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Thermodynamic Feasibility for Civil Aircraft Fuel Cell APU

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Agenda

- The problem
  - Existing APU emissions
- The solution
  - Low temperature fuel cell
  - Fuel cell thermodynamics
  - Mass & volume comparison
  - Acoustic comparison
- Closing remarks

THE PROBLEM

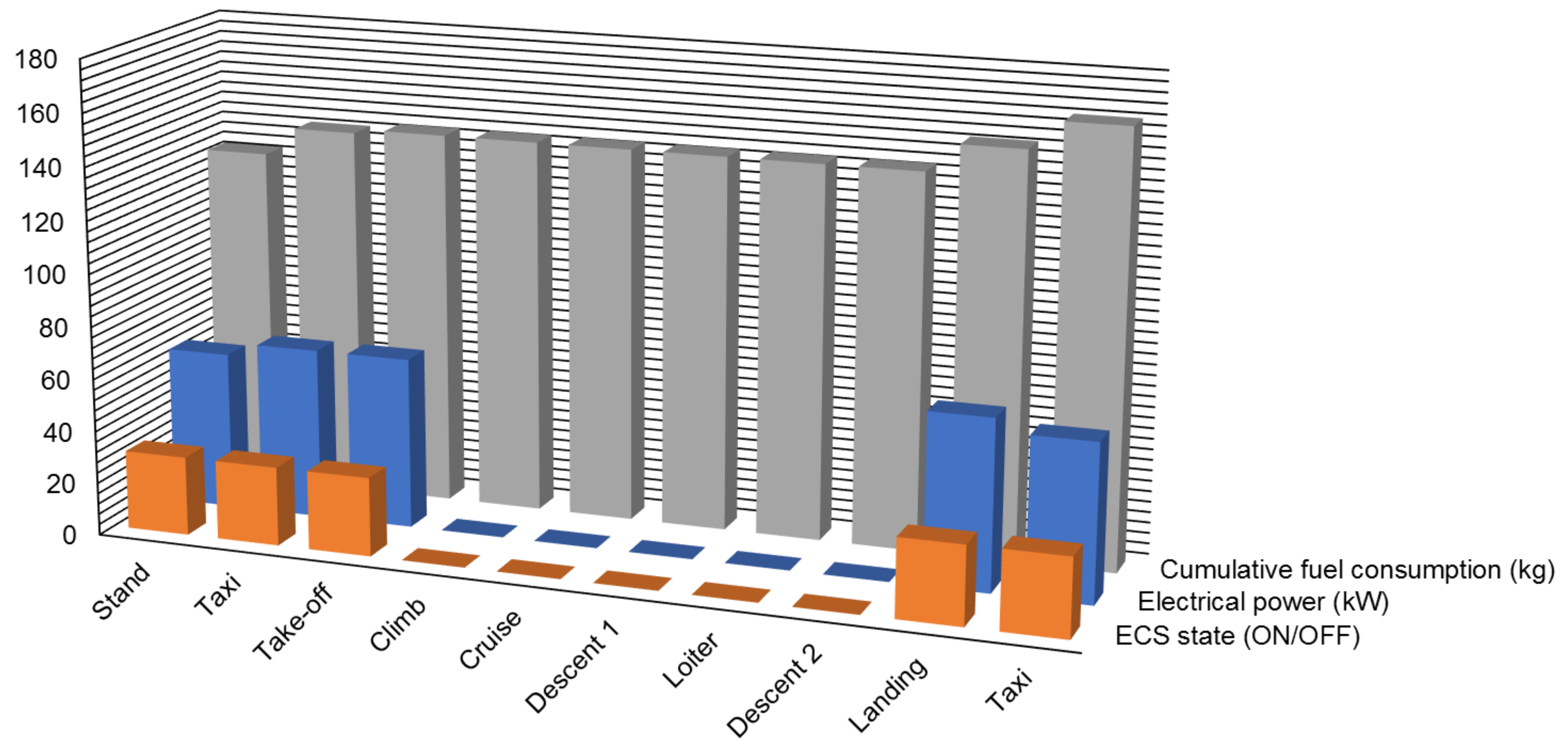
The problem

- Existing gas turbine based Auxiliary Power Units (APU).
  - Work based on Honeywell 131-9 from Boeing 737-600.
- Local environment degradation,
  - Noise – ≈ 92 EPNdB [1]
  - Heat – exhaust temperature of ≈ 600 °C [2]
  - Pollutants [3]:
    - NO_x – 0.35 kg/hr
    - CO – 0.26 kg/hr
    - HC – 0.02 kg/hr
- Fossil fuel consumption.

Normal operating conditions

- APU assumed to only be used during ground operations.
- Fuel consumption = 0.036 kg/s [2] (2-pack environmental control system (ECS) + 65kW electrical)

Operation	Time (min)	Fuel consumed (kg)
Stand	60	130
Taxi (1)	5	11
Take-off	1	2
Landing	5	11
Taxi (2)	5	11
	Total	165

