Integrating Hydrogen Technologies at Airports & Vertiports

HySky Society Webinar Series

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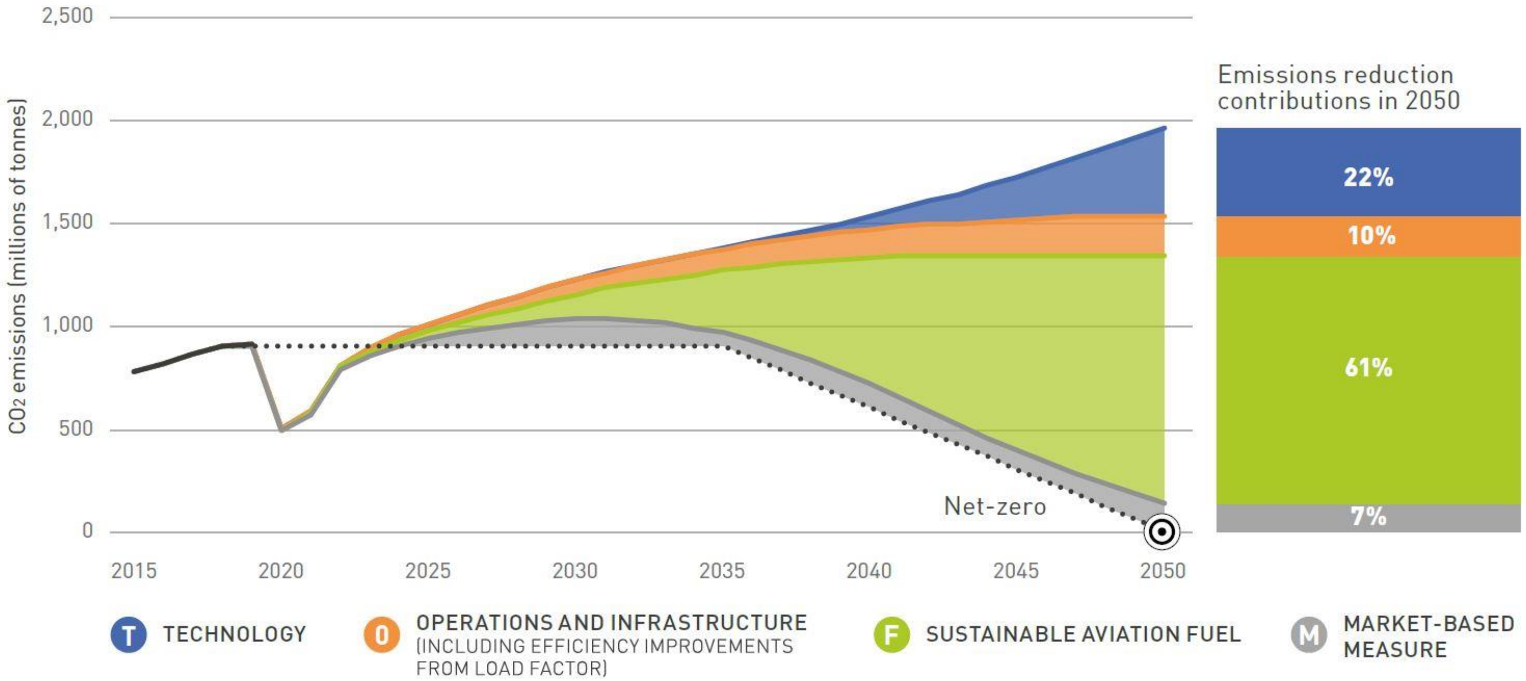
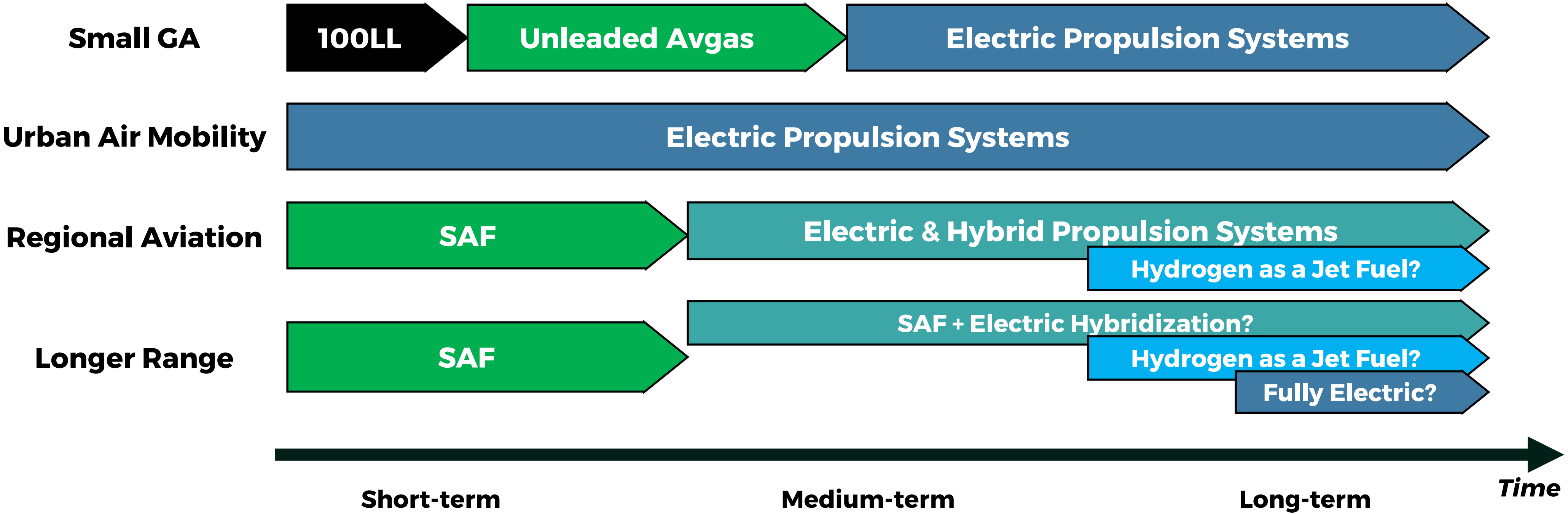
A Journey Toward Net Zero Aviation

