Objective:
To evaluate:
(1) the operational and economic feasibility of electrification strategies, and
(2) the life-cycle emissions and their associated impacts, relative to conventional petroleum-powered aircraft.

Today’s focus:
Comparison of fuel production and distribution, with specific focus on energy demand and upstream investments for PtL and hydrogen scenarios

Project Benefits:
Provide data and guidance on the most promising electrification approaches for aviation

Research Approach (fuel production and distribution):

**Energy and fuel demand**
Calculate the fuel and energy demand for year-2019 traffic

**Fuel production and logistics**
Model the production and logistics for aviation fuels

**Energy system**
Model the electric power generation to produce fuels

**Airport fuel infrastructure**
Model required fueling infrastructure

Operating Costs
Energy demand
Other environmental impacts

Investment pathways (CapEx)
Lifecycle emissions and impacts

Major Accomplishments (to date):
For PtL and LH₂ scenarios: We analyzed...

1. Production pathways and lifecycle impacts
2. Energy demand
3. Investments for fuel production
4. Logistics and distribution challenges

Future Work / Schedule:
- Integration of aircraft model to assess feasibility and impacts at the system-level
- Provide integrated economic and environmental assessment
- Compare to other electrification strategies
Production of LH$_2$ and PtL as aviation fuels: Role of electric power

(Liquid) Hydrogen

LH$_2$ will require new aircraft and fueling systems

LH$_2$ can be produced with different cost and GHG footprint

Electrolysis with carbon-free electricity offers potential for near-zero GHG emissions

PtL fuels are liquid drop-in fuels derived from CO$_2$ and electricity.

Example: Co-electrolysis pathway:

Lifecycle GHG emissions: dependent on carbon intensity of electricity

Power consumption: $1.4$ to $1.7 \frac{MJ_{(elec)}}{MJ_{(fuel)}}$

Power consumption: $> 1.8 \frac{MJ_{(elec)}}{MJ_{(fuel)}}$
Energy requirements for PtL and LH$_2$ production: *Paris CDG*

Electric power consumption of fuel production
*broken down by process step, in GW*

<table>
<thead>
<tr>
<th>Process</th>
<th>Power Consumption (GW)</th>
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<tbody>
<tr>
<td>E-fuel (RWGS-PEM)</td>
<td>1.2</td>
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<tr>
<td>E-fuel (RWGS-SOEC)</td>
<td>3.2</td>
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<tr>
<td>E-fuel (Coelec)</td>
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<tr>
<td>LH$_2$</td>
<td>2.9</td>
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<tr>
<td>Total</td>
<td>13.09</td>
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<tr>
<td>Total</td>
<td>17.35</td>
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</table>

For comparison:
- French total installed capacity: ~133 GW
- Largest nuclear plant in the world (capacity): ~7 GW
- Largest solar power plant (capacity): ~2.2 GW

How much land is needed to produce LH$_2$ using renewable solar?
- H$_2$ Gas Pipeline + Airport Liquefaction: >490 km$^2$
- Cryogenic H$_2$ Transport from Offsite Liquefaction: >585 km$^2$
- Electrofuel: >700 km$^2$
Energy requirements for PtL and LH$_2$ production: **Global**

Electric power consumption of LH$_2$ fuel production, *in GW, by airport*

<table>
<thead>
<tr>
<th>Airport</th>
<th>E-fuel (RWGS-PEM)</th>
<th>E-fuel (RWGS-SOEC)</th>
<th>E-fuel (Coelec)</th>
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</tr>
</tbody>
</table>

Capacity of largest existing nuclear power station

U.S power generation capacity (2019)

Global cumulative PV capacity (2019)

Year-2019 passenger aviation

Electric power consumption of fuel production broken down by process step, *in GW*
Investment requirements for scaled-up LH\textsubscript{2} use in aviation

Upstream fuel production and airport fuel distribution investment

*in trillion USD*

For comparison:
- Global power sector investment 2020: $679bn USD
- Global year-2020 solar-PV investment: $108bn USD
- IRENA: Yearly energy investment 2021-2050 PES: $3.3 tr USD
- IRENA: Yearly investment scenario 2021-2050 TES: $4.4 tr USD

Airport infrastructure

- Truck-Based Refuelling
- Remote Hydrant Refuelling
- At-Gate Hydrant Refuelling

Does not consider:
- Storage to smooth out electricity production
- Investments in global LH\textsubscript{2} distribution infrastructure

Year-2019 passenger aviation
4 LH₂ Distribution Challenges

- LH₂ volume is ~4x higher than PtL.
- Handling of cryogenic fuel requires insulated equipment.
- Different layouts are possible for hydrogen production and logistics.

Transport challenges (Case study: CDG)

- Maritime + Road transport: ~170 tanker ship and ~300,000 tanker truck deliveries per year to supply CDG (all flights).
- Gaseous pipeline: Gaseous Hydrogen can be transported to an on-site liquefaction facility.
- LH₂ pipeline: Proposed, but unproven and with limited range.

Airport distribution challenges

- Longer refueling times
- New infrastructure needed (likely in addition to existing infrastructure for transition)