AIR LIQUIDE
ADVANCED BUSINESS & TECHNOLOGIES

Air Liquide in Aeronautics

Our Vision for the Use of Fuel Cells and Hydrogen On Board Large Civil Aircraft at the Horizon 2030

Joint Cleansky FCH JU workshop on FCH technologies in aeronautics 2015

Potential applications of FC in aircrafts

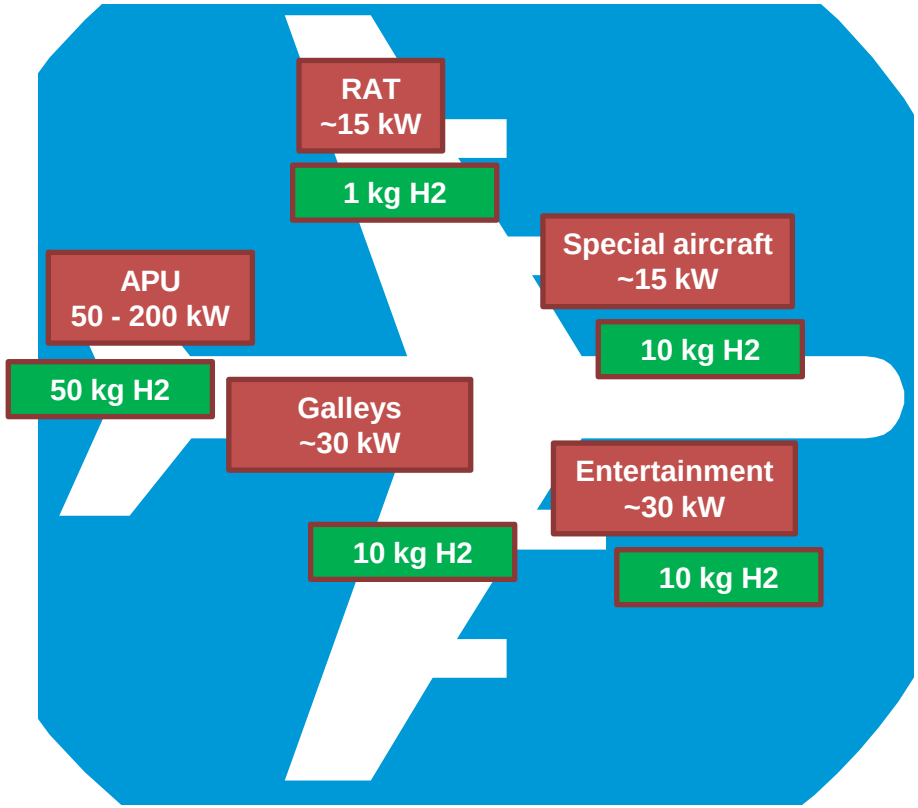
- Ram Air Turbine and Fire Extinguisher

- Galleys

- APU

Typical powers and storage capacities for single aisle A/C

(source : livre blanc H2 aéronautique, DGAC, 2014)



Potential applications of FC in airports

- Example of Roissy airport :
  - 5000 vehicles, incl 1800 with licence plates
  - 66% gas oil and 24% electrical

