E2Flight Presentation:
Potential Propulsion Architecture for a Reduced Climate Impact of Civil Aviation

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Introduction

Aviation global CO_2 contribution (2018) ~2%

Aviation global temperature impact contribution (2018) ~5%

Goal: Reduced Impact of Aviation.

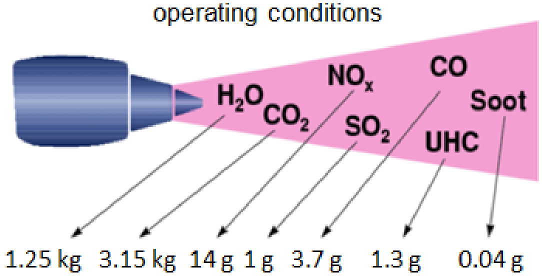
Possible means:

- Non-fossil fuels with renewable energy sources:
    - mainly CO_2 impact mitigation (~1/3)
    - NO_x?, Contrails?, H_20?

- Alternative propulsion systems aiming:
    - reducing the fuel consumption of the aircraft fleet
    - Reduction of the non-CO_2 emissions

Air Traffic Emissions at Cruise

Combustion products depend on the operating conditions



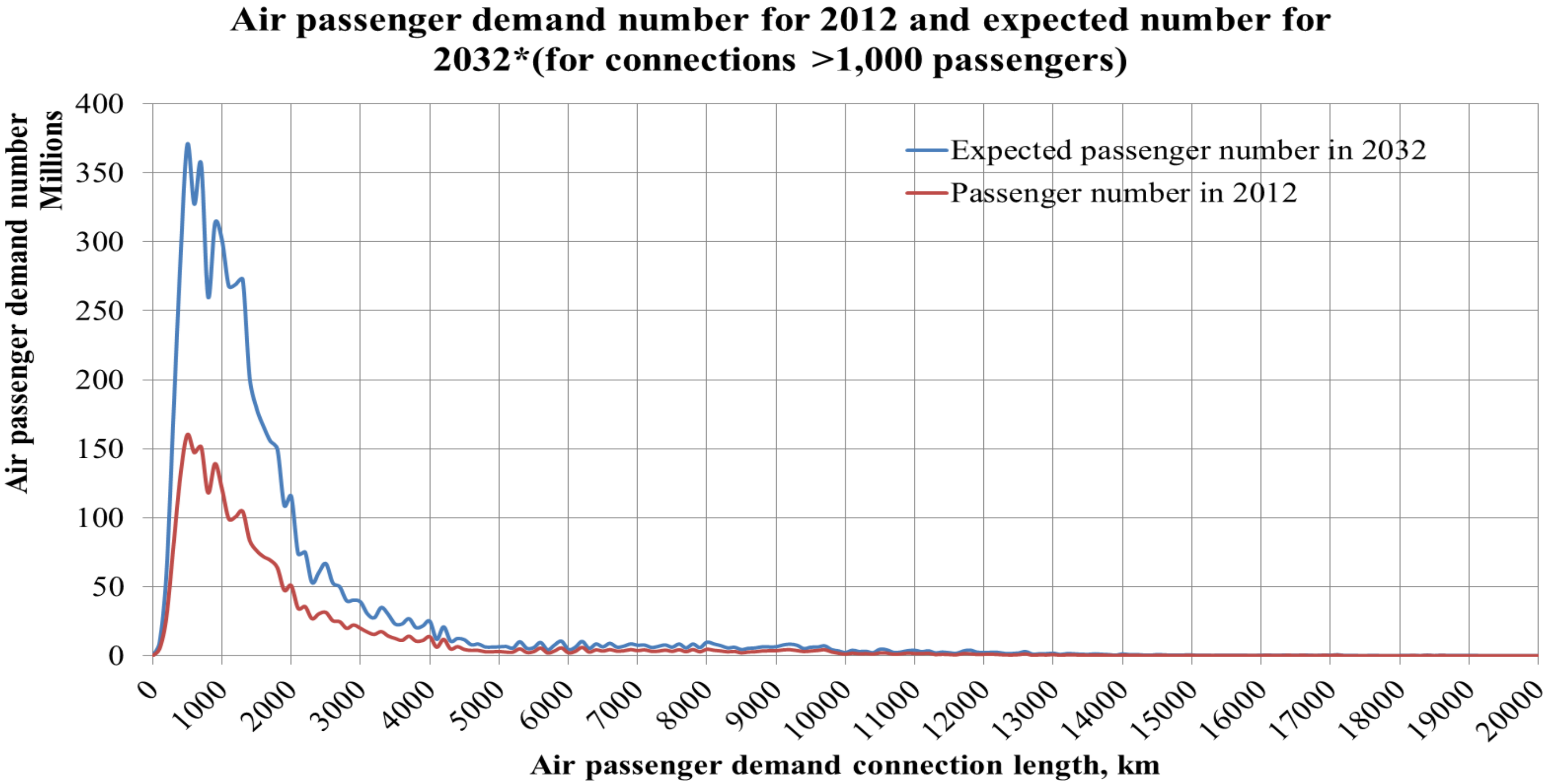
(per kg kerosene) **(IPCC1999)**

• CO_2	~1/3 impact
• NO_x • Contrails • H_20	~2/3 impact Source: **Grewe et al (2019)**

Focus of the presentation:

➢ Hybrid-electric architecture with the battery as the main power provider.