- Aviation accounts for 2% of CO_2 emissions & 3.5% of climate change's drivers.
- Aviation has worked on keeping its emissions in check for over two decades.
- Aviation has a plan to achieve net-zero by 2050.

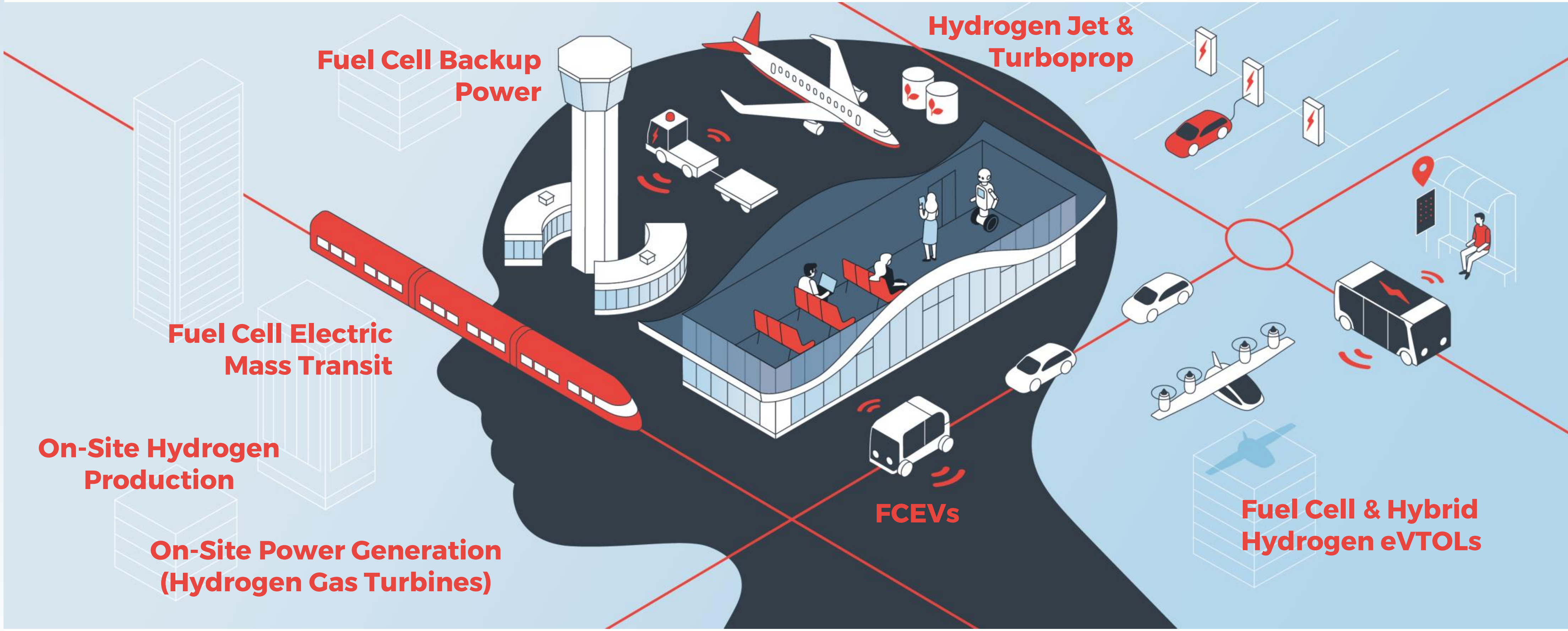


Source: ATAG

A Journey Toward Net Zero Aviation



Hydrogen at Airports
Potential Applications from the Curb to the Gate



The Stakeholder Ecosystem is Expanding

- ✓ Airport/vertiport operators
- ✓ AAM providers and their flight operators
- ✓ Existing flight operators (including GA community)
- ✓ **Aircraft rescue and firefighting (ARFF) / City FDs**
- ✓ FAA ADO and AFS
- ✓ Air traffic control tower (ATCT)
- ✓ Aircraft ground support providers
- ✓ Fixed-base operators (FBO)
- ✓ **Utility providers and hydrogen suppliers**
- ✓ Maintenance, repair, and overhaul (MRO)
- ✓ Ground transportation (TNC, transit authority, etc.)
- ✓ **Federal/state regulators**
- ✓ **Local governments**
- ✓ Metropolitan & regional planning organizations
- ✓ Communities and small businesses
- ✓ Building and land-owners