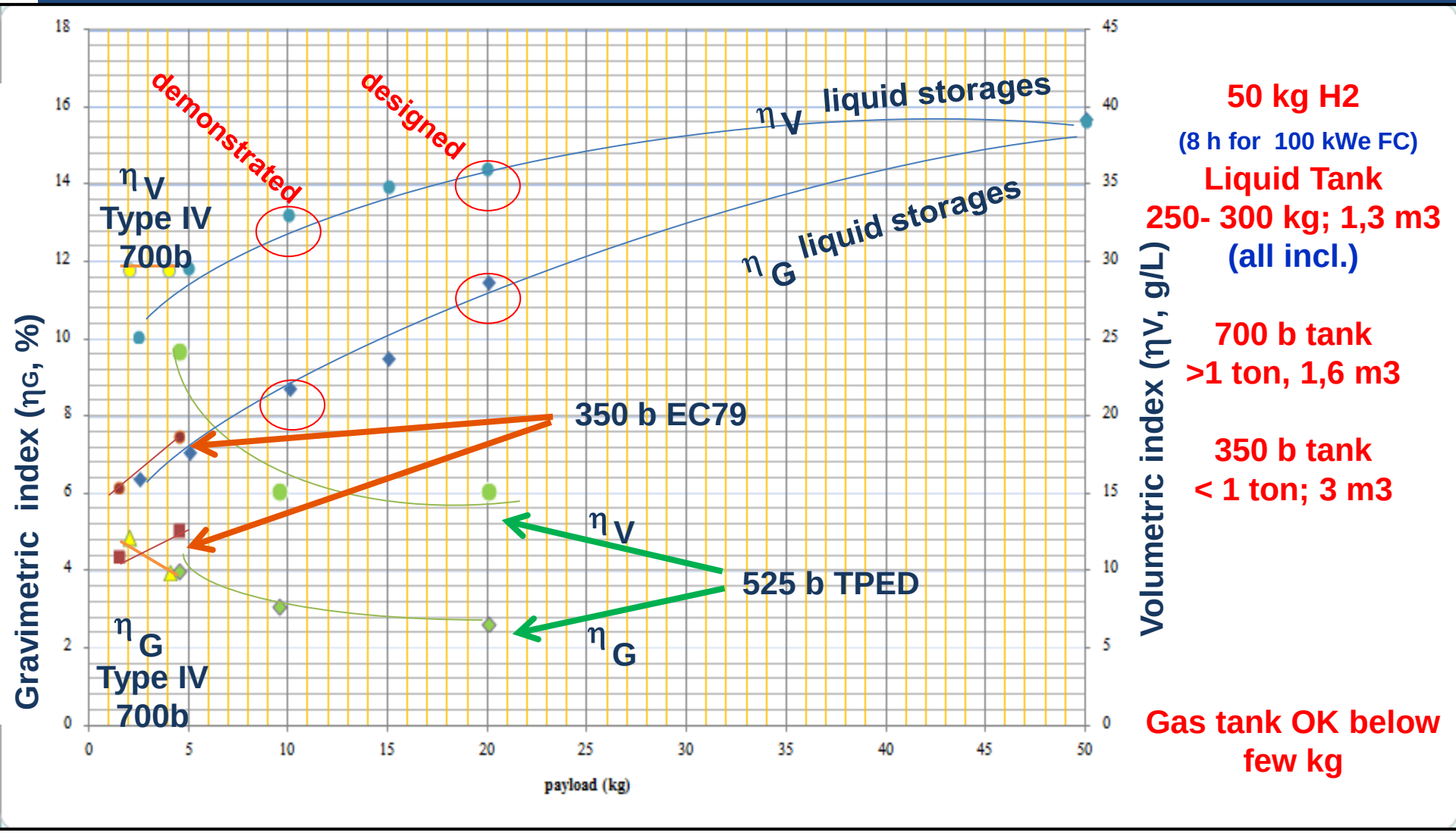
- But most GSE are low duty vehicles (engines run few hours/day)
  - good business cases for FC in heavy duty warehouses (7/24) thanks to fast refill
  - **We must target heavy duty GSEs and FC cars/buses**

- Air Liquide is installing 2 HCS in Roissy and Orly for FCVs « over the fence » (city side, not runway side)
  - Many airport vehicles could be turned into FCVs and refuel there since they can « cross the fence » (because they have license plates)
  - Utility FCVs already on the market
    - BEV with H2 range extender (Renault Kangoo / 350 b)

- Other initiatives in Hamburg, Kansai, Memphis airports…..

H2 starts entering into airports!

What infrastructure for which onboard storages?



50 kg H2

(8 h for 100 kWe FC)

Liquid Tank

250- 300 kg; 1,3 m3

(all incl.)