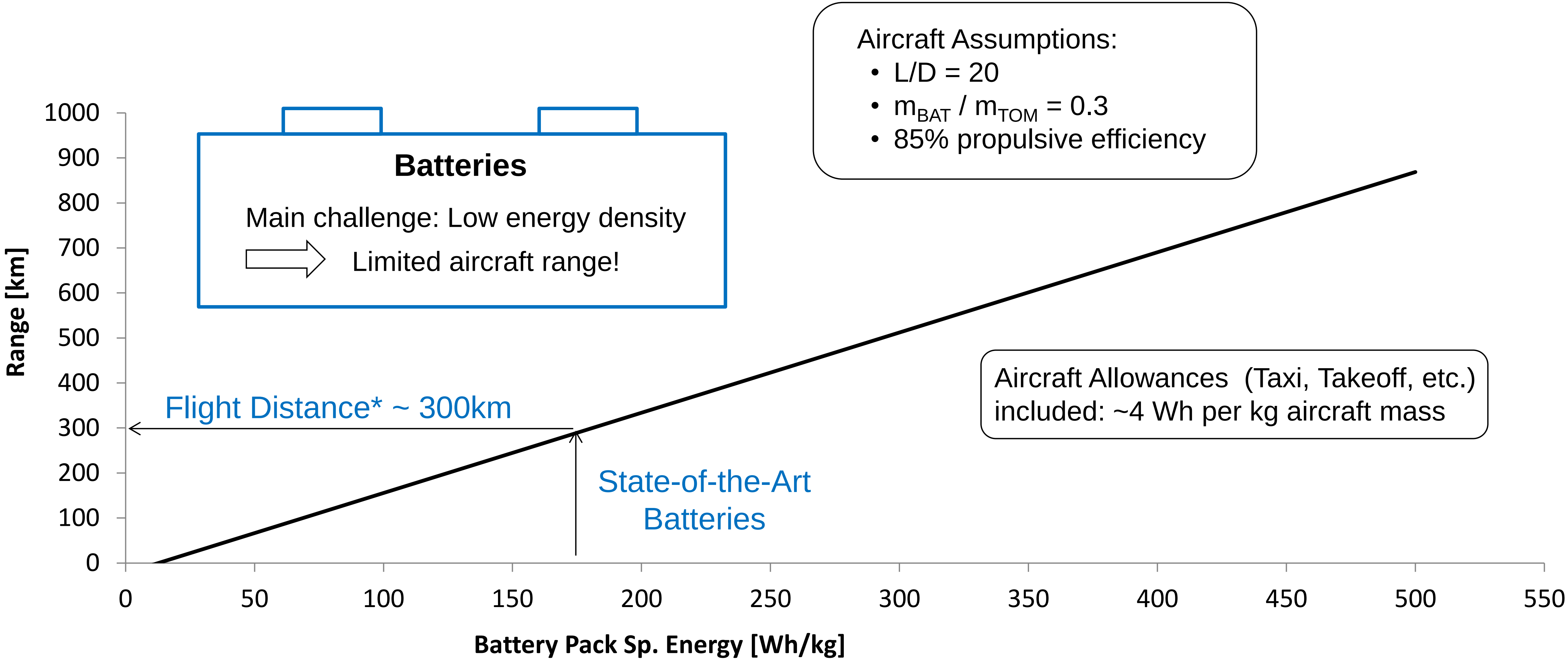
Motivation for Batteries



* Based on the UN GEO-4 socio-economic scenario Sustainability First. Expected APD number is obtained from the APD forecasting model on city level – *D-Cast*.

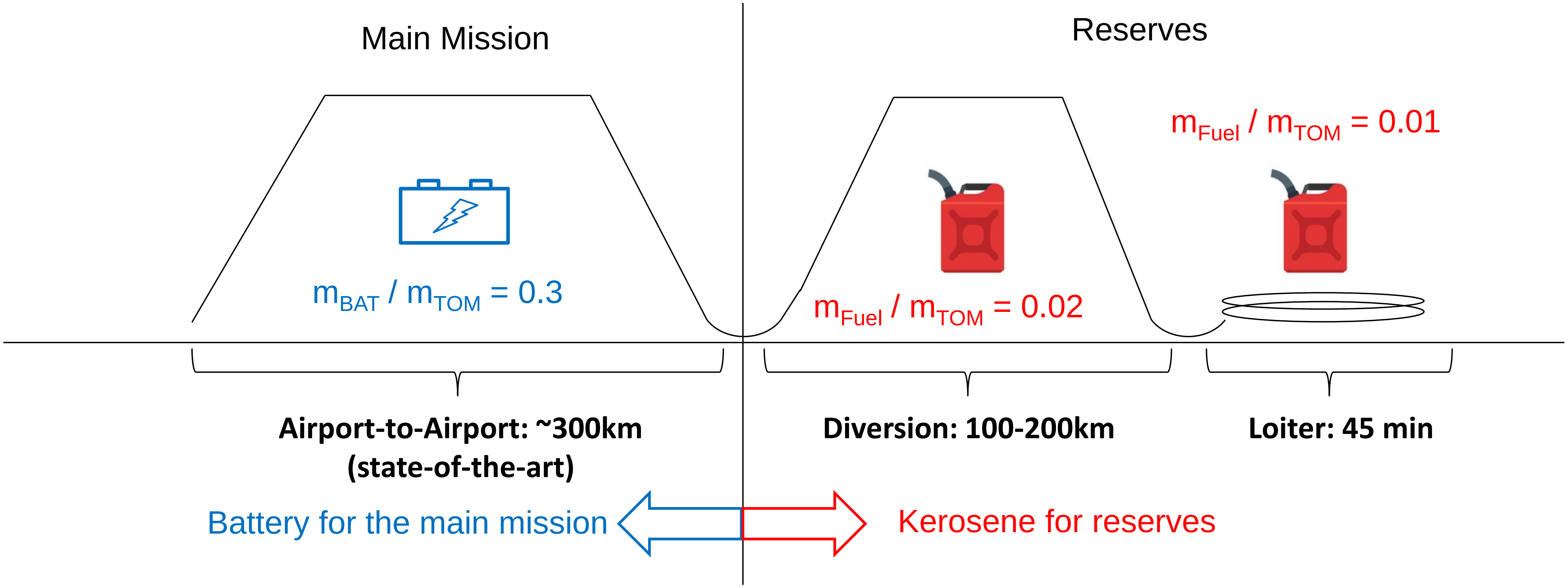
A significant portion of the air traffic takes place at distances, attainable by battery powered aircraft

Battery-Driven Aircraft Design



*5% Contingency included.

Range Extender for Increased Electric Range



Battery + Range Extender

~10% of Power Train Mass

E-Motors:

- ➢ Sized for fully electric operation (incl. takeoff).

~10% of Power Train Mass

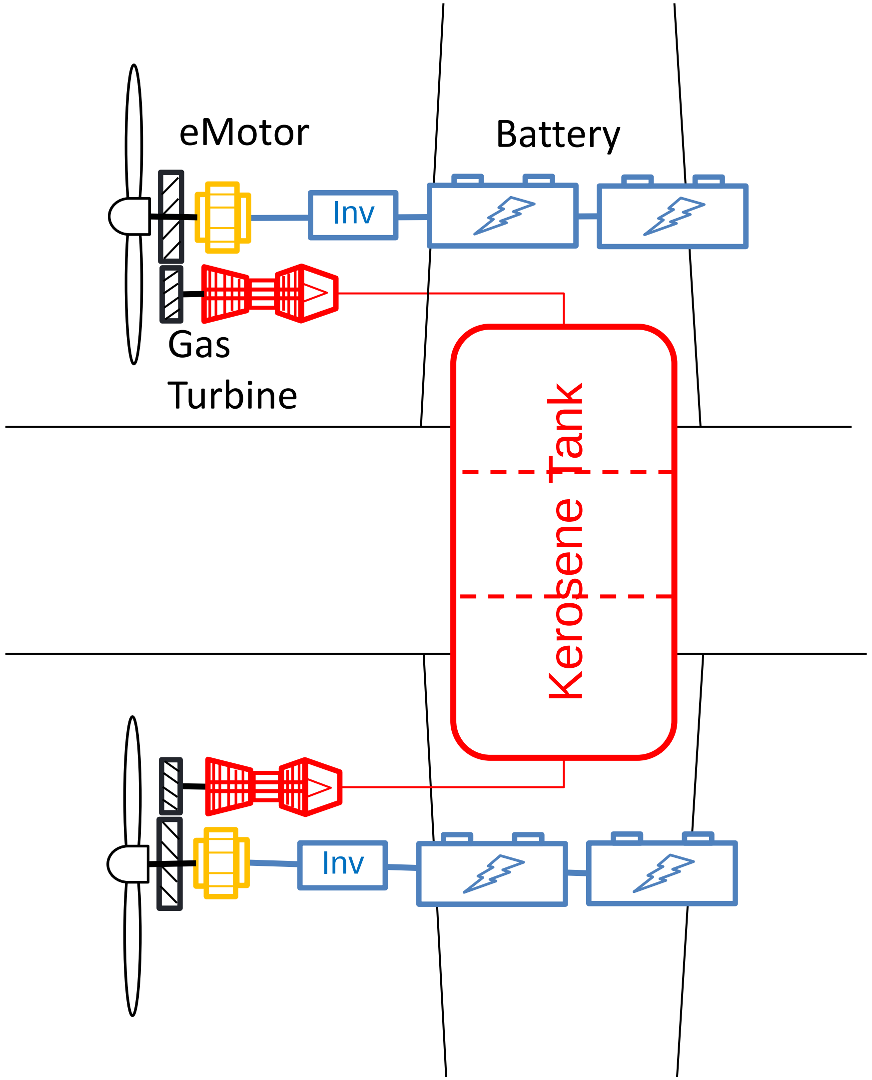
Range extenders & fuel tank:

- ➢ In parallel with e-motors, via a gear / clutch.
- ➢ For full mission reserves with kerosene.
- ➢ For range flexibility with kerosene.
- ➢ Sized for diversion speeds.