Four Keys to Successful Implementation

1. **Safe**
2. **Compatible**
3. **Relevant**
4. **Inclusive**

Navigating Operational Safety at Aviation Facilities

Typology of Risks

	Vertistation	Small GA	Small CS	Hub Airport
General Ramp Safety Risks				
Risk of leak, fire, or explosion (hydrogen)				
Increase in the severity of an aircraft accident				
Increase in the ARFF response time				

Growing Level of Risk and/or Lack of Specific Lessons Learned & Practices

Navigating Operational Safety at Aviation Facilities

“Most Wanted” Safety Hazards

Atypical Aircraft Design

Recharge/Fueling Operations

High-Energy Accident

ARFF Ops

Battery Runaway/Smoke

Worker/Passenger Physical Injuries

Undesired Arc Flash/Discharge

Hydrogen Transportation

Hydrogen Fueling

Hydrogen Storage Leak

Navigating Operational Safety at Aviation Facilities
“Most Wanted”: Hydrogen Storage & Distribution

Overall Risk:

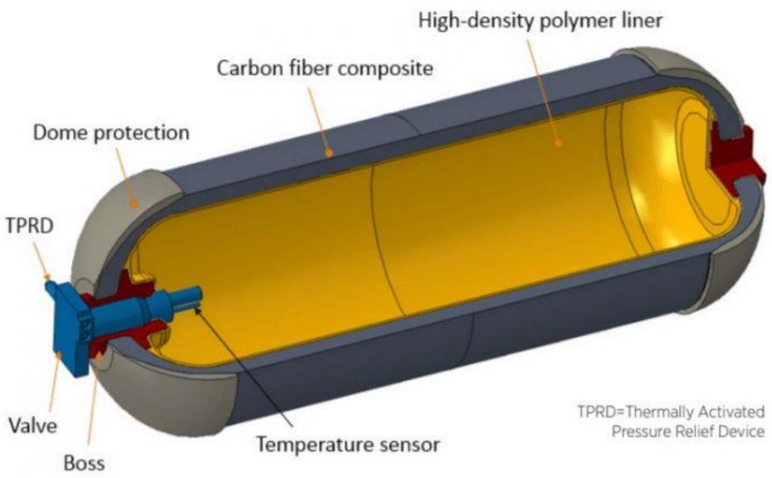
H_2 and hydrogen carriers would be new gases/fluids at airports to be stored, transported, and processed–inducing new hazards.

Current Conditions & Trends:

Safety standards exist for their safe storage and handling in other industries/non-aviation contexts.

Assessment and Potential Mitigation:

- The supply chains for aviation hydrogen are to be developed.
- Firefighting standards already exist for hydrogen technologies. NFPA guidance on fueling systems to be revised.



Navigating Operational Safety at Aviation Facilities

"Most Wanted": Accident Increases in Severity

Overall Risk:

Battery fire/runaway or leak/explosion of hydrogen tank following a high-energy safety occurrence (e.g., runway excursion).

Current Conditions & Trends:

- Airliners already carry powerful batteries (e.g., A350, 787).
- Large aviation hydrogen tanks & pods are novel (even per other transportation industry standards).

Assessment and Mitigation:

Batteries/hydrogen tanks and pods, by design, should not increase the severity of such occurrences (assuming reasonable scenarios) and should be able to withstand some of them (e.g., runway excursions).

Navigating Operational Safety at Aviation Facilities

“Most Wanted”: Atypical Configurations

Overall Risk:

Unusual propulsion systems & lower noise increase risk on the ramp.

Current Conditions & Trends:

Over 100 e-aircraft projects with atypical config. (ACRP RR 236).

Assessment:

Risk should be assessed for each type or novel configuration.

Potential Mitigation:

- Joint training sessions with the ramp community.
- Specific configurations may warrant visual aids (e.g., markings).

Aircraft/Airport Compatibility

What is Aircraft/Airport Compatibility?

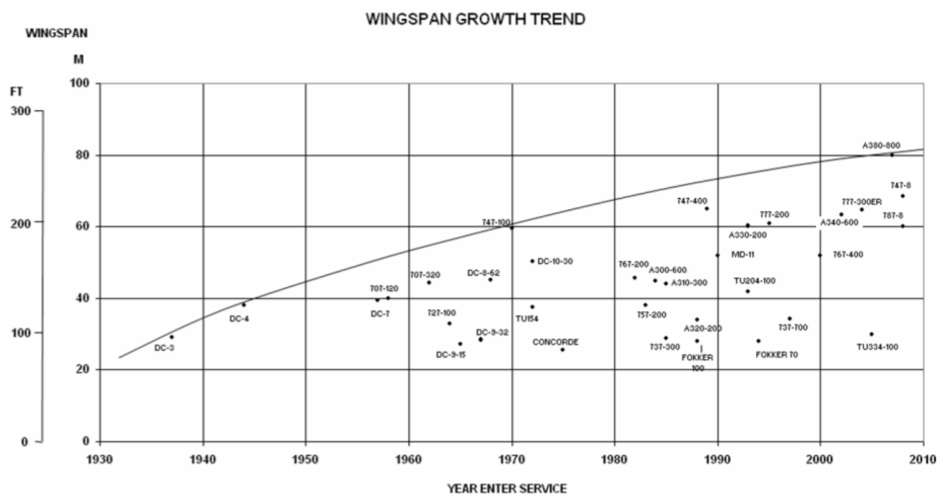
Will it fit?