700 b tank

>1 ton, 1,6 m3

350 b tank

< 1 ton; 3 m3

Gas tank OK below few kg

Dual fill H2 station liquid + 350 or 700b

Possible aircraft hydrogen charging stations (HCS)

For 1~2 kg onboard storage < 500 b

- Full-for-empty swapping preferable
- H2 charging at airport by balancing with 700 bar ground cylinders

For liquid onboard storage

- Mobile LH2 charging station (20 feet ISO container)
- Charging 8~10 m3, zero boil-off storage
- Depressurization, thermalization, pumping
- No civil work

AEROLHYstation project: mobile, versatile, autonomous, cost efficient

Enough storage to refill 10-20 A/C plus GSEs@350b and FCVs@700b

Logistics at the airport :

centralized storage & distribution

LH2 Delivery

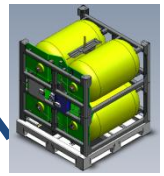
storage

350b

700b

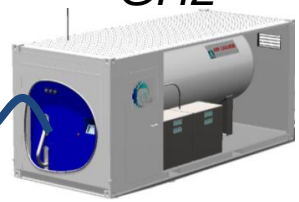
LH2

Ground carts

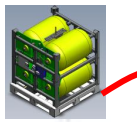


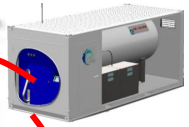
GH2

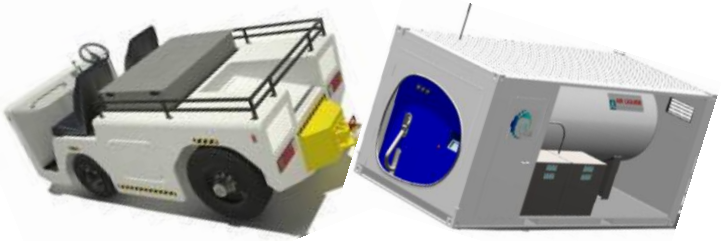
Mobile tanks



LH 2







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How many airports to equip?

30 busiest airports in the world in 2011, ACI

Aircraft LTO cycles

Busiest airports - aircraft LTO cycles, ACI 2011

Rank	City (Airport)	Total
1	ATLANTA GA, US (ATL)	461 998
2	CHICAGO IL, US (ORD)	439 399
3	LOS ANGELES CA, US (LAX)	351 448
4	DALLAS/FORT WORTH TX, US (DFW)	323 402
5	DENVER CO, US (DEN)	314 398
6	CHARLOTTE NC, US (CLT)	269 921
7	BEIJING, CN (PEK)	266 629
8	LAS VEGAS NV, US (LAS)	265 769
9	HOUSTON TX, US (IAH)	258 631
10	PARIS, FR (CDG)	257 030
11	FRANKFURT, DE (FRA)	243 581
12	LONDON, GB (LHR)	240 466
13	PHOENIX AZ, US (PHX)	230 995
14	PHILADELPHIA PA, US (PHL)	224 065
15	DETROIT MI, US (DTW)	221 514
16	AMSTERDAM, NL (AMS)	218 542
17	MINNEAPOLIS MN, US (MSP)	218 253
18	MADRID, ES (MAD)	214 695
19	TORONTO ON, CA (YYZ)	214 382
20	NEWARK NJ, US (EWR)	205 012
21	MUNICH, DE (MUC)	204 978
22	NEW YORK NY, US (JFK)	204 365
23	SAN FRANCISCO CA, US (SFO)	201 782
24	MIAMI FL, US (MIA)	197 286
25	TOKYO, JP (HND)	189 835
26	BOSTON MA, US (BOS)	184 494
27	NEW YORK NY, US (LGA)	183 299
28	SALT LAKE CITY UT, US (SLC)	179 001
29	MEXICO CITY, MX (MEX)	175 016
30	GUANGZHOU, CN (CAN)	174 630

