The role of electric-powered flight in real-world commercial operations

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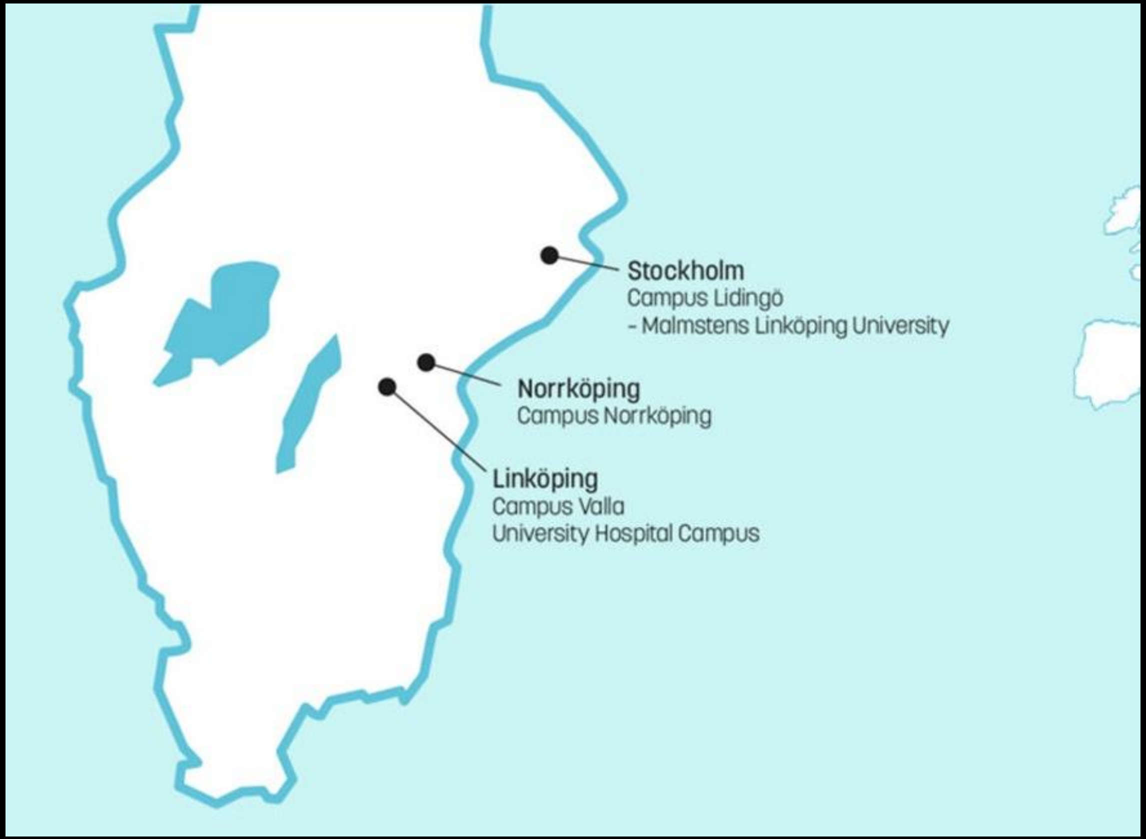
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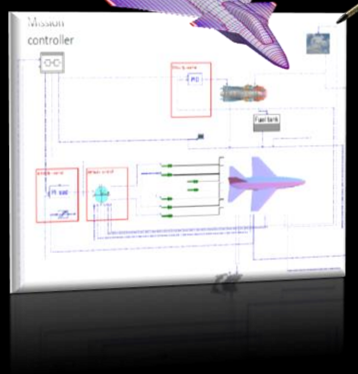

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About this talk

1. Why electric? (fully electric, battery powered)
2. Challenges (some)
3. Effects on today’s (yesterday’s?) air transportation market
4. Key enablers
5. Conclusions

