- Future efforts – ACRP, FAA, NREL, NASA, DOE, etc.

Thank You

www.nrel.gov

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NREL – Airports/Seaports
https://www.nrel.gov/workingwithus/partners/partnership-airports-seaports.html

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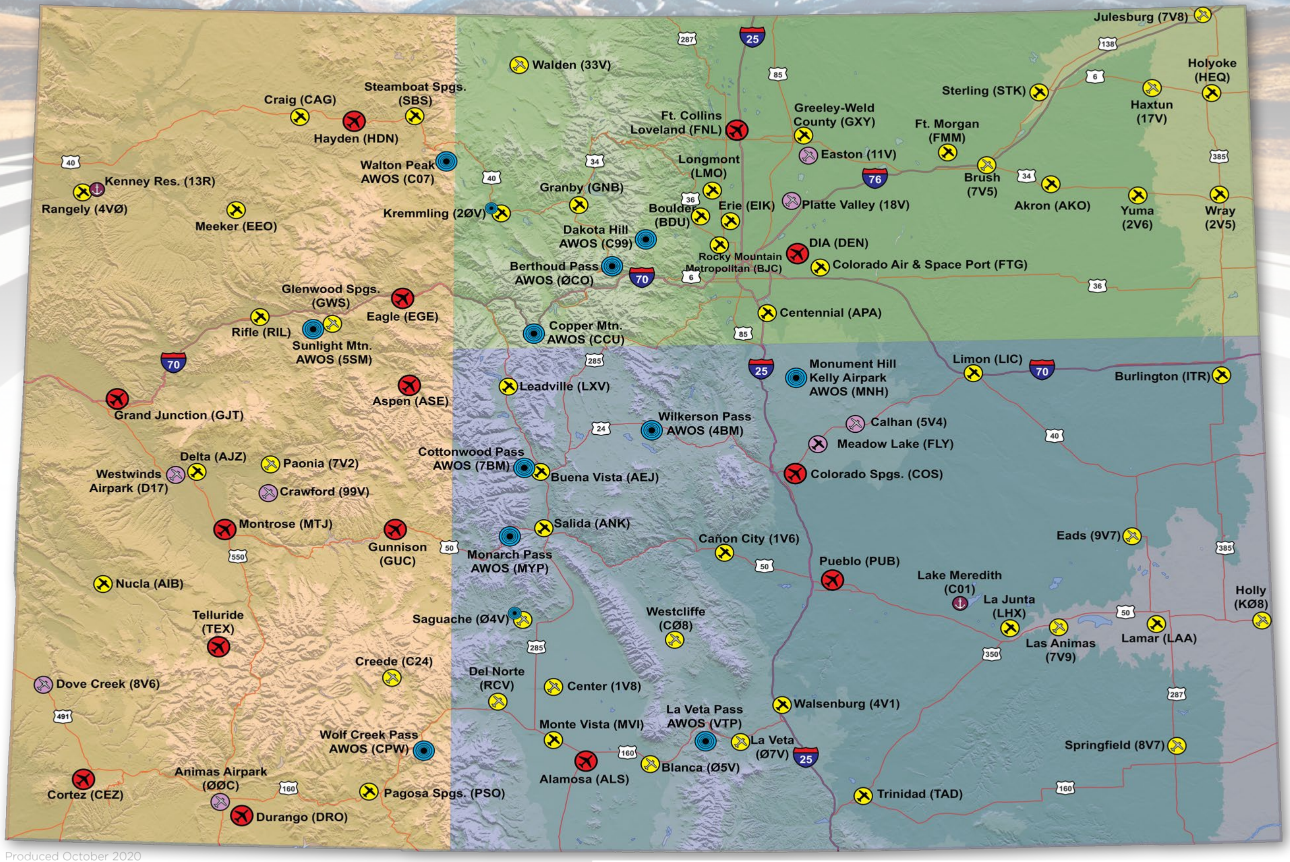
NREL
Transforming ENERGY