- 10 to 20 AEROLHY-type HCS /airport: **~500 ww**
- DLR study in Frankfurt
  - If all single aisle A/C were equipped (330 LTO/d):
    - 2.4 t H2/day for taxiing; add 2,4 for hold period
    - Total 5 t/day 2012 = 7-8 t/days 2030
    - **2 trucks/day**

Infrastructure scenarios

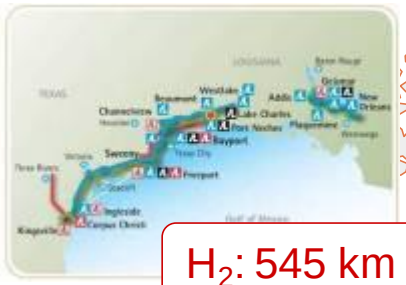
- Entry Into Service: 2030 ⇒ 5 000 single aisle a/c in 2035 (15% of the fleet)
  - Airbus & Boeing are producing more than 40 A/C per month today!
  - 5 000 a/c with 100 kW APU ⇒ H2 ~ 100,000 t/y (≈1 million Hydrogen cars)
    (Notice : Air Liquide's production > 1 million tons)
  - Longer term potential for 3-5X growth: 50% fleet + ground operations
  - EIS 2030 = TRL6 in 2023 = R&D NOW!

- Ex : Frankfurt (330 single aisle/day)
  - 1 A/C has enough H2 for 4 flight/day (50 kg)
  - 30-40% refill there : 100-150 A/C refuellings/day
  - 10-15 HCS needed and for 250 000 LTO
  - 300-400 HCS for 8 millions LTO (30 largest airports) based on 2015 traffic

- 500-700 HCS worldwide in 2035

- HCS for GSE and FCVs not included

Example of production/deliveries : Air Liquide's H2 production capabilities



H_2: 545 km

Key features on H2

- 200 H2 plants
- > 900 000 t/year
- > 1 850 km H2 pipeline
- 6,000 FC forklifts in operation
- More than 60 H2 stations built

Key features

- 15,4 Md€ sales
- 50 000 employees
- 80 countries

OTF: Over the Fence supply,

H_2: 40 km

H_2: 950 km

Fourniture H_2 AL:

- Unité de production H_2 – fourniture H_2 OTF
- Unité de Purification H_2 - fourniture H_2 OTF
- H_2/CO Unité de production (SMR / POX)

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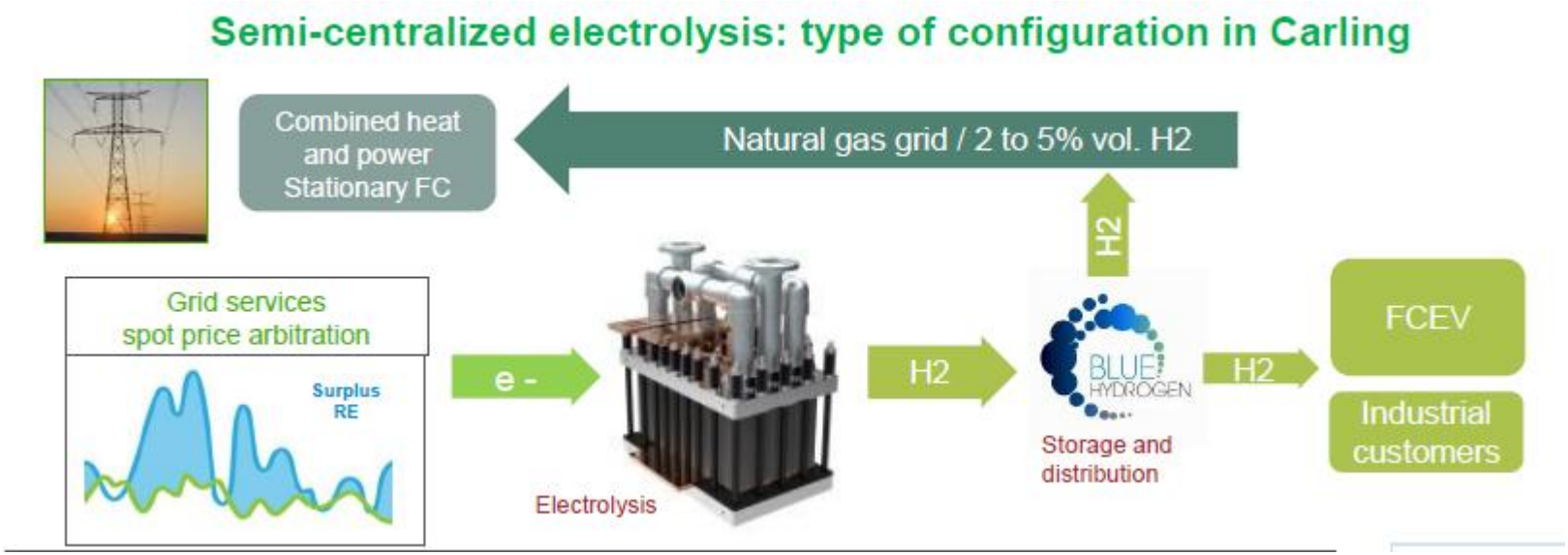
A green on-site production at airport