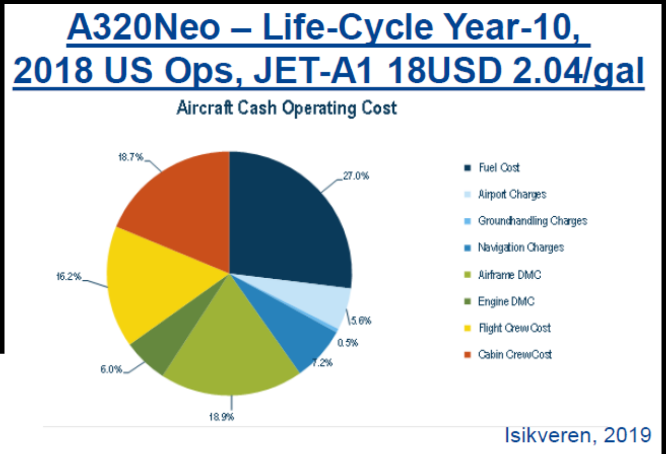
Temporal context

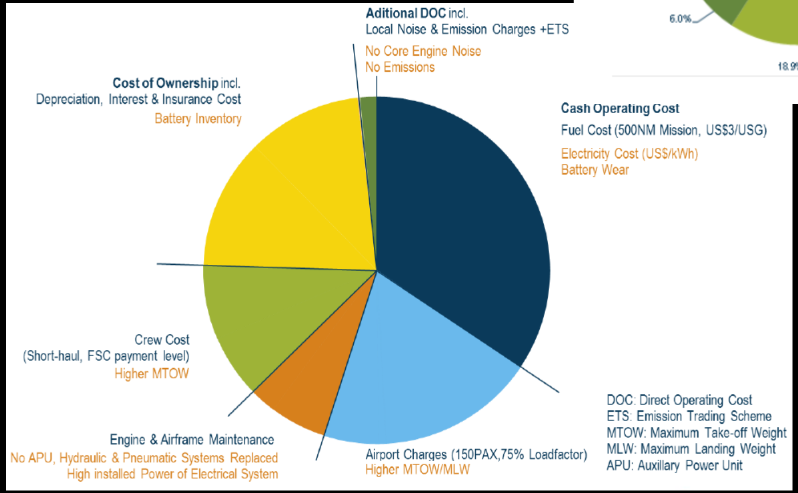
- **April 2017** First Uber Elevate summit
- **2017** Air transport data samples
- **March 2018** Norway aims to electrify regional flights by 2040
- **2019** Development of electric commuters start in Sweden
- **Summer 2019** Air transportation reaches highest volumes ever
- **Sept. 2019 – Dec. 2019** This study is done
- **Jan. 2020** Covid-19 is declared as pandemic
- **Oct. 2020** ECATS conference

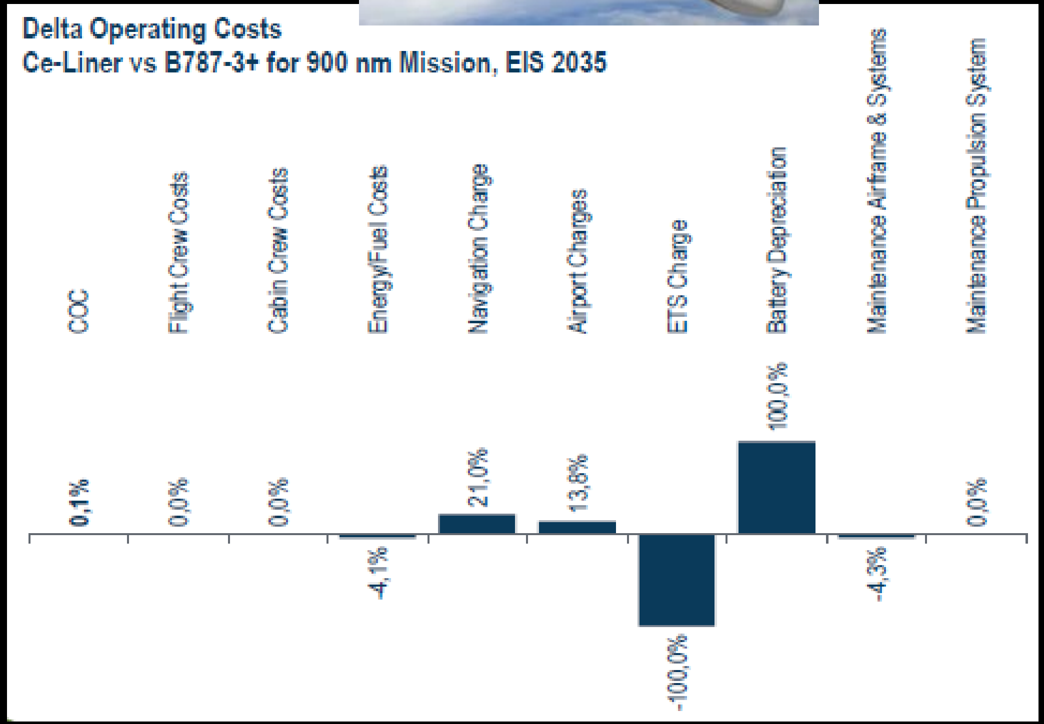
Electric flight: why are we here?