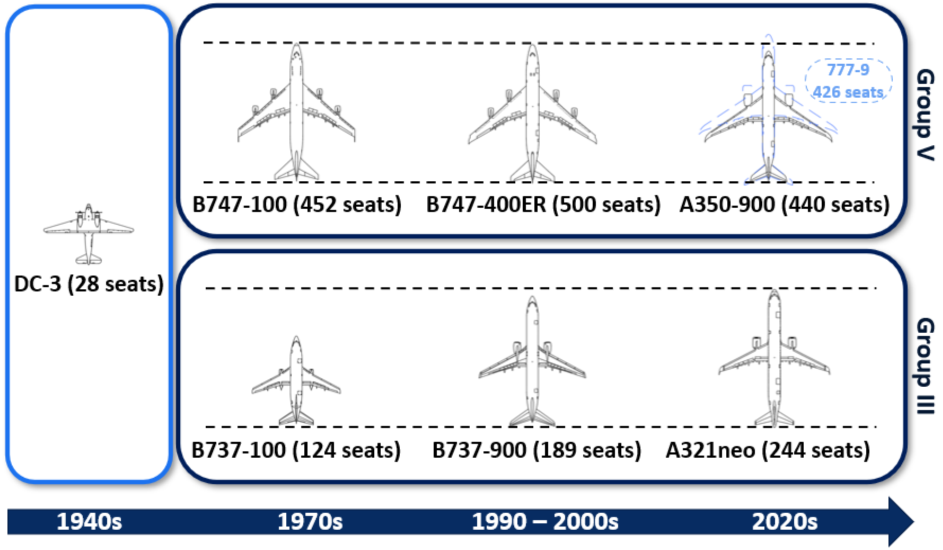
Aircraft/Airport Compatibility

About Aircraft/Airport Compatibility

- **Commercial aircraft of same market segment/use case have grown consistently over time.**
- **Most commercial airports are:**
  - **Public-use facilities that shall consider all OEMs and many flight operators.**
  - **Facilities accommodating the general public subject to safety oversight.**
  - **National assets subject to planning policies & economic regulation.**

> **Provisions to ensure aircraft/airport compatibility have been embedded into standards and policies since the end of WW2.**





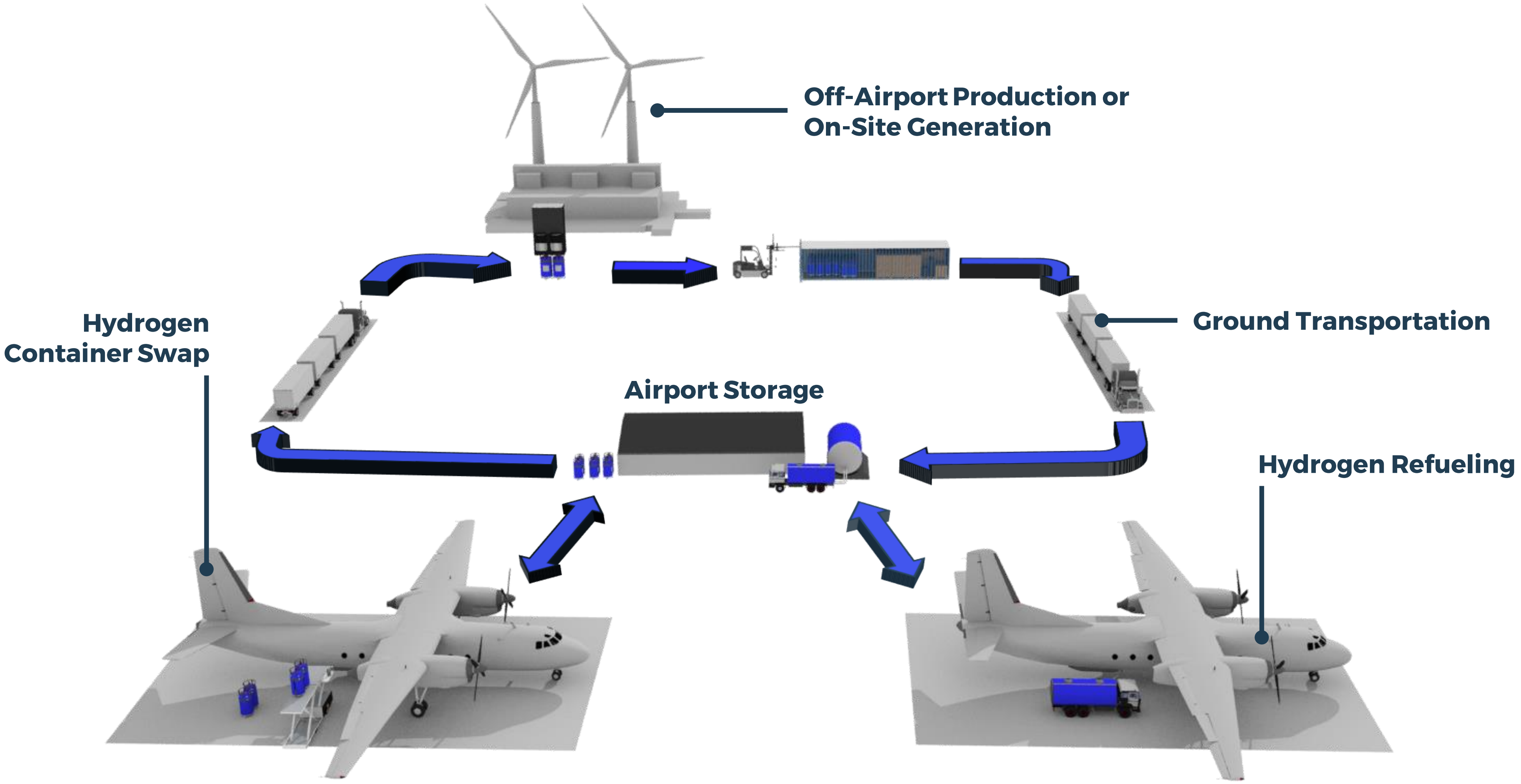
Aircraft/Airport Compatibility
Compatibility Criteria