COLORADO
AIRPORT SYSTEM

LEGEND

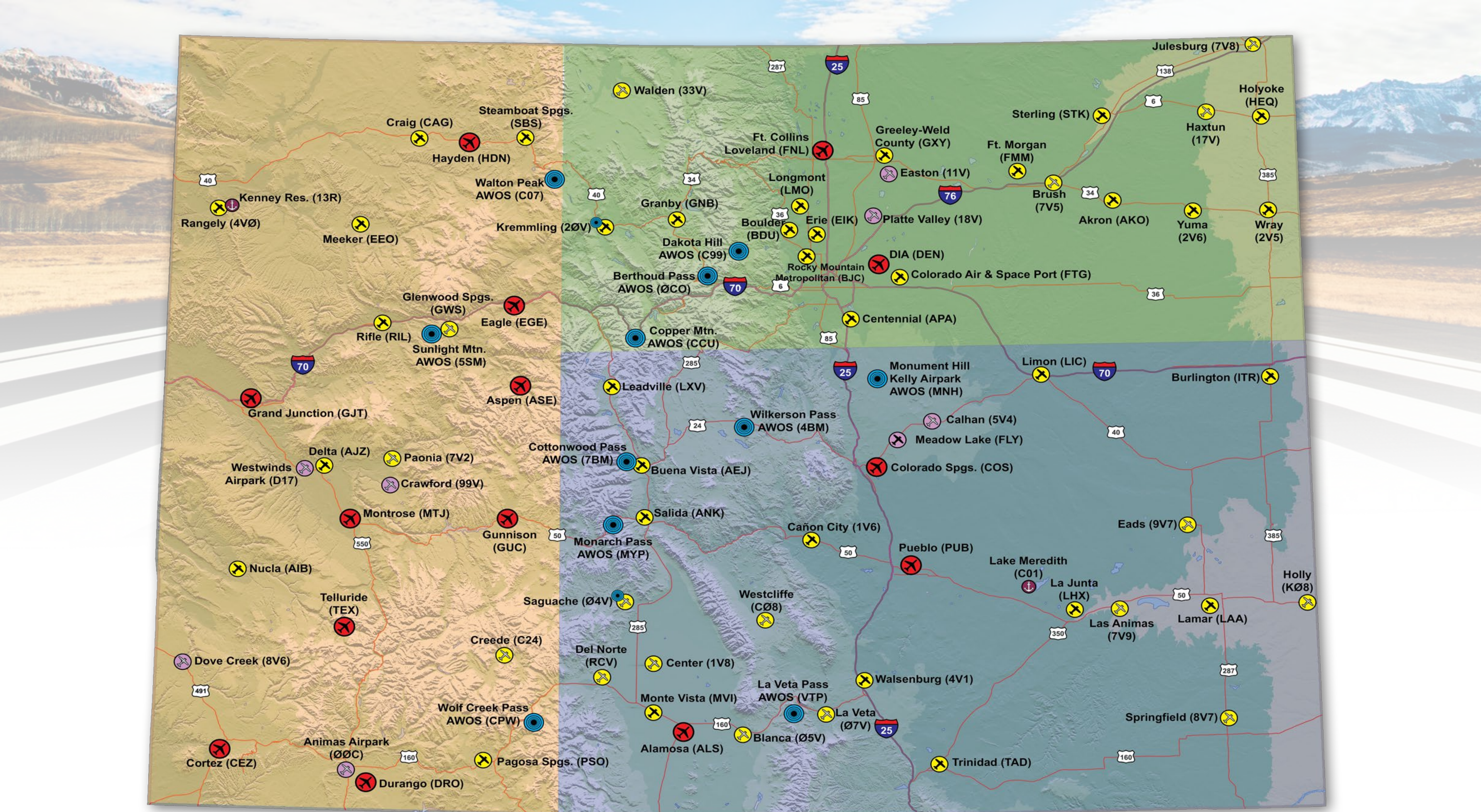
- Commercial Service Airport (14)
- Publicly-Owned & Operated Airport (51)
- Privately-Owned Airport Open to the Public (8)
- Seaplane Base (2)
- Non-NPIAS Airport (25)
- Mountain Automated Weather Observing System (AWOS) (13)