- Power-to-Gas : about 60 kWhe to produce 1 kg of H2



- Air Liquide is going to install such a plant in Denmark
  - Creation of certificates of origin

- 20 MW P-to-G plant for 8 tons/day for a Frankfurt type airport
- Airports are equipped with cogeneration plants > 10-20 MW
  - : can be used for P-to-G overnight since low duty

- 2 t/day on-site liquefiers already exists (12 kWh/kg; 8 kWh possible)

An original initiative for the automotive market

- The H2 Mobility Deutschland GmbH & Co. KG (H2M) is a **cross-industry joint venture of the shareholders Air Liquide, Daimler, Linde, OMV, Shell, and Total**. H2M is working on the build up of a nationwide hydrogen refueling station network in Germany.
- The objective of this initiative is to be prepared for the planned series launch of fuel cell electric vehicles (FCEVs) and to **create a hydrogen refueling station (HRS) network infrastructure covering the whole country by 2023**.
- Beyond the **six shareholders, currently five Associated Partners** from the automotive industry (BMW, Honda, Intelligent Energy, Toyota, and Volkswagen) are also accompanying the H2M initiative. In addition the National Organization of Hydrogen and Fuel Cell Technology (NOW) will interact as an interface to the Federal Ministry of Transport and Digital Infrastructure.

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OMV TOTAL

Under discussion since 2013, started in february 2015, based in Berlin

The same will be needed in aeronautics before 2025

AEROLHY : Air Liquide's program for demonstrating the infrastructure in airports

1. Install HCS in airports « city side » and promote existing utility FCVs deployments (with range extenders or others)

2. Target heavy duty GSE with OEM and operators

3. start building a mobile, dual fill HCS demonstrator (LH2, 350&700 b)
   *Good demo = **introduce a real object into the real environment***
   Only way to identify critical technologies and regulations

4. Look to on-site P-to-G H2 generation and liquefaction
   Discuss with airports about overall energy management

5. Build-up operationnal scenario with airlines, airports, OEMs

6. From 3, 4 & 5, derive investments needed and ramp-up strategy

Conclusions

- Entry into service of A/Cs using FC in 2030 means R&D shall be completed before 2020
- Urgent need to demonstrate the feasibility/economics of an H2 infrastructure before going too far on airborne system developments
  - Should turn to an European one asap
  - Regulations/standards : the key (or the show-stopper!)
- Should FCs find their case on-board, we already see promising hints about the H2 infrastructure :
  - B-to-B, not B-to-C market
  - Few hundreds HCS compared to thousands for the automotive market
  - Captive fleets (both A/C and FCV/GSE)
  - 100 000 t/year horizon 2035 : few % of ww production
  - Airports = good candidates for on site Power-To-Gas H2 production (overall airport energy management)

THANK YOU FOR LISTENING

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