- Airspace & procedures
- **Airfield design**
- Aircraft performance & runway requirements
- Load-bearing & structural considerations
- **Ground operations & turnaround time**
- **Fuel & power requirements**
- **Local communities' buy-in (public desirability)** including noise compatibility
- Other criteria: weather conditions, security requirements, **FBO/MROs**, etc.

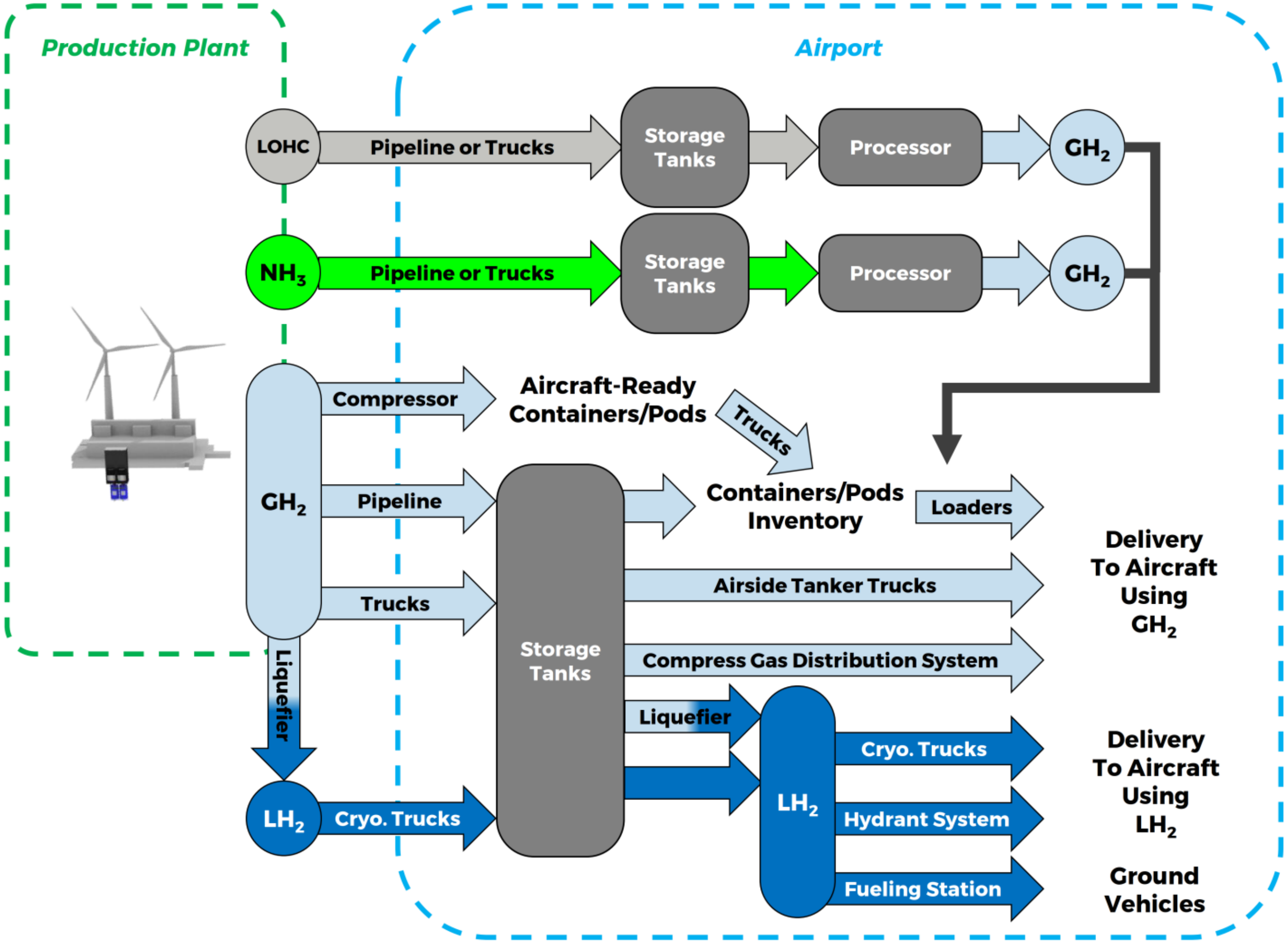
"On the surface achieving compatibility between airports and aircraft seems a relatively simple task. [...] However, the task becomes increasingly difficult as the details of the design are established"