Electric flight: why are we here?

Economic?







* source: Ploetner et al., 2013; Bauhaus Luftahrt; via A. T. Isikveren, 2019

Electric flight: why are we here?

Social?

* source: Uber Elevate; Eviation Inc.; 2019

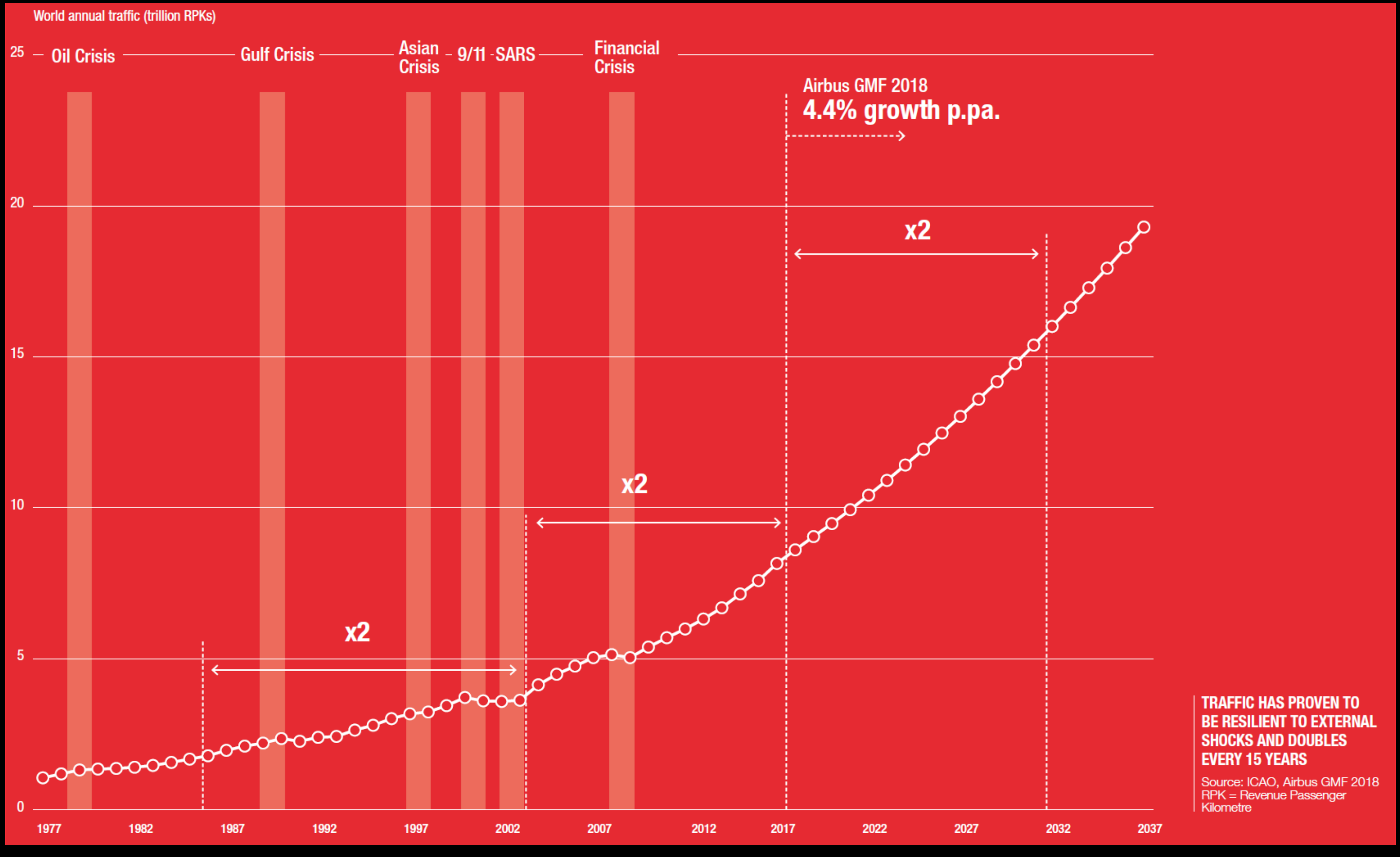
Electric flight: why are we here?