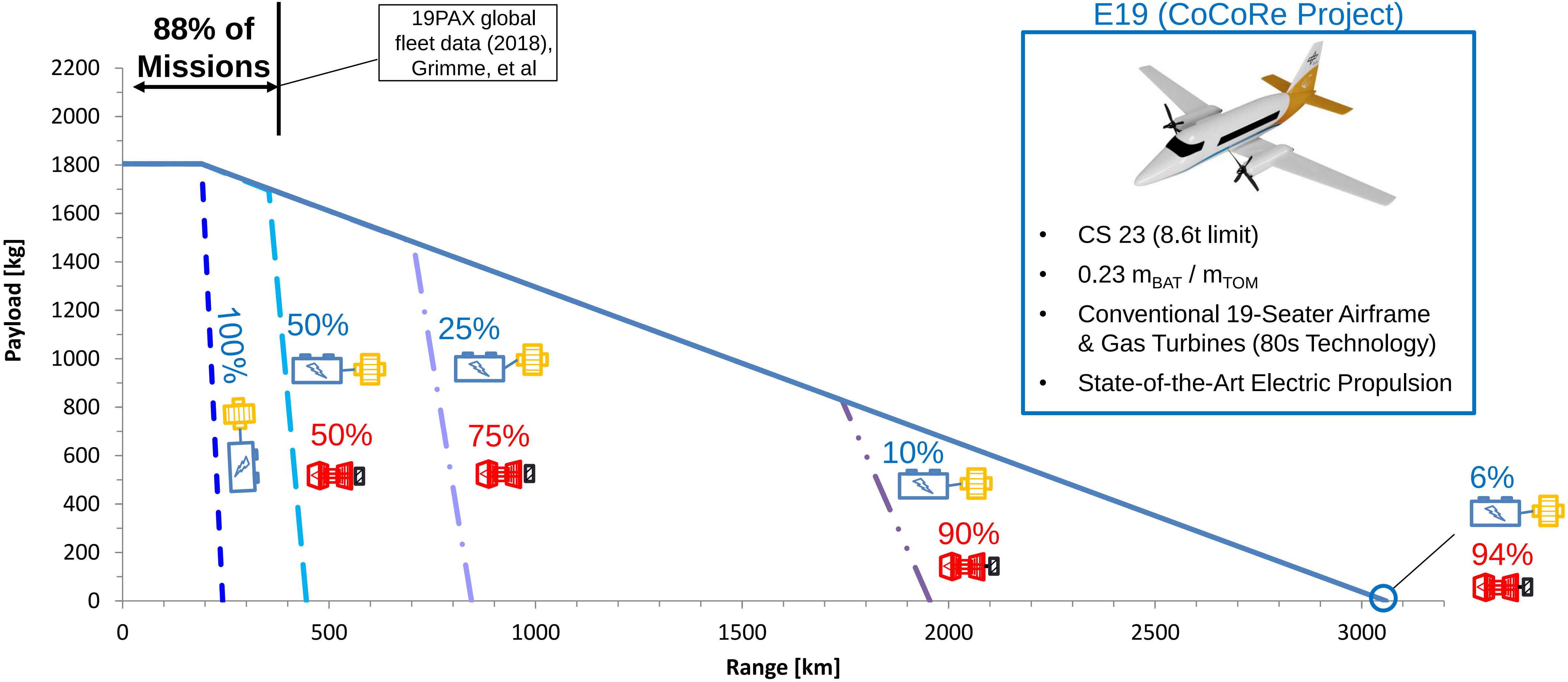
~80% of Power Train Mass

Batteries:

- ➢ Sized for all-electric operation.
- ➢ No need to consider mission reserves.



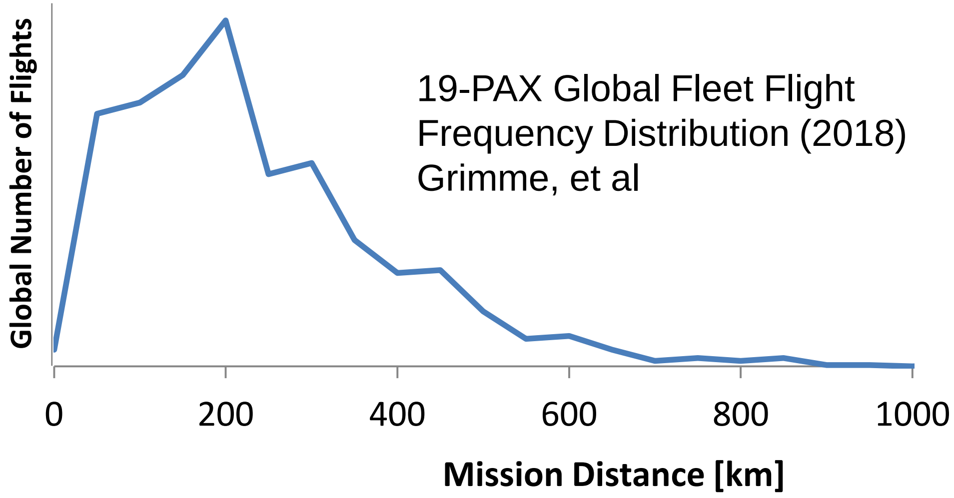
19-Seater Electric Aircraft with a Range Extender

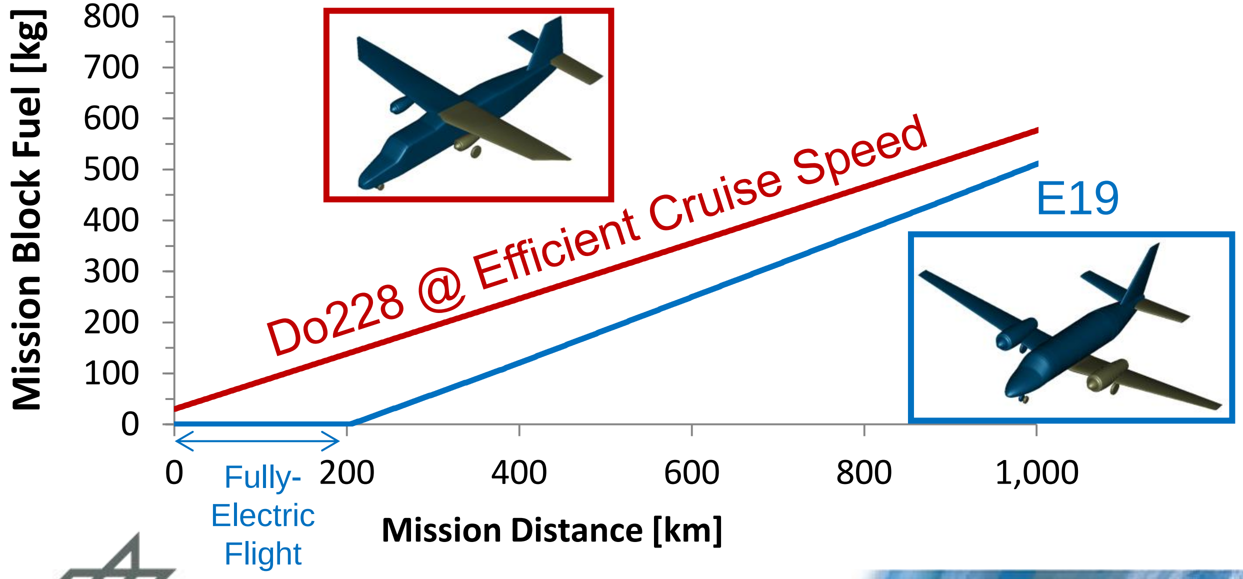


E19 (CoCoRe Project)