Parsons and Wilfert, 1981

Aircraft/Airport Compatibility
Refueling Aircraft with Hydrogen

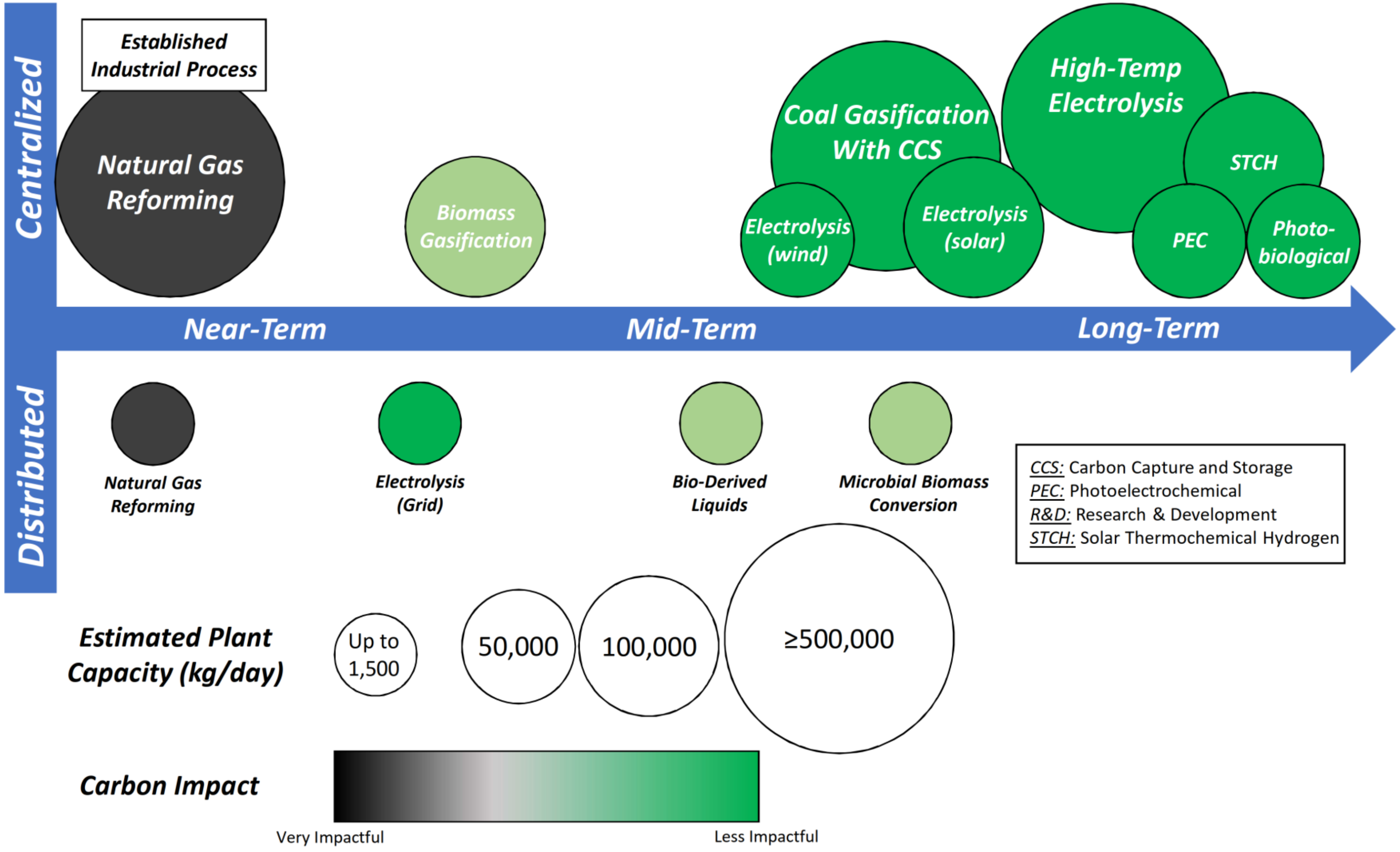


Hydrogen Supply Chains
Potential Aviation Supply Chains



Note: ***LOHCs (Liquid Organic Hydrogen Carriers)*** *are organic compounds that can absorb and release hydrogen through hydrogenation/dehydrogenation reactions. Viable candidates for LOHC systems include carbon dioxide/methanol (CH_4), benzene/cyclohexane, toluene/methylcyclohexane (MHC), naphthalene/decalin, N-ethylcarbazole (NEC)/perhydro-NEC, dibenzytoluene (DBT)/perhydro-DBT.*