Environmental!

* source: NASA's archive

Electric flight: why are we here?

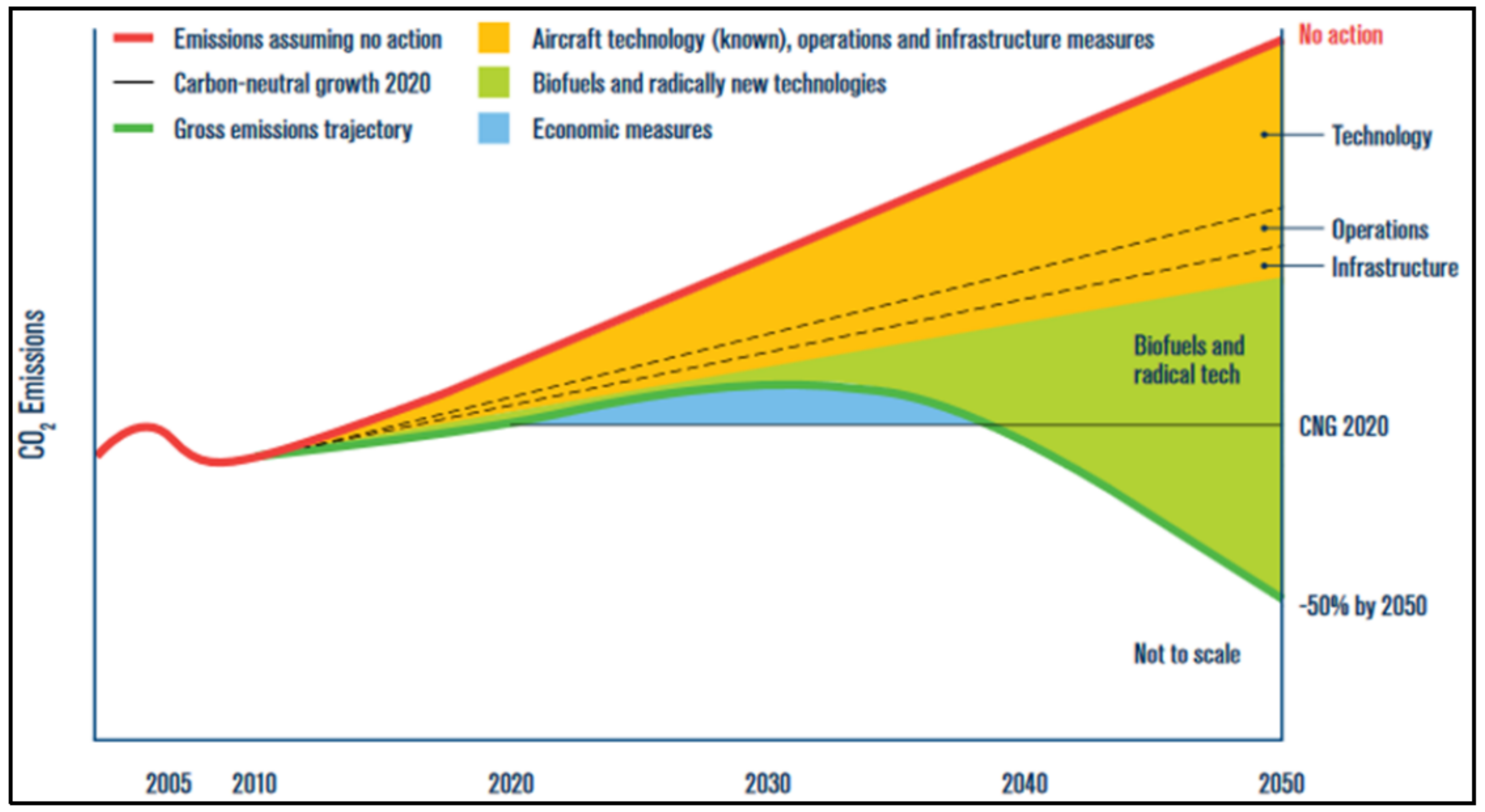
Environmental!