- CS 23 (8.6t limit)
- 0.23 m_{BAT} / m_{TOM}
- Conventional 19-Seater Airframe & Gas Turbines (80s Technology)
- State-of-the-Art Electric Propulsion

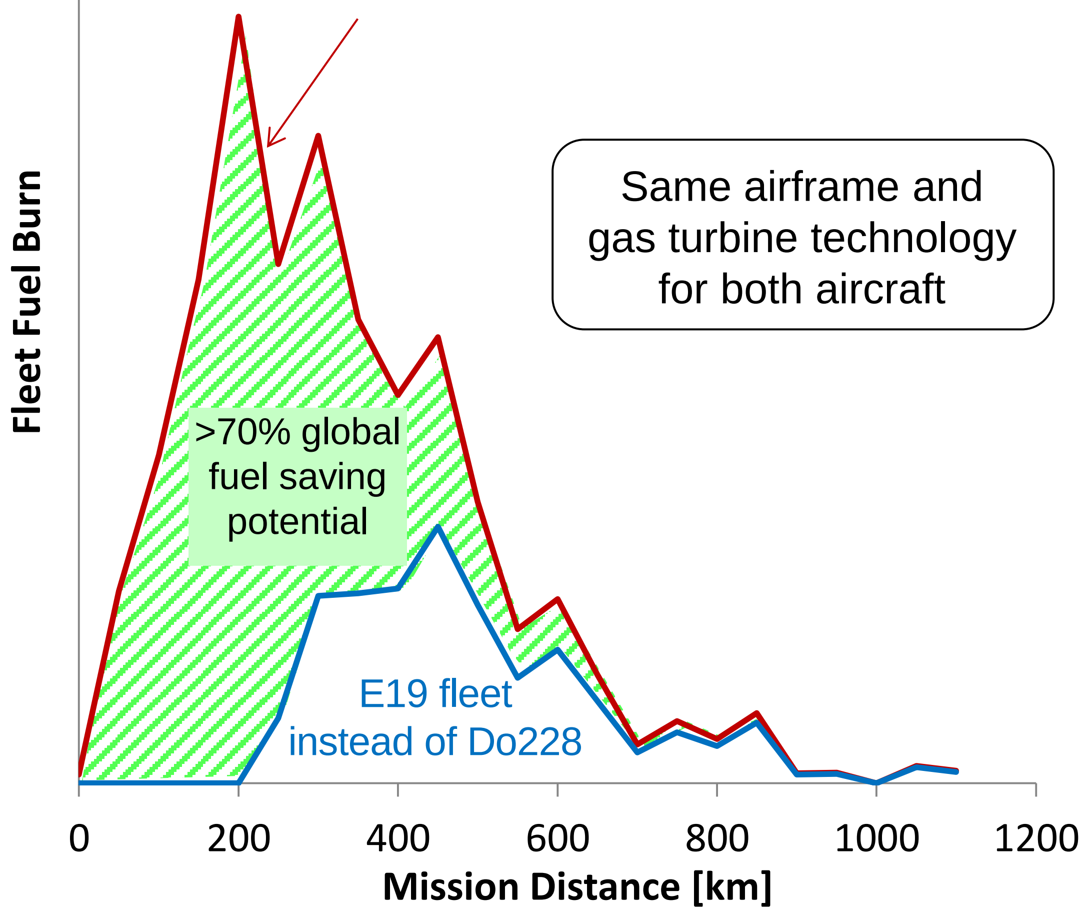
19-Seater Electric Aircraft with a Range Extender





19PAX global fleet fuel burn profile.
Assumptions.

- comprised only of Do228
- operated at efficient cruise speed



State-of-the-Art Perspective

1kWh (P_{Shaft}*t)

Production & Logistics:

~60g eq. CO_2 / kWh*

Combustion:

~260g CO_2 / kWh

Gas Turbine

Do228 size

Efficiency: ~25%

~ 4 kWh Kerosene:

- **1280 g CO_2**
- **+ Impact from NO_x and H_2O**

German Mix (2018)