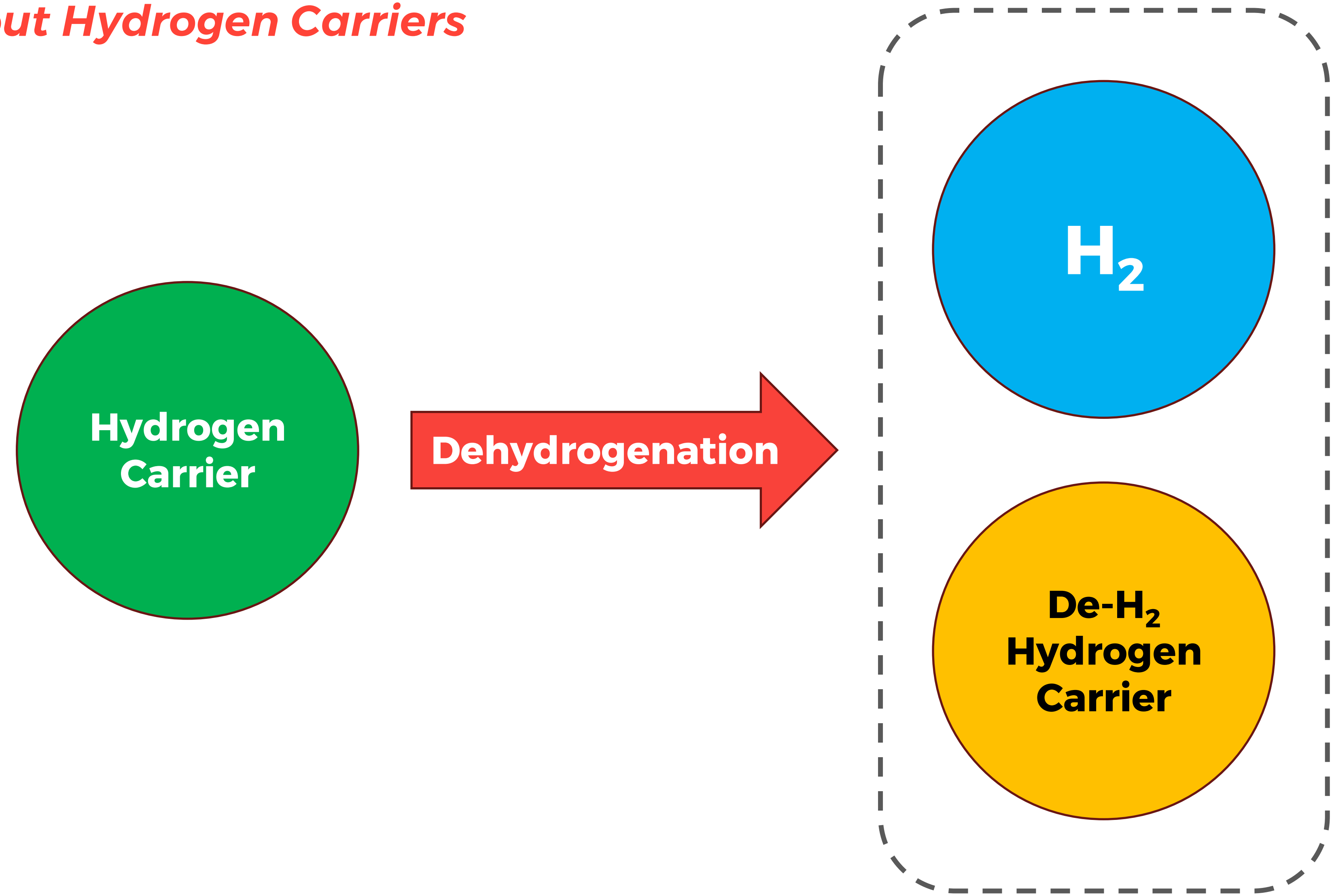
Hydrogen Supply Chains
Methods to Produce Hydrogen