* source: ICAO, Airbus, 2018

Electric flight: why are we here?

Environmental!



* source: IATA, “CO2 reduction roadmap”

Electric flight: why are we here?

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Ready to go electric?

“A flight releases 74,000 times more CO_2 than a train for the same trip"

FLYGSKAM

“All domestic air transport in Norway electrified by 2040”

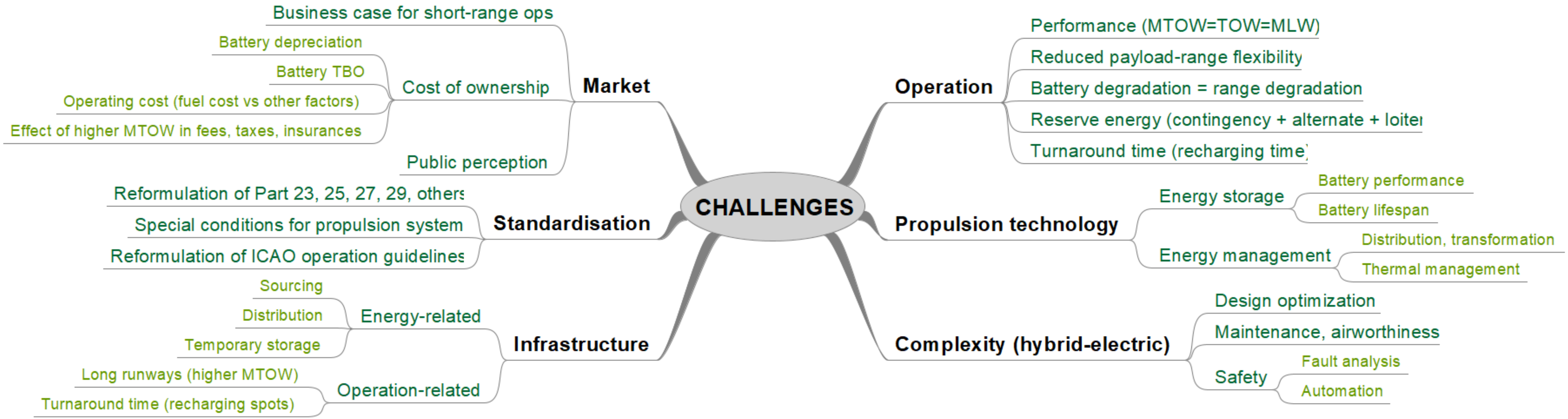
The strategic objective for 2030 is that all domestic flights are fossil free. For 2045 the strategic objective is that all flights originating from Sweden are fossil free.

* various sources

Ready to go electric?

* source: European Commission

Not that easy...