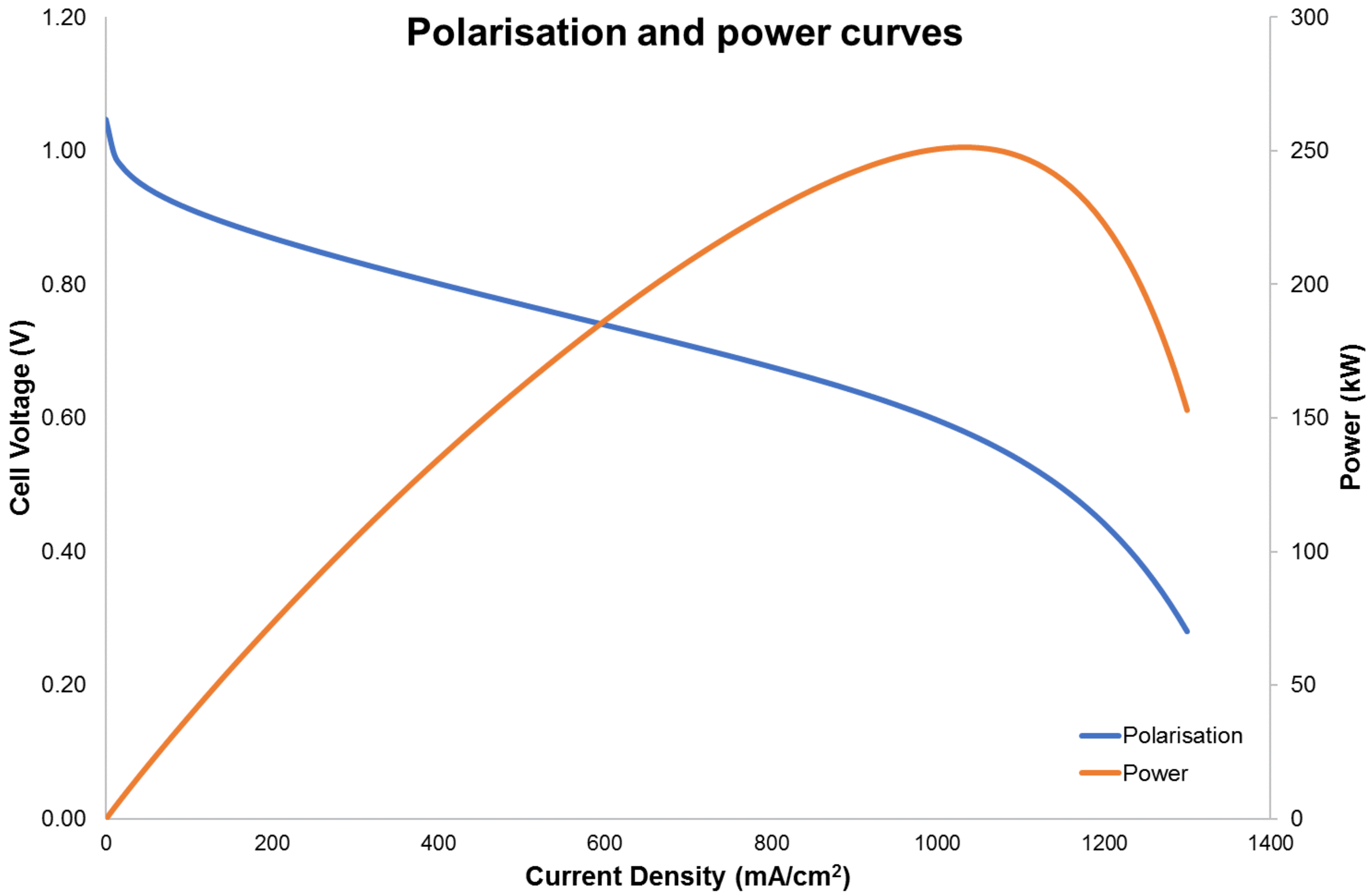


THE SOLUTION

Low temperature fuel cell APU

- Power requirement = 235 kW (assuming electric ECS).
- Account for compressor power gives a total fuel cell power requirement = 252 kW (assuming ambient air).

Fuel cell specifications	