Source: U.S. DOE

Hydrogen Supply Chains

About Hydrogen Carriers

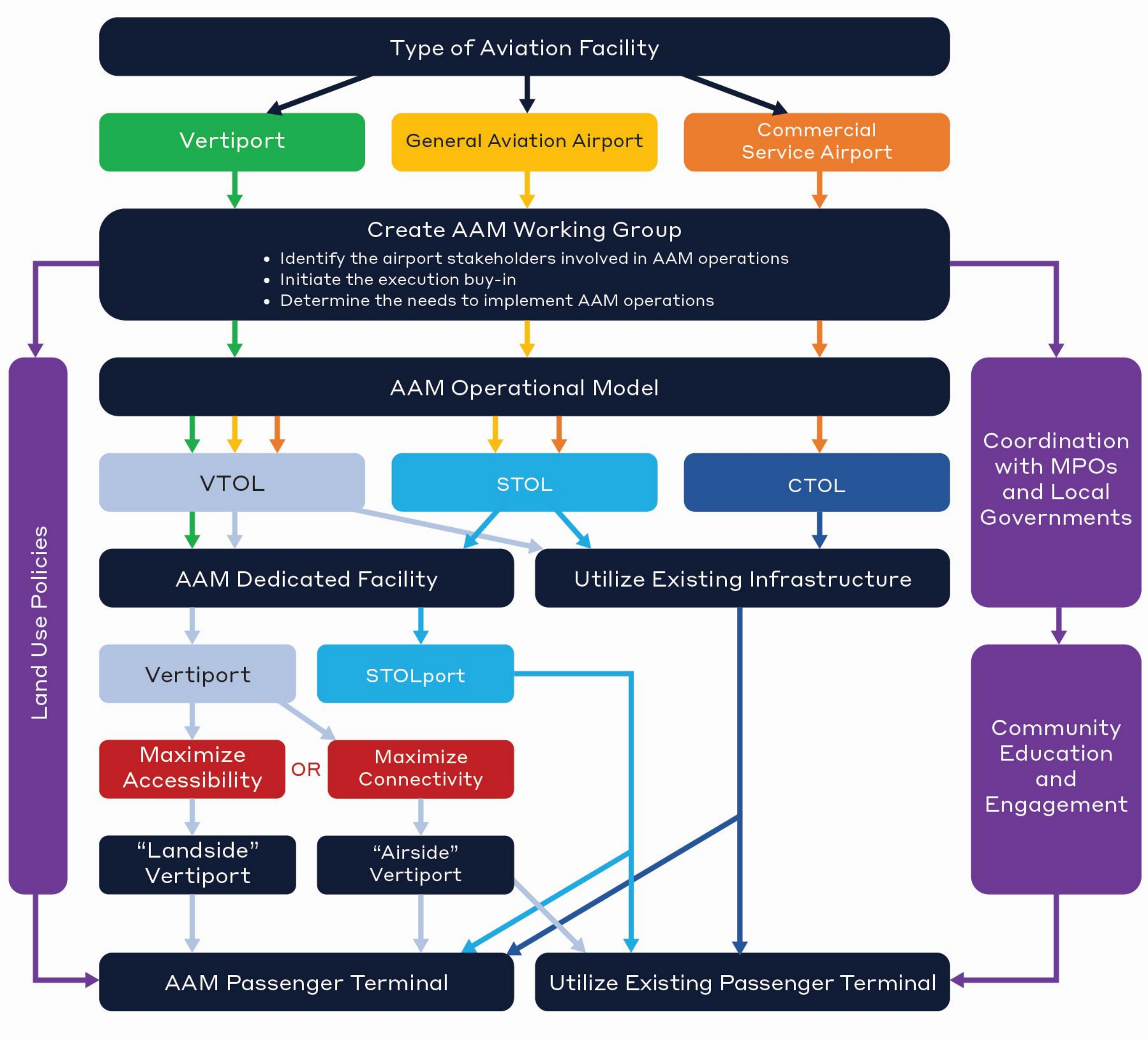


Hydrogen Supply Chains

About Hydrogen Carriers

	LOHCs					Other HCs		Dihydrogen	
HC candidate	**NEC H_0/H_{12}**	**DBT H_0/H_{18}**	**NAP H_0/H_{10}**	**TOL H_0/H_6**	**AB H_0/H_6**	**CO2/MEOH H_0/H_4**	**N_2/NH_3 H_0/H_3**	**GH_2 (300 bar) H_2**	**LH_2 H_2**
Molecular formula	$C_{14}H_{13}N$ / $C_{13}H_{23}N$	$C_{21}H_{20}$ / $C_{21}H_{38}$	$C_{10}H_8$ / $C_{10}H_{18}$	C_7H_8 / C_7H_{14}	C_6H_6 / C_6H_{12}	CO_2/CH_3OH	N_2/NH_3	H_2	H_2
Common name	9-ethyl-carbazole /perhydro-9-methylcarbazole	Dibenzyl-toluene /perhydro-dibenzyl-toluene	Naphthalene/ Decalin	Toluene/ Methylcyclohexane	Benzene/ Cyclohexane	Carbon dioxide/ methanol	Nitrogen/ ammonia	Gaseous hydrogen	Liquid hydrogen
Hydrogen (wt %)	5.8	6.2	7.3	6.2	7.1	12.6	17.6	100	100
Energy density (kWh/l)	2.5	1.9	2.2	1.6	2.4	4.4	4.3	0.75	2.36
Dehydrogenation temperature (˚C)	180-270	270-310	210-300	250-450	80	65-95	400		
Hydrogenation temperature (˚C)	80-180	150-200	80-160	90-150	80	250			
Reaction enthalpy (kJ / mol_{H2})	-53.2	-65.4	-66.3	-68.3	-35.9	-29	-30.8		
Hazard information		H305	H228, H302, H351, H400, H410	H225, H304, H315, H361d, H336, H373, H412		H280	H221, H280, H332, H314, H318, H335, H400	H220, H280, OSHA-H01, CGA-HG04, CGA-HG08	H220, H281, OSHA-H01, CGA-HG04, CGA-HG08

Planning for AAM at Airports/Vertiports



Policy Considerations: Impact on Fuel Revenues

Aviation fuel taxes in Colorado:

- **Aviation Fuel Excise Tax** on aviation gasoline (**6¢ per gallon**) & fuel (**4¢ per gallon**) with exemptions for air carriers.
- **Aviation Fuel Sales Tax** on aviation jet fuel used in turbo-propeller or jet engine aircraft.
- **Special Taxation Districts:** RTD (Regl. Transportation District) and RTA (Rural Transportation Authority) sales tax.
- **Flowage Fees:** Aviation fuel or gasoline can be subject to a fuel flowage (in-plane) fee imposed by the airport.

During FY 2019-2020, **$26.4 million** of state aviation fuel tax revenues were collected. These tax revenues support, develop, and maintain the Colorado aviation system.

Battery-electric and hydrogen-electric aircraft will not use conventional aviation fuels. Hybrid-electric aircraft will use less fuels than conventional aircraft.

Food for thought:

— **What will be the impact of emerging aviation fuels on legacy fuel revenues over time?**

— **How can this loss of revenue be offset?**

— **Should these emerging fuels pay the difference? Or should they be incentivized?**

Further Reading

An Airport & Vertiport/Aircraft Compatibility Approach of eVTOL Aircraft Design

Safety Considerations on the Operation of eVTOLs at Airports & Vertiports

Further Reading

**ACRP Research Report 236:
Preparing Your Airport for Electric
Aircraft & Hydrogen Technologies**

**ACRP Research Report 243:
Urban Air Mobility:
An Airport Perspective**

Fly safe!

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