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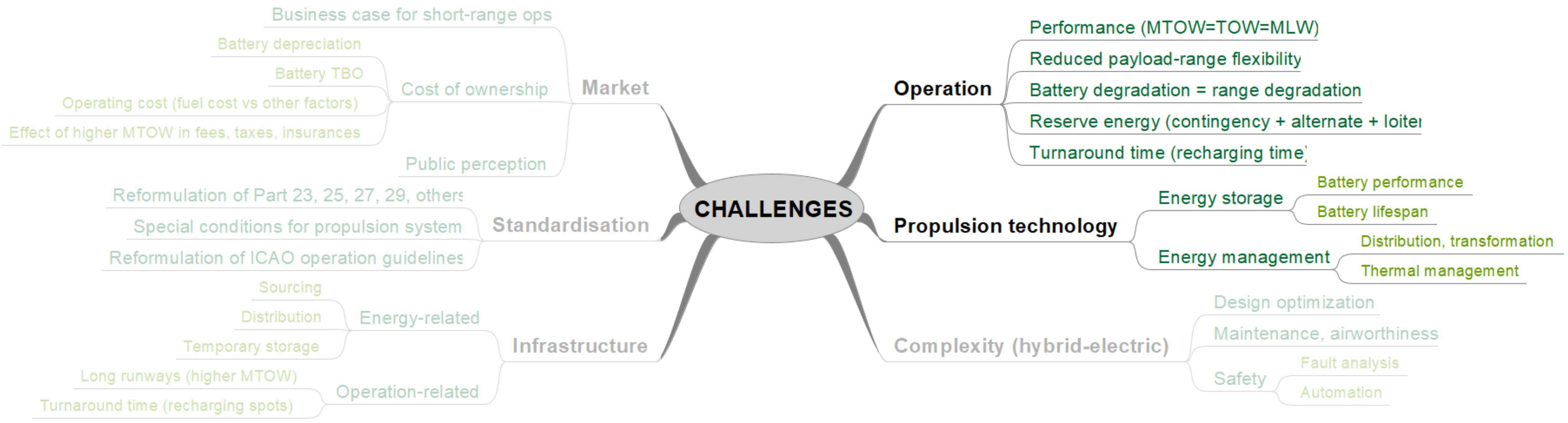
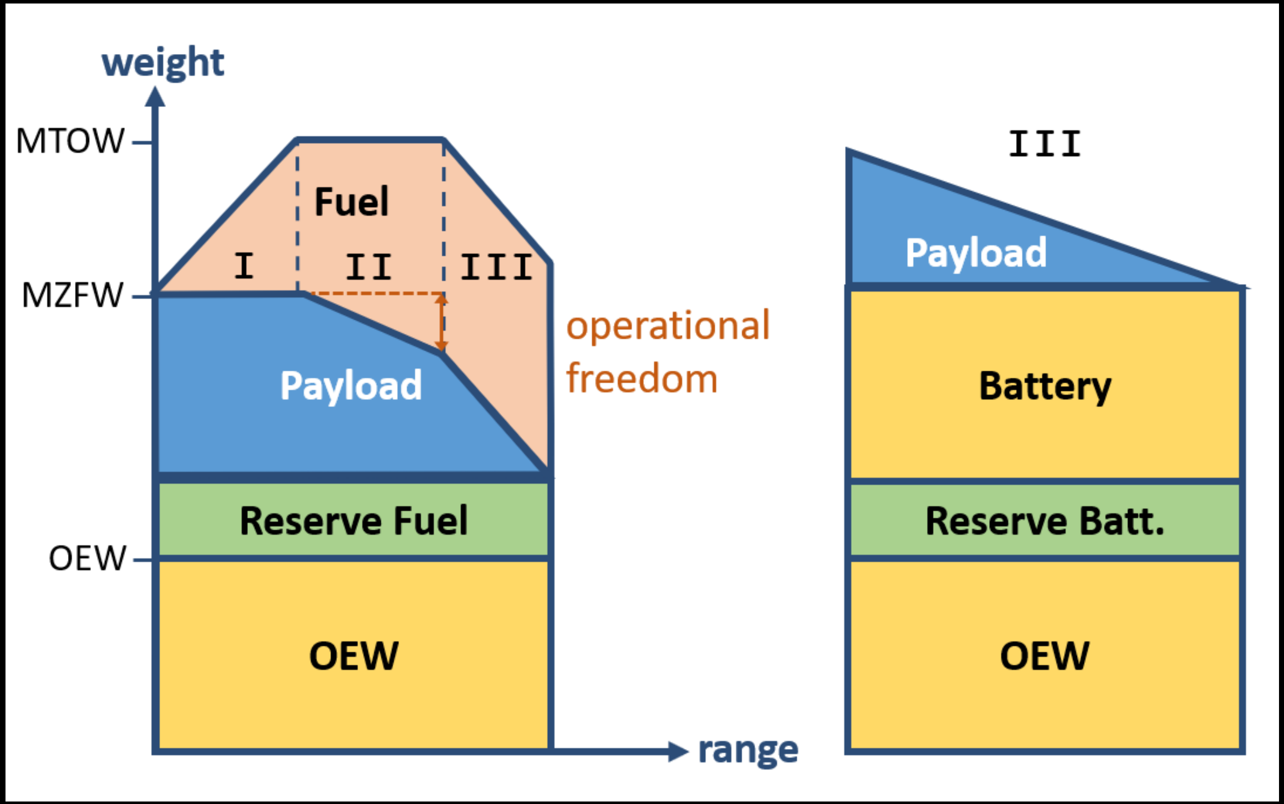