Produced October 2020

(a) 9-pax flight network

To conclude, 182 airports out of the 202 considered within the Northeast corridor of the United States are served with these new regional air mobility operations. This represents an improvement of 227% over the number of airports (80) currently served by scheduled air carriers and commuter operators in this region. This is achieved profitably and with a carbon footprint of 0.065 kg_{CO_2}/seat/mi which is less than a fourth of current-generation small-size regional jets (about 0.294 kg_{CO_2}/seat/mi on a 172 mi (150 nmi) mission [73]), and about 80% of the average passenger vehicle carbon emissions (about 0.081 kg_{CO_2}/seat/mi) [74].



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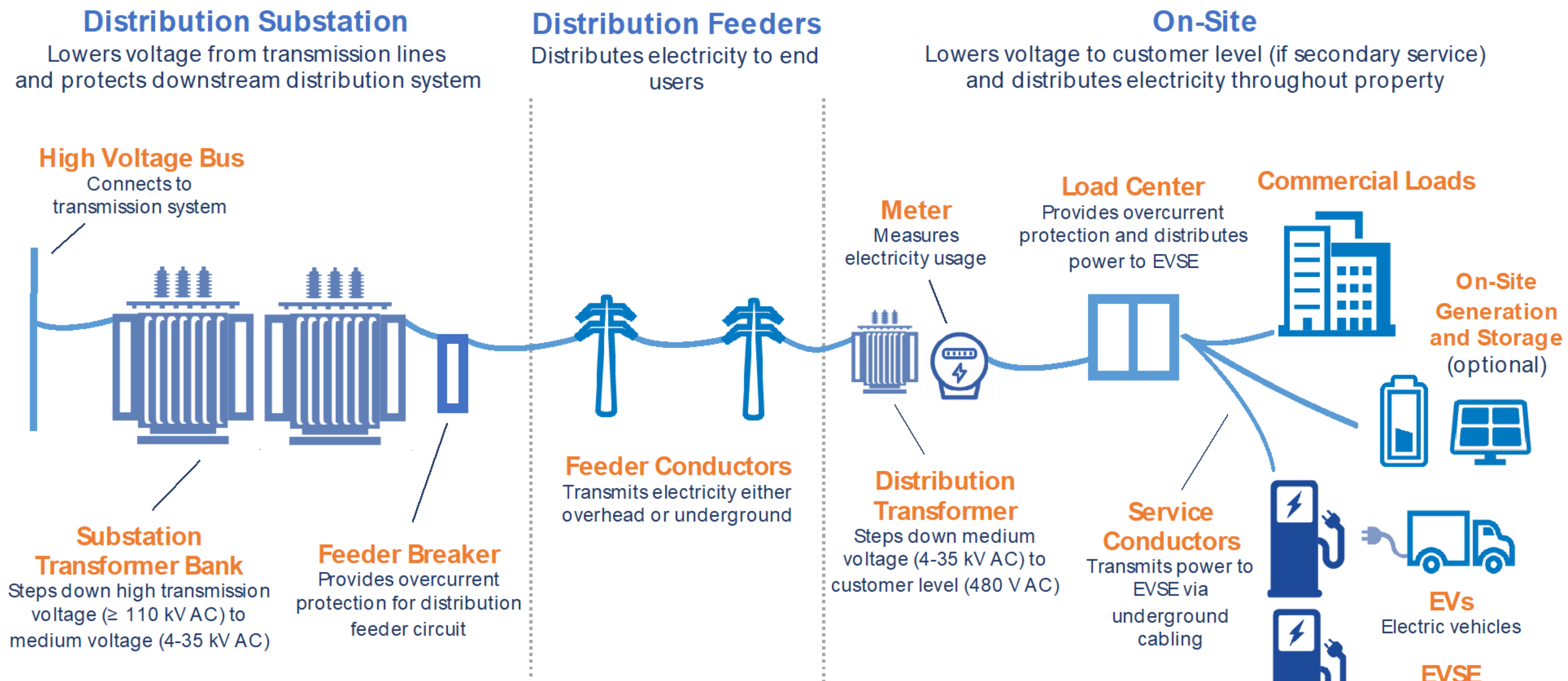
Delivering Power to EVSE