~ 474g** CO_2 / kWh

2000 cycles
160 Wh/kg

Life Cycle

~ +50g*** CO_2 / kWh

Battery | eMotor

Inv

~90% | ~94%

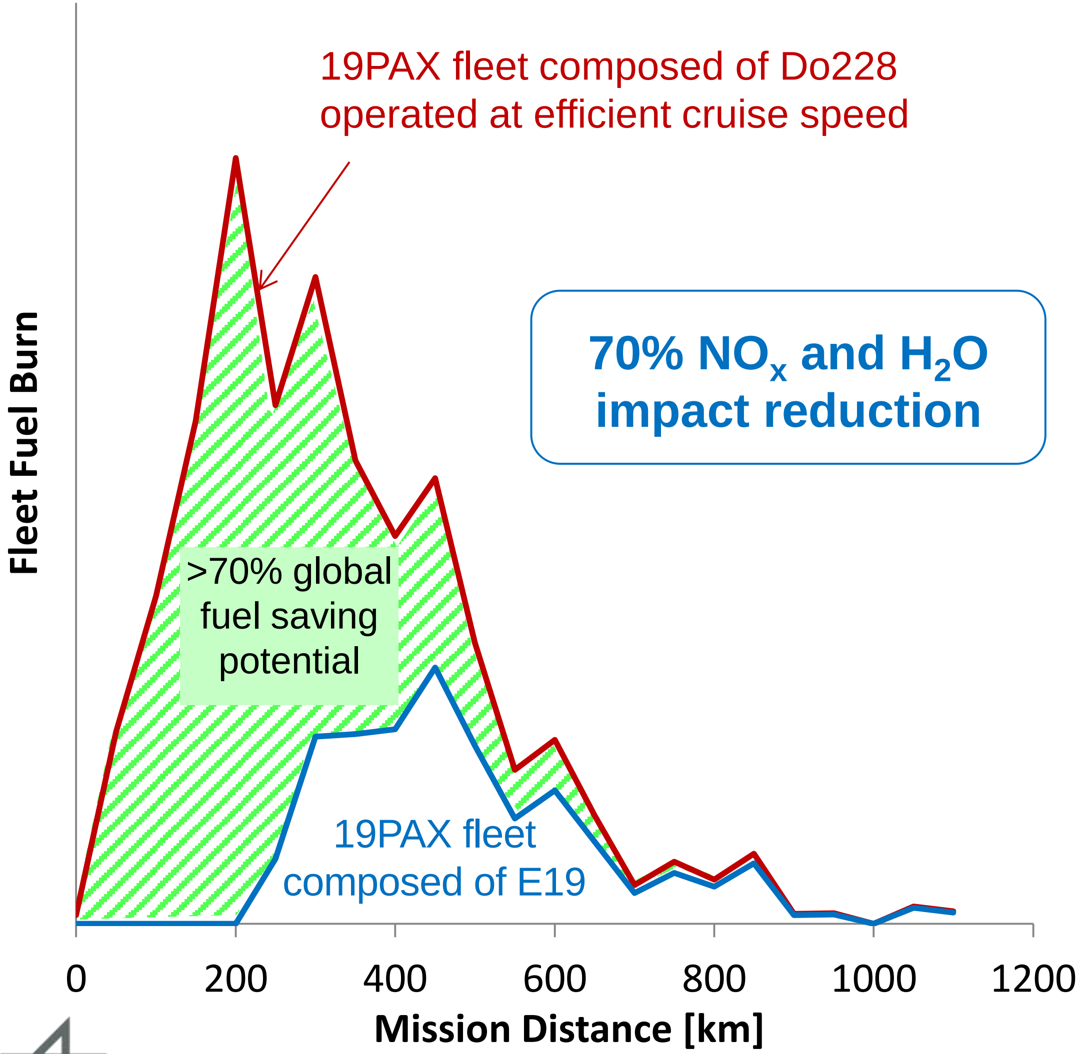
Total Eff ~85%

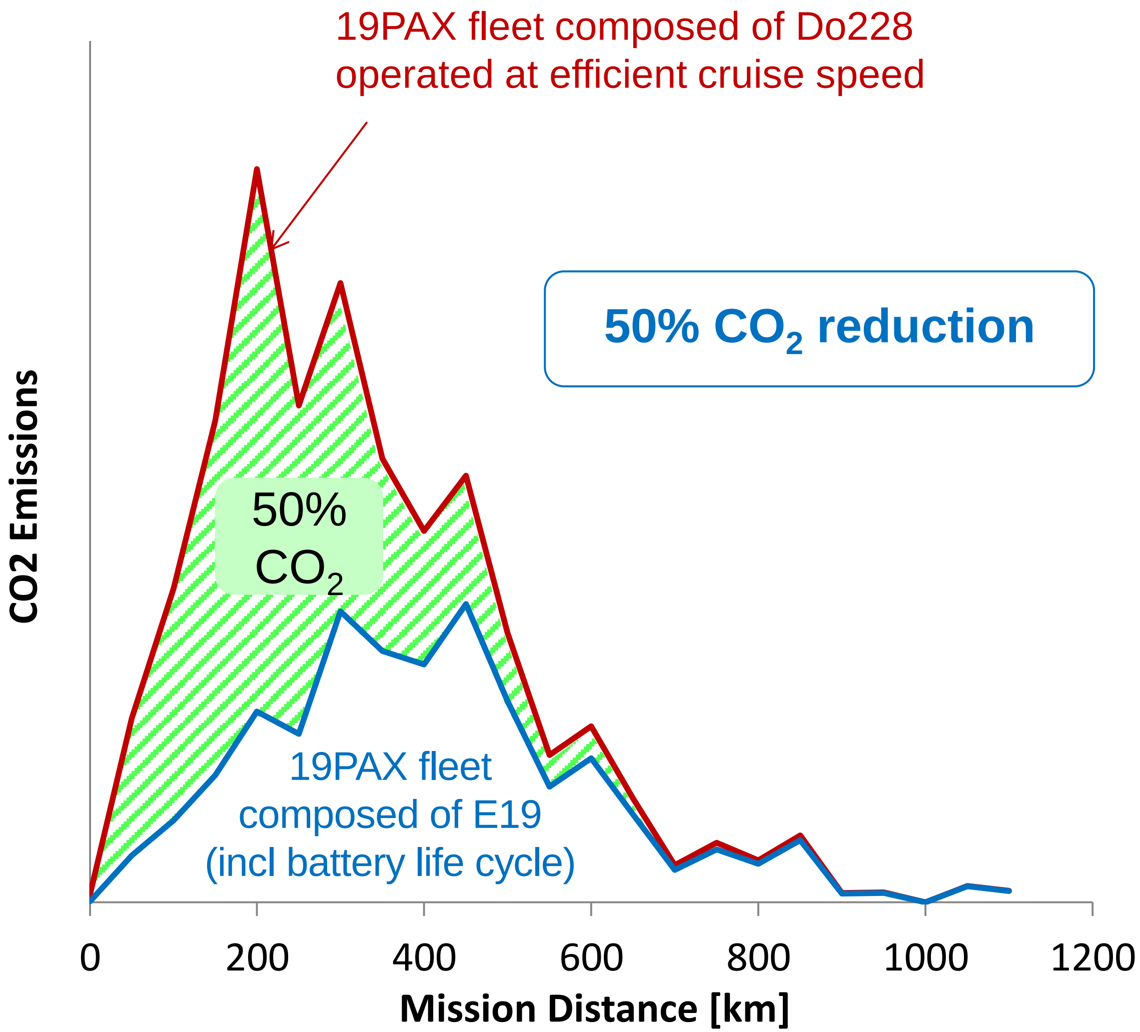
~ 1.2 kWh e-Power

- **600 g CO_2**

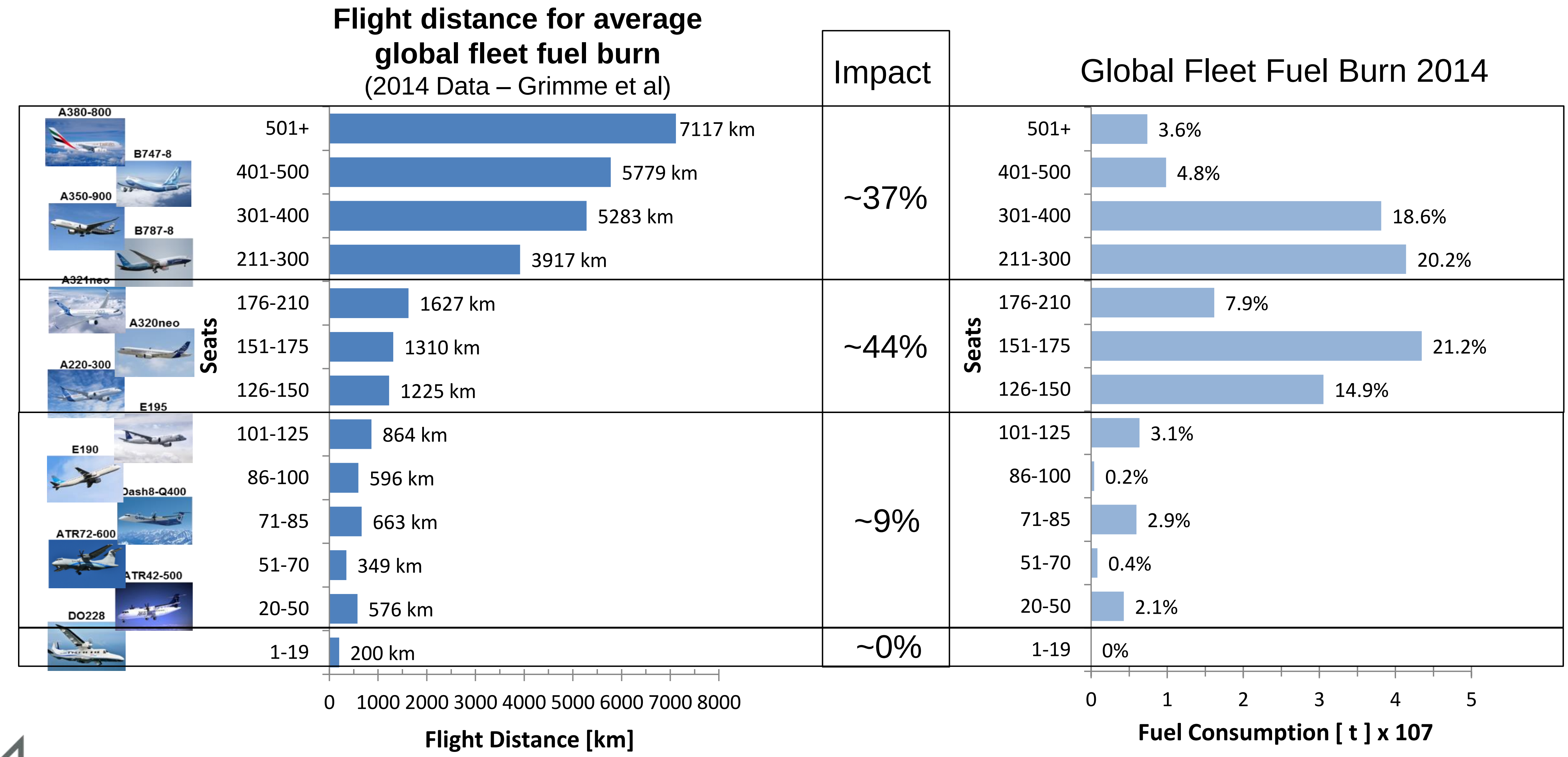
* EU Commission - Report EUR 26237 EN
** Umweltbundesamt (2018a/b)
***Calculated using data from Fraunhofer StudypFHG-SK: ISE-PUBLI