Operation

- No emissions!
- Performance: MTOW = MLW
- Reduced op. flexibility (but high system efficiency)
- Turnaround time becomes (very) relevant
- Battery degradation = range degradation?
- High “price” for reserves



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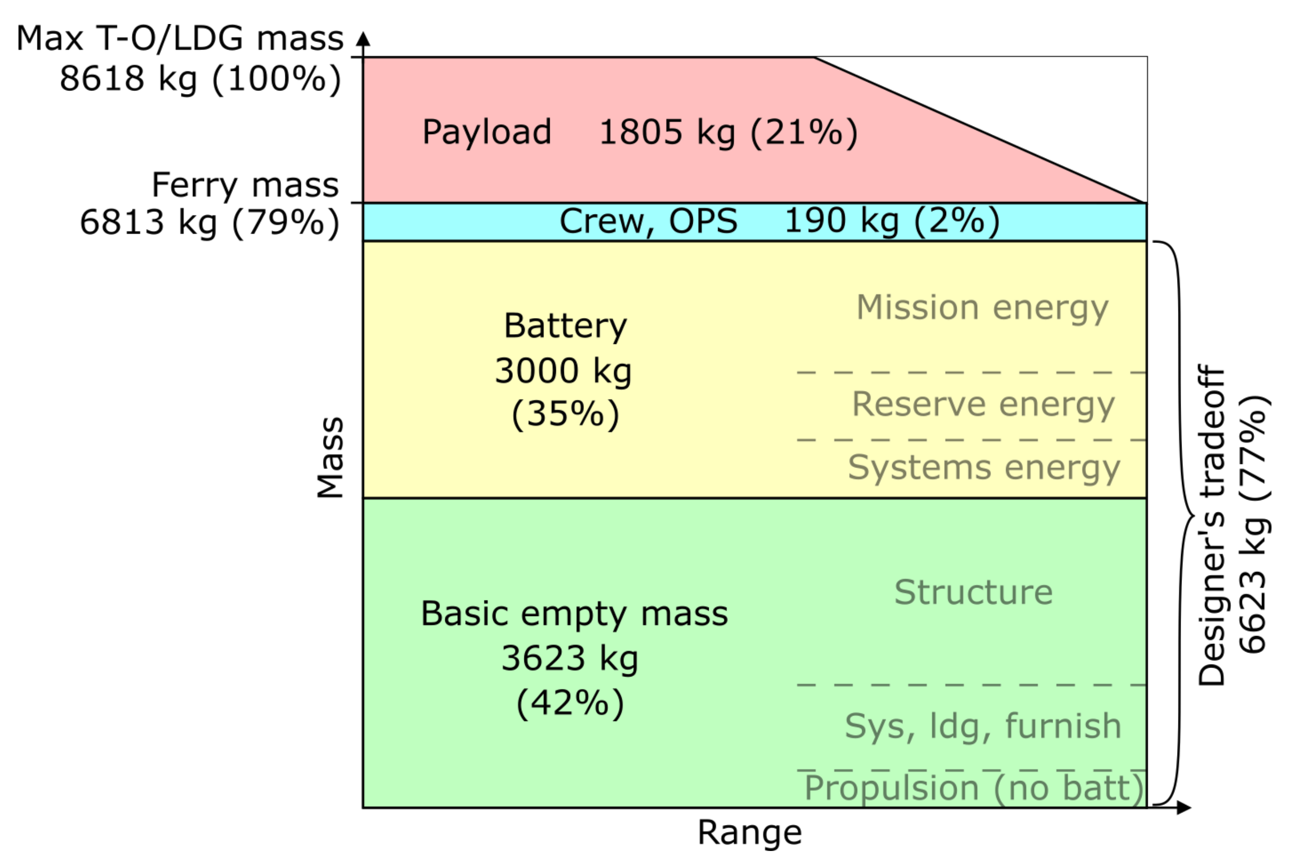