Number of cells (n)	525
Operating cell voltage (Vc)	0.6 V
Operating current (A)	800 A
Airflow required	332 g/s
Fuel (H_2) requirement	6.6 g/s
Water production rate	39.2 g/s



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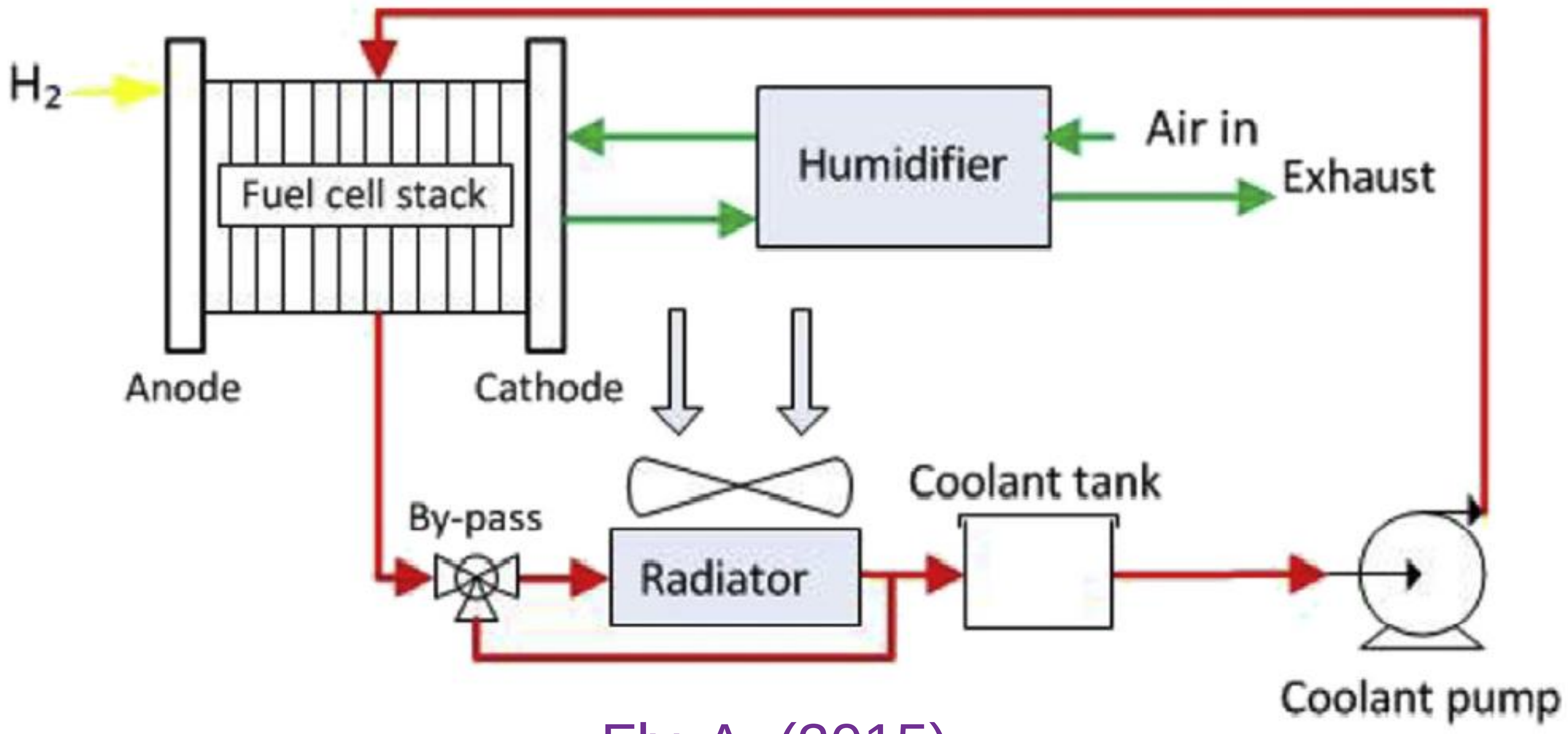
Fuel cell thermodynamics