E19 Potential Impact



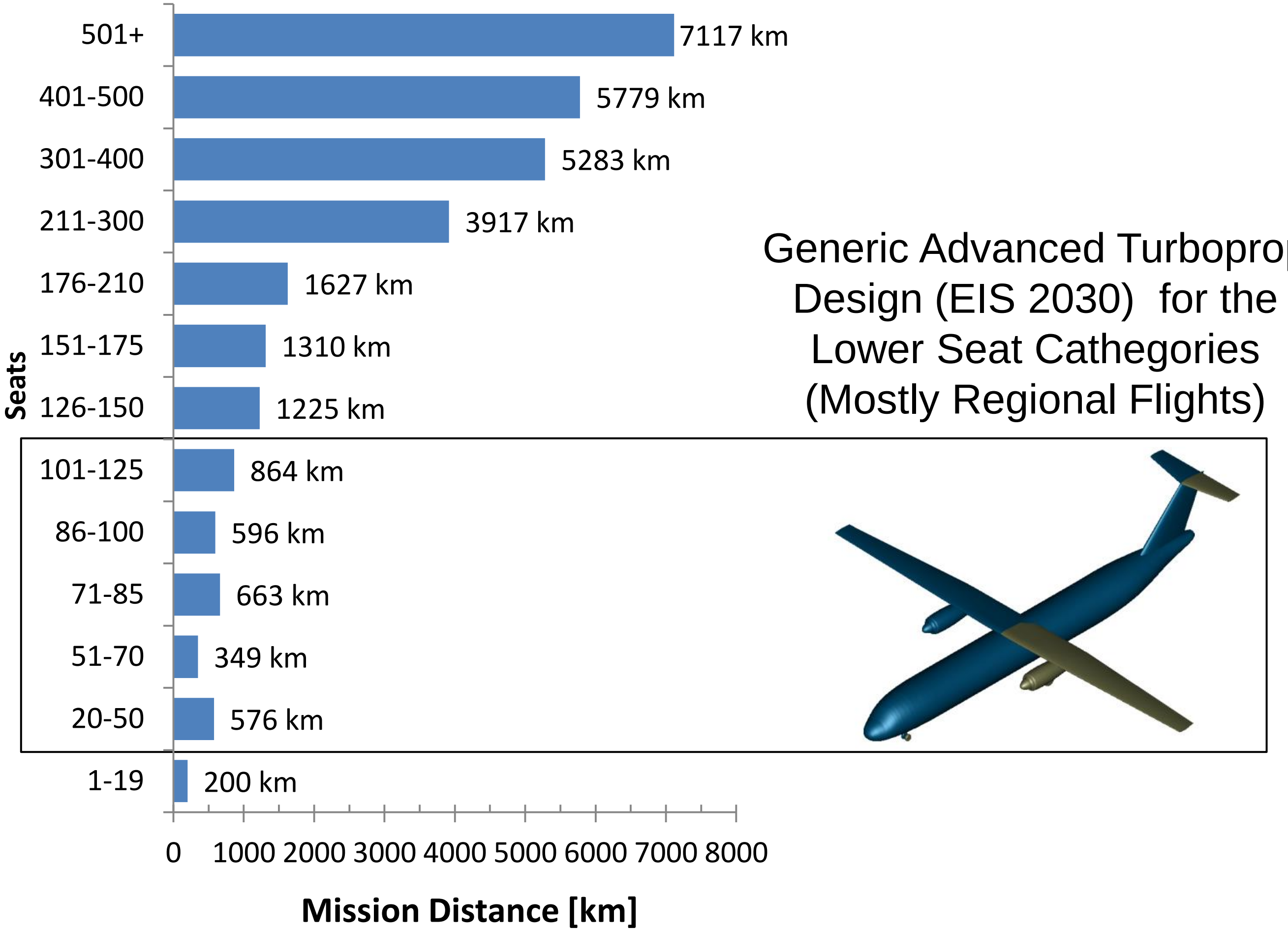


Aircraft Class Impact Breakdown



Fuel Impact Mitigation EIS2030 – Baseline Conventional Turboprop Aircraft

Mission distance for average fuel burn



Top-Level Aircraft Requirements (TLARS):

- Mach = 0.5
- SPP Range = 1200 nm
- Cruise ALT 29000ft
- Takeoff Field Length = 1300 m
- Approach Speed = 120 kCAS

Technology Assumptions:

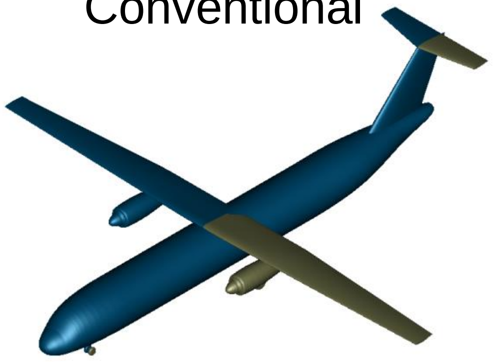
- CFRP Wing & Fuselage
- Fly-by-Wire
- Gas Turbine (EIS 2030) Eff = 35%

Performance Characteristics:

- $m_{Payload} / m_{TOM} = 0.3$
- L/D (cruise) = 19
- Propeller Eff = 87%

EIS2030+ Szenario

Conventional



- $m_{Payload} / m_{TOM} = 0.3$
- $m_{OEM} / m_{TOM} = 0.4$
- $m_{Fuel} / m_{TOM} = 0.15$
- L/D (cruise) = 19

- Same TLARS
- Const. Aspect Ratio
- Const. Wing Loading
- Complete Snowball Effects

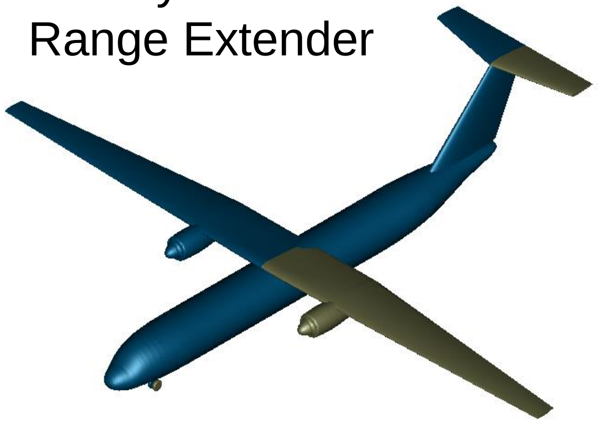
EIS 2030+ Assumptions:

Renewable electric power

Cell Level: 500Wh/kg

Pack level (useful) 300 Wh/kg

Battery + Range Extender

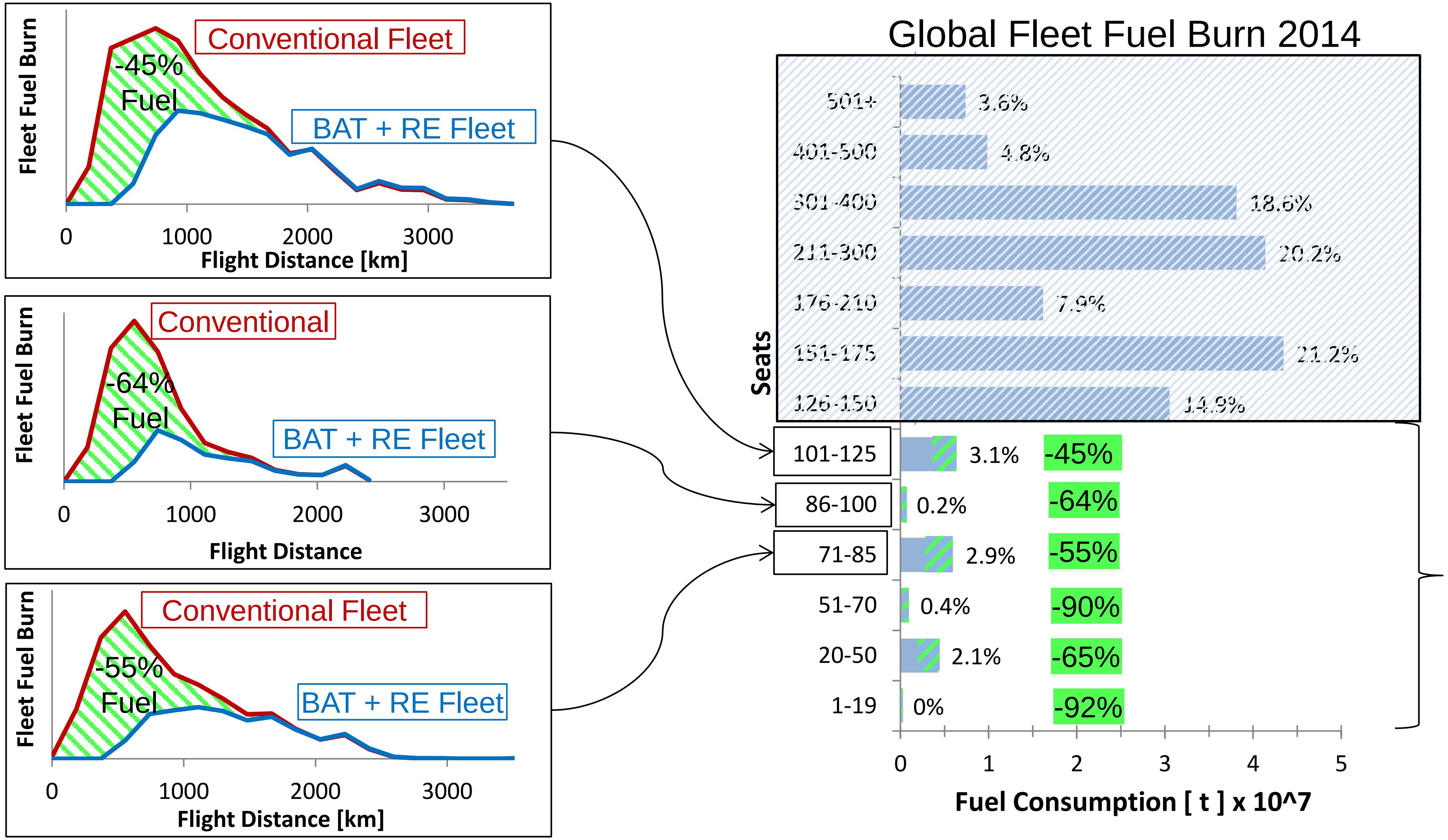


- $m_{BAT} / m_{TOM} = 0.27$
- m_{TOM} increase: +86%
- L/D (cruise) = 22 (big wing for same fuselage)

Electric Range ~ 500km

Potential: Fuel Imact ~ Global Temperature Impact.

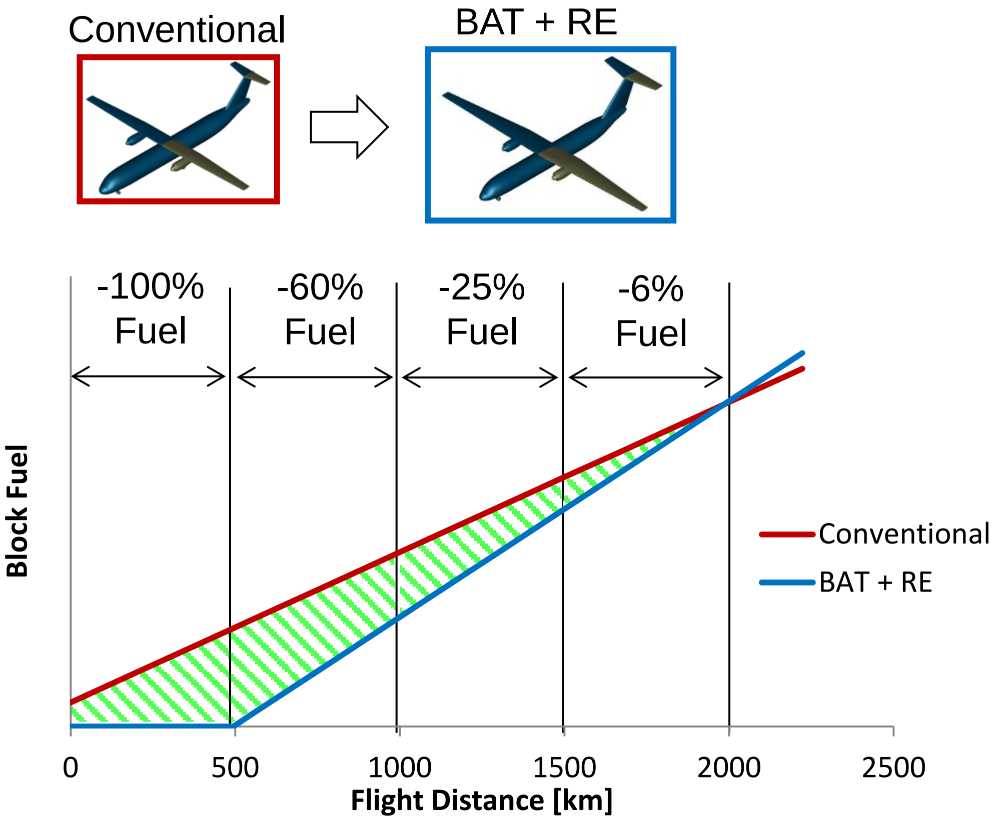
Battery + Range Extender applied on Lower-Seat-Cathegories