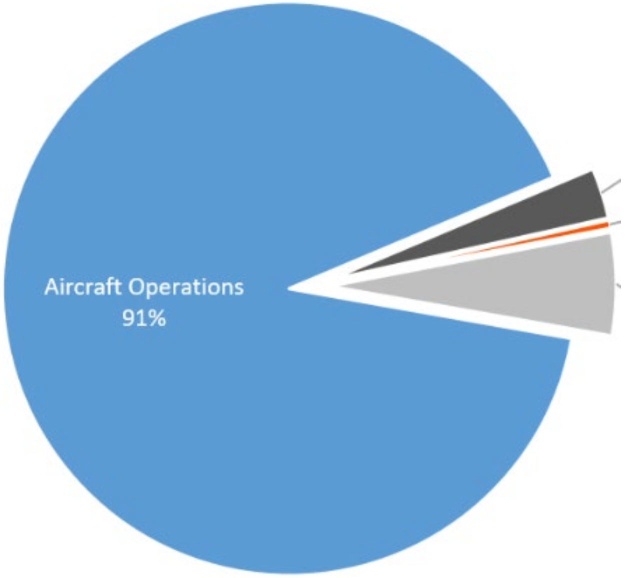


SOURCE: Borlaug et al., "Heavy-Duty Trucks: Opportunities for Electrification and the Electricity Distribution System Requirements for Depot Charging", Forthcoming.

How large is a desired RAM charger?

- Initial charging sizing
  - 480V- 3 Phase Power
  - 700-800 kW transformer
- Options exist
  - Slow charging offsite
  - Onsite energy storage
  - Onsite generation

Large Hub Emissions profile



SAF - An "All of the Above" Approach Will Have To Be Used To Achieve 35 BGPY of SAF

ASTM Approved Pathways Address a Broad Range of Feedstock To Achieve Scale

Feedstock	Pathway	Approved Name	Blending Limitation
Municipal solid waste, agricultural and forest wastes, energy crops	**Fischer-Tropsch Synthetic Paraffinic Kerosene**	FT-SPK, ASTM D7566 Annex **A1**, 2009	50%
Municipal solid waste, agricultural and forest wastes, energy crops	**FT-SPK with Aromatics**	FT-SPK/A, ASTM D7566 Annex **A4,** 2015	50%
Oil-based feedstocks (e.g., jatropha, algae, camelina, and yellow grease)	**Hydroprocessed Esters and Fatty Acids**	HEFA-SPK, ASTM D7566 Annex **A2**, 2011	50%
Algal oil	**Hydrocarbon-Hydroprocessed Esters and Fatty Acids**	HC-HEFA-SPK, ASTM D7566 Annex **A7**, 2020	10%
Fatty acids or fatty acid esters or lipids from fat oil greases	**Catalytic Hydrothermolysis Synthesized Kerosene**	CH-SK or CHJ, ASTM D7566 Annex **A6,** 2020	50%
Sugars	**Hydroprocessed Fermented Sugars to Synthetic Isoparaffins**	HFS-SIP, ASTM D7566 Annex **A3**, 2014	10%
Cellulosic biomass, waste gas, syngas	**Alcohol-to-Jet Synthetic Paraffinic Kerosene**	ATJ-SPK, ASTM D7566 Annex **A5**, 2016	30%