- Hydration essential for the operation of low temperature PEM FC.
- Current efficiency of ≈ 40%
  - ∴ 252 kW electrical power → 370 kW heat to be dissipated.
- Operating temperature generally 70 °C.
  - Existing APU exhaust temperature ≈ 600 °C.
- Hydrogen storage could be used as a heat sink.
  - Compressed gas (CGH2)
  - Liquid (LH2) – storage temperature of ≈ 20 K.

Cooling technologies – LC

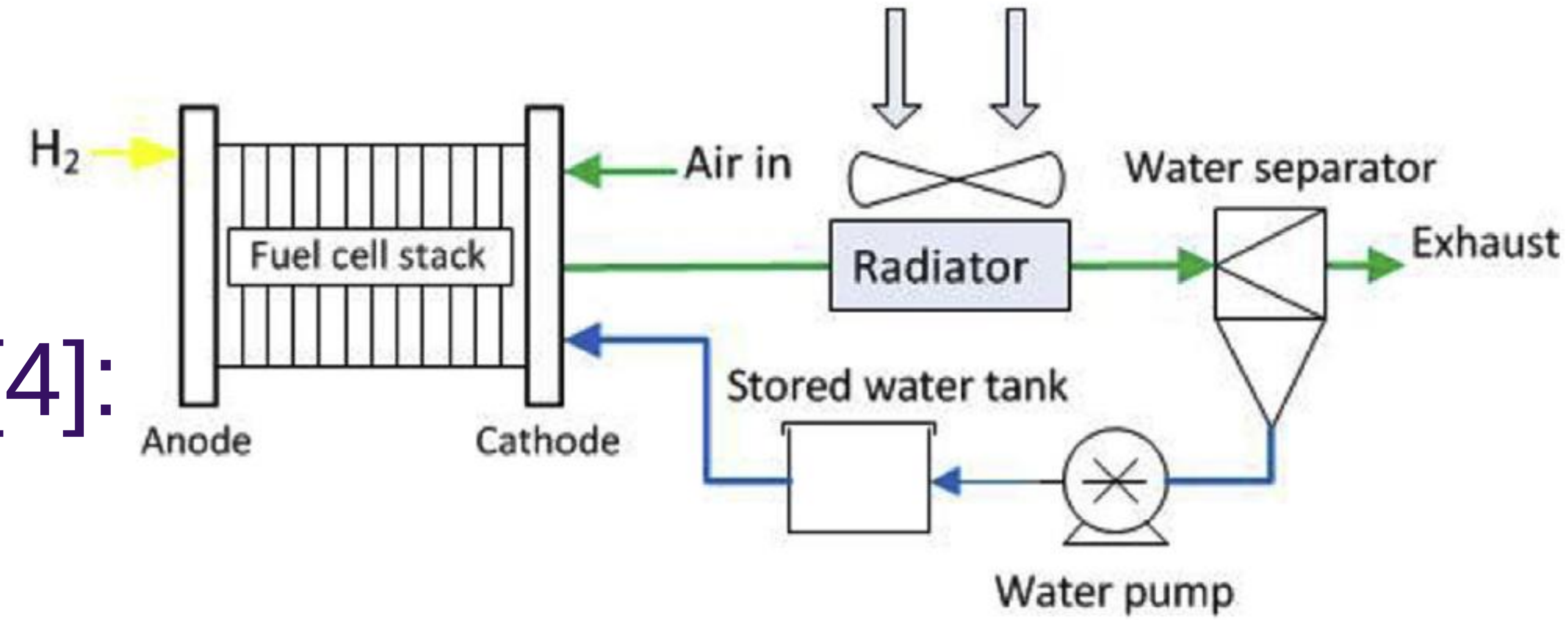
- Liquid cooling (LC),
  - Separate cooling loop, similar to automotive water/glycol system.
  - Typically, more heat needs to be rejected through a heat exchanger than EC systems.
  - Additional sub-subsystem required for stack humidification.
- Size to cool 252 KW FC [4]:
  - Mass ≈ 98.8 kg
  - Volume ≈ 0.116 m^3