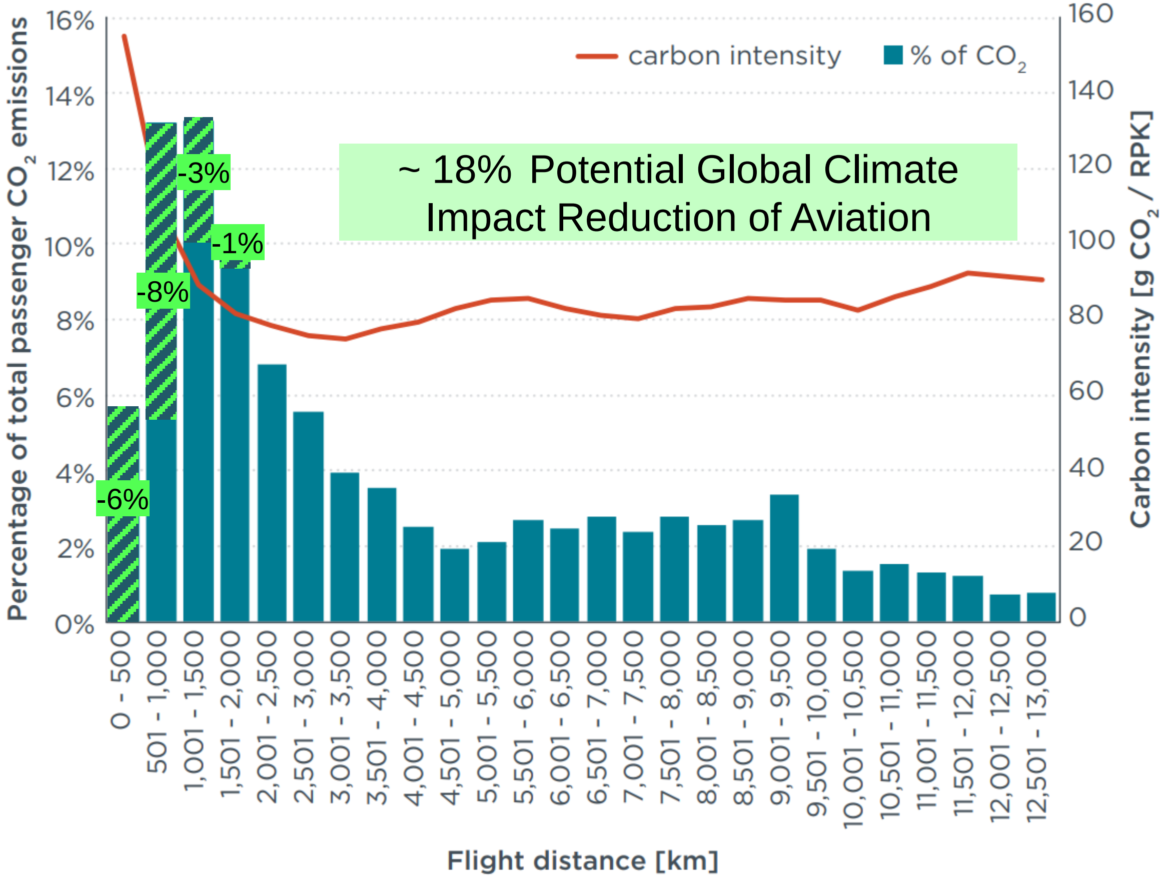
Potential Global Climate Impact Reduction: ~5%

Only the smaller aircraft cathegories!

Global Potential of Battery + Range Extender Concept (EIS2030+ Technology)



ICCT Data (2018)



Significant potential for global emissions reduction already for near-term battery development expectations.

Battery Technology Level Effect on Global Potential

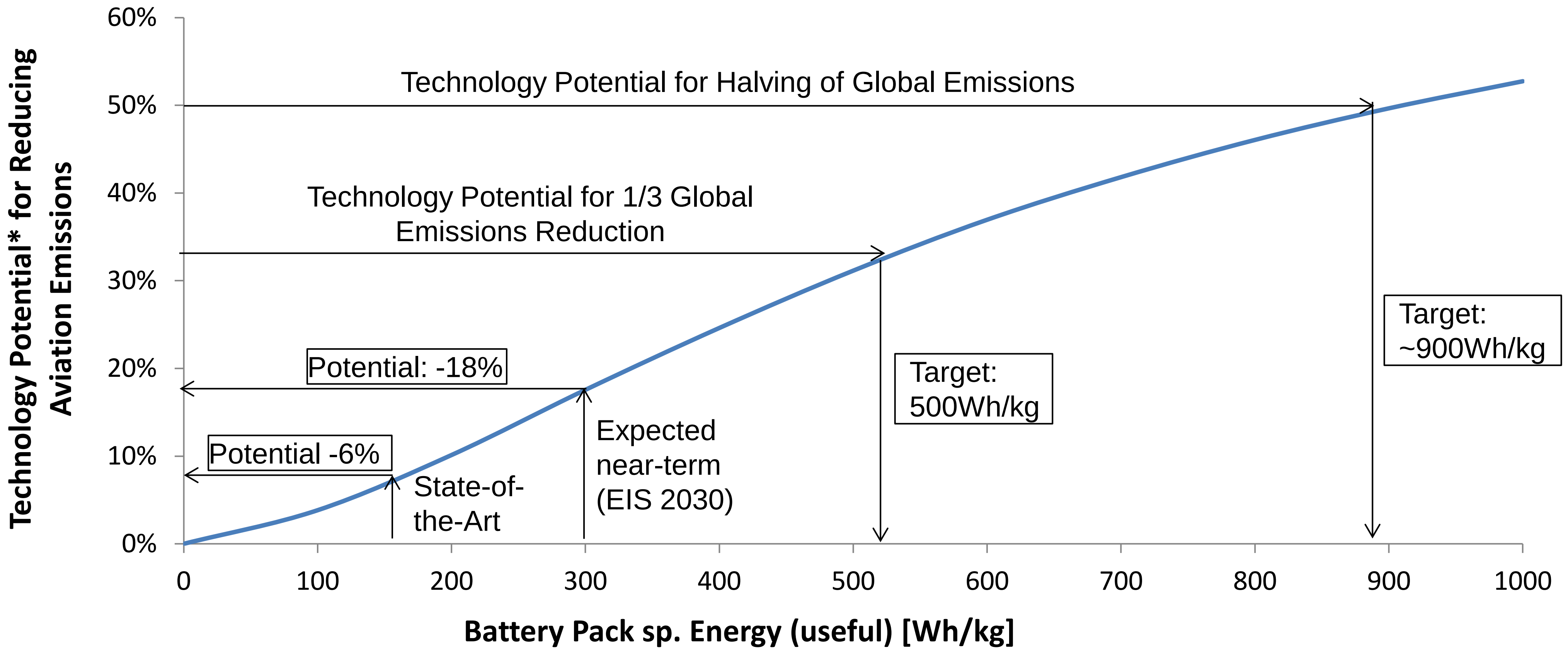


Diagramm based on ICCT 2018 global fleet data. Needs to be improved with market growth expectations.

* Potential as defined in the previous slide

Concluding Remarks

- Specific power needed for propeller-driven aircraft, assuming m_{BAT} / m_{TOM} = 0.3 is around 0.5kW/kg

  → Specific power of high-energy battery cells is not a potential showstopper.

- The validity of the presented results can be expected to hold for mach numbers of up to 0.65, after which a counter-rotating propeller or a turbofan architecture would be required, which would offset the overall result.
- The presented results are on a conceptual level and do not include an aircraft configuration optimisation for the new power train.

Thank you for your attention!