Fly, A. (2015)

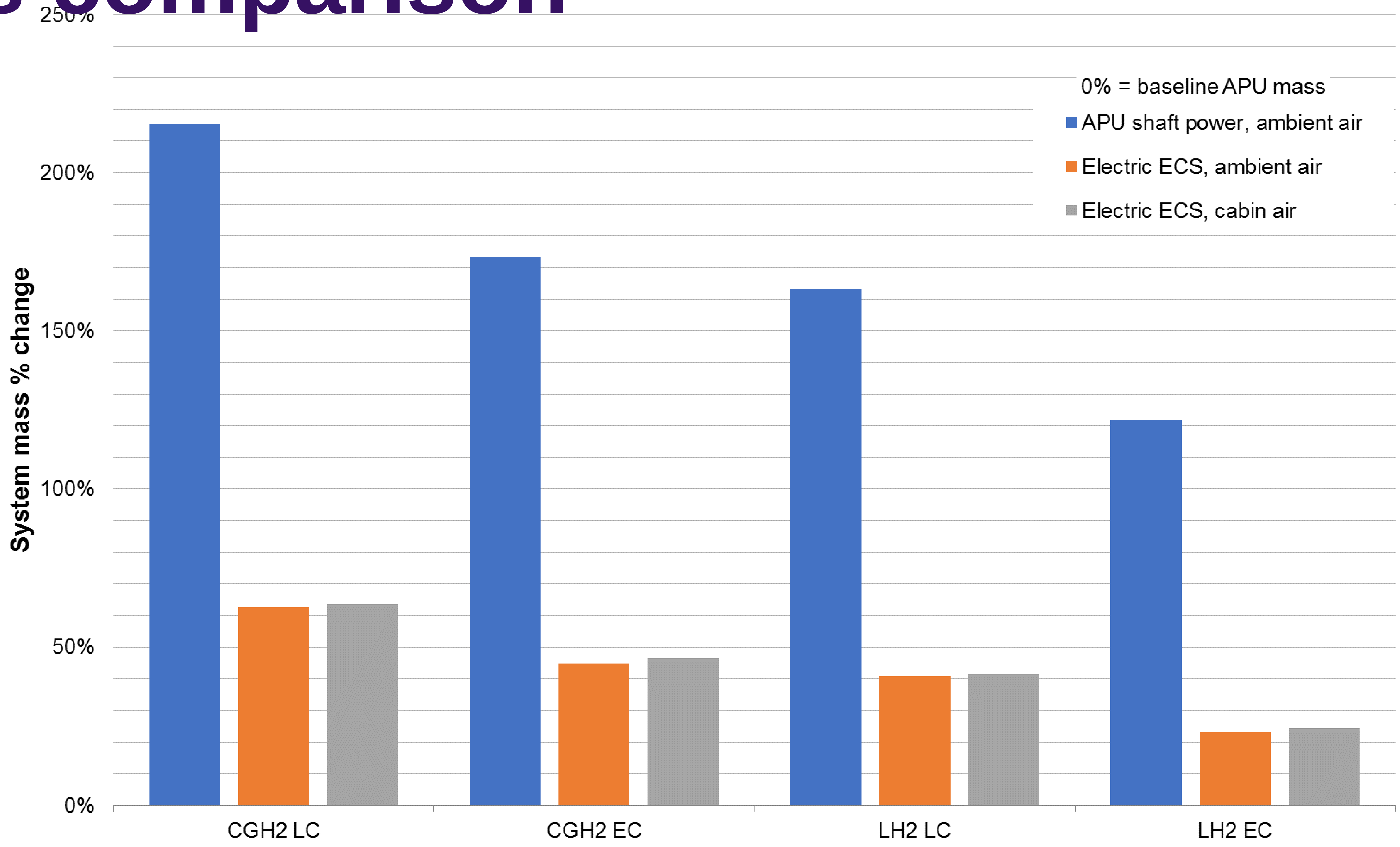
Cooling technologies – EC

- Evaporative cooling (EC),
  - Requires direct injection of ultra-pure de-ionised water.
  - Cooling and cell humidification are combined.
  - Reduced balance of plant compared to LC system.
- Size to cool 252 KW FC [4]:
  - Mass ≈ 67.7 kg
  - Volume ≈ 0.146 m^3

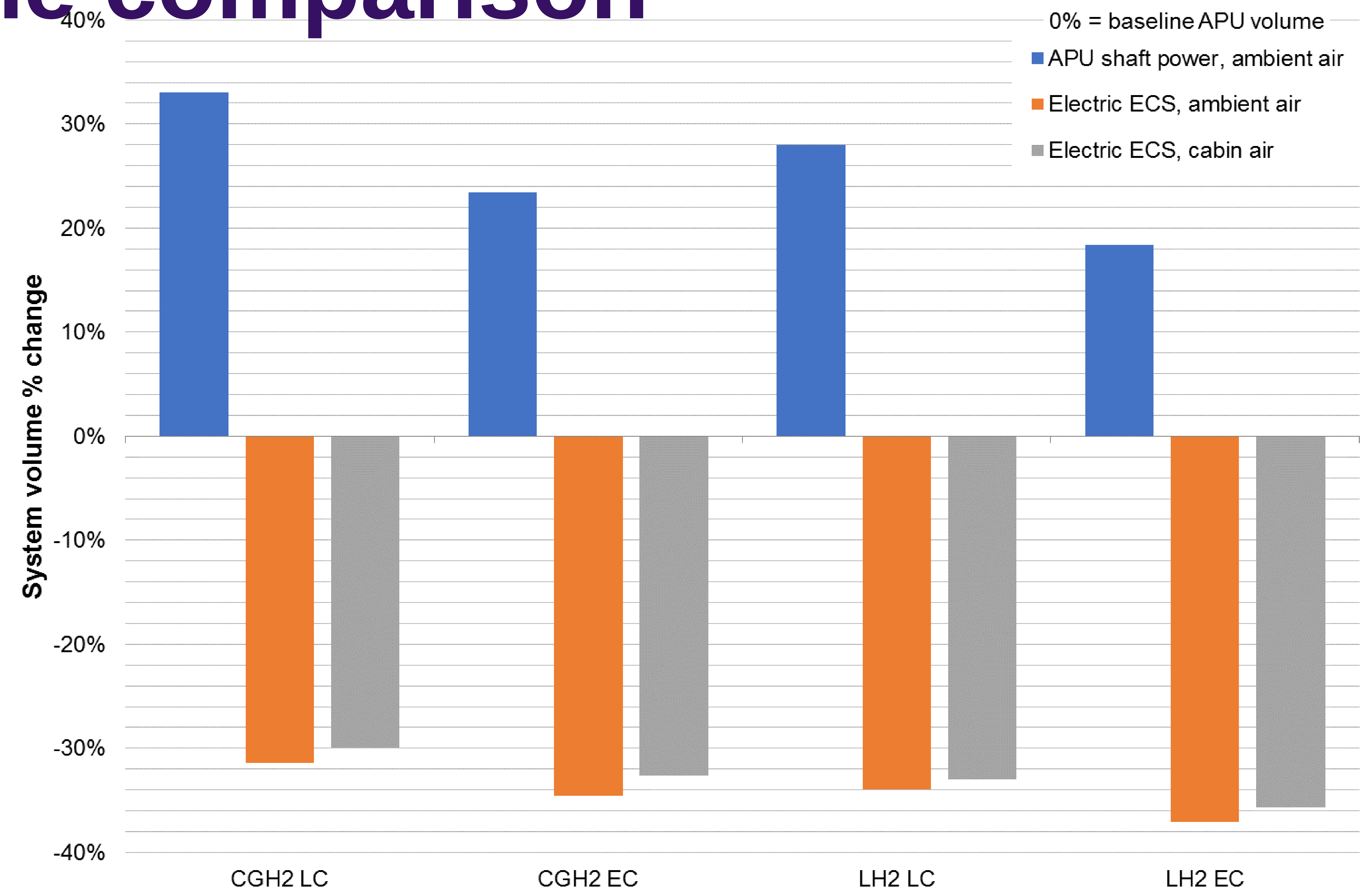


Fly, A. (2015)

Mass comparison

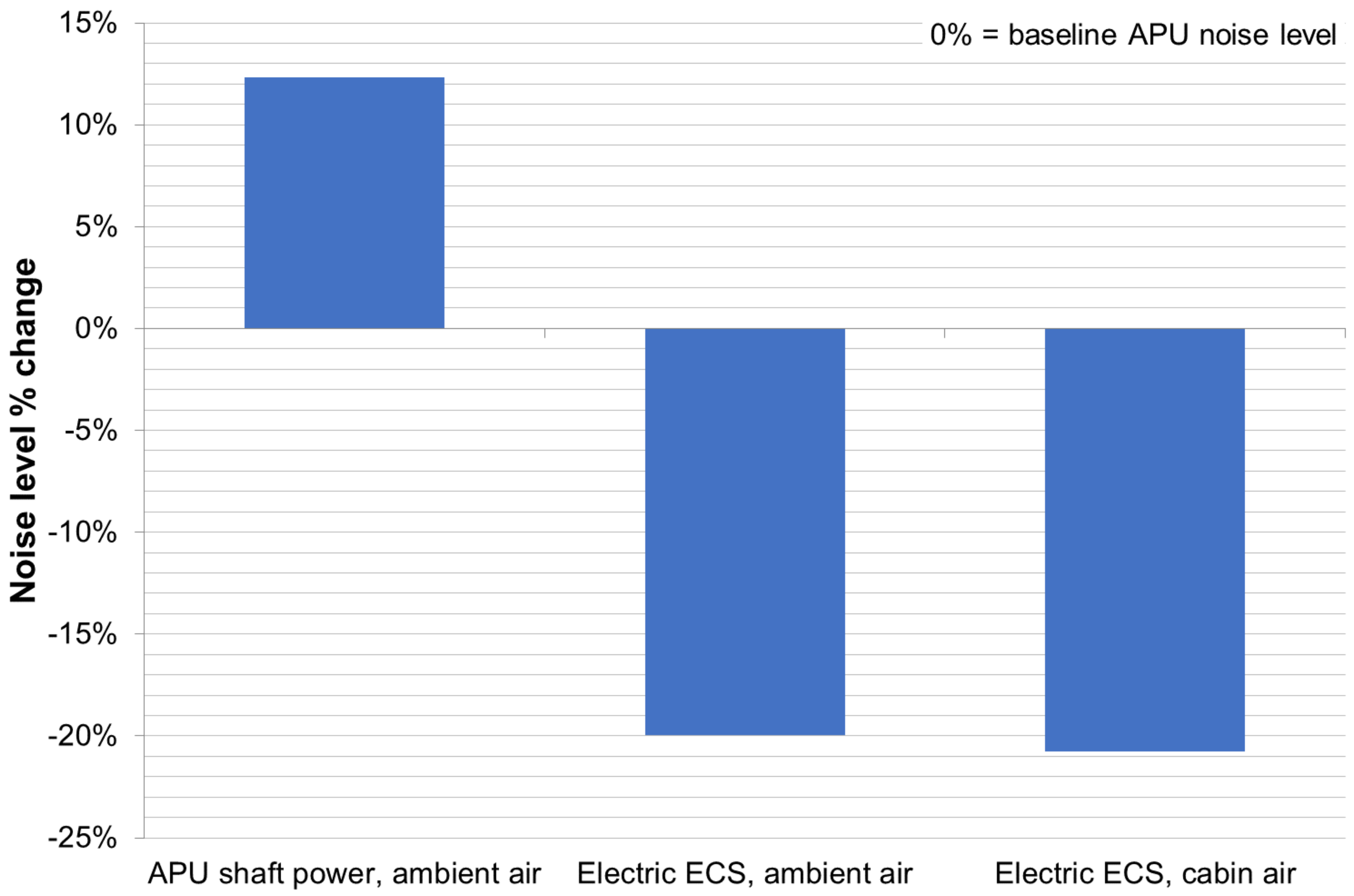


Volume comparison



Acoustic comparison

- Key factor for ground support crew at airports.
- Typical APU ≈ 92 EPNdB.
- Fuel cell system up to 10 dB quieter.
- Less turbomachinery combined with lower air mass flow rate.



System comparison

- Fuel cell exhaust has a significantly lower temperature than baseline APU ($\Delta T = 530$ °C).
  - Additional cooling components required for a fuel cell system compared to baseline APU.
- Baseline APU has a lower mass than any of the fuel cell systems considered.
- Fuel cell systems have a reduced volume compared to baseline APU if an electric ECS is used.
- Fuel cell systems can have a reduced acoustic signature compared with the baseline APU.

CLOSING REMARKS

Conclusions

- A fuel cell APU can be thermodynamically feasible for a civil aircraft,
  - Liquid cooled system leads to a slight weight penalty over and evaporatively cooled system.
  - Using fuel as a heat sink was found not to be necessary at this stage.
- Elimination of pollutants during operation.
- Fuel cell system found to be up to 10 dB quieter than existing APU, improving working environment for ground staff.
- Most suitable fuel cell system configuration found to be:
  - 252 kW (using electric ECS).
  - Liquid hydrogen storage and evaporatively cooled for reduced mass and volume.

Future work

- Integration of aircraft ECS into fuel cell system air loop.
  - Possible further reduction in turbomachinery equipment required.
- Consideration of using liquid hydrogen fuel as a sink for other heat loads on the aircraft.
- Further development of EC fuel cells to improve durability and lower cost.
- Further development in hydrogen storage to allow for lower system mass and volume.

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References

1. International Civil Aviation Organization, 2008. *Annex 16 to the Convention on International Civil Aviation: Environmental Protection Volume I.*
2. Chase Aerospace Inc., 2013. *APU Information GTC131-9B.*
3. Wade, M.D., 2002. Aircraft/Auxiliary Power Units/Aerospace Ground Support Equipment Emission Factors. , pp.1–68.
4. Thirkell, A. Chen, R. Harrington, I., 2017. A Fuel Cell System Sizing Tool Based on Current Production Aircraft, *SAE Aerospace Congress and Exhibition 2017.*

Thank-you!

Any questions?

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