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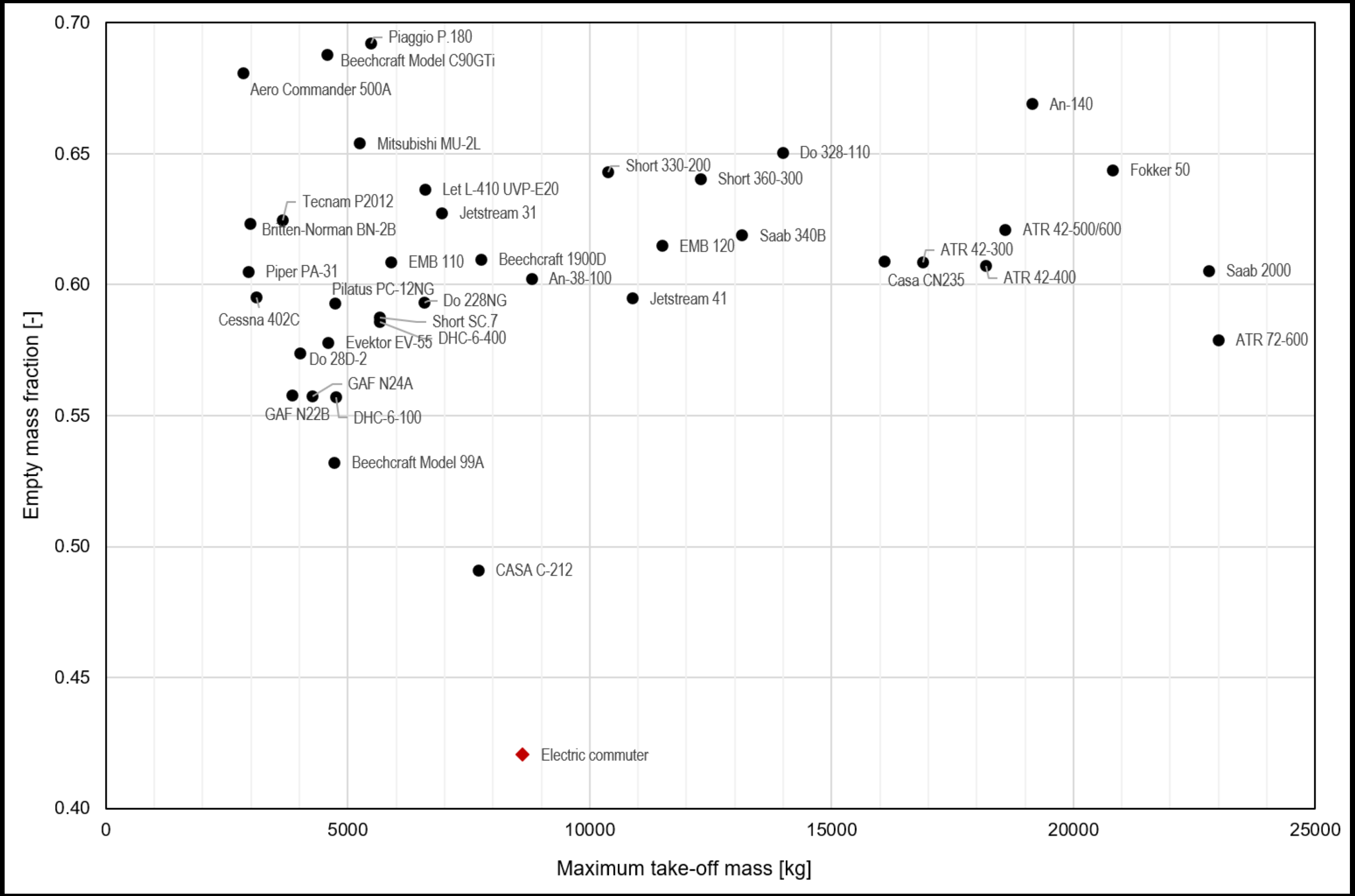


Operation

$$R = \boxed{E_{batt}} \cdot \boxed{\frac{m_{batt}}{m_{tot}}} \cdot \boxed{\frac{L}{D}} \cdot \boxed{\eta_p} \cdot \frac{1}{g}$$

Specific energy

Structures

Aerodynamics
20

Systems
0.8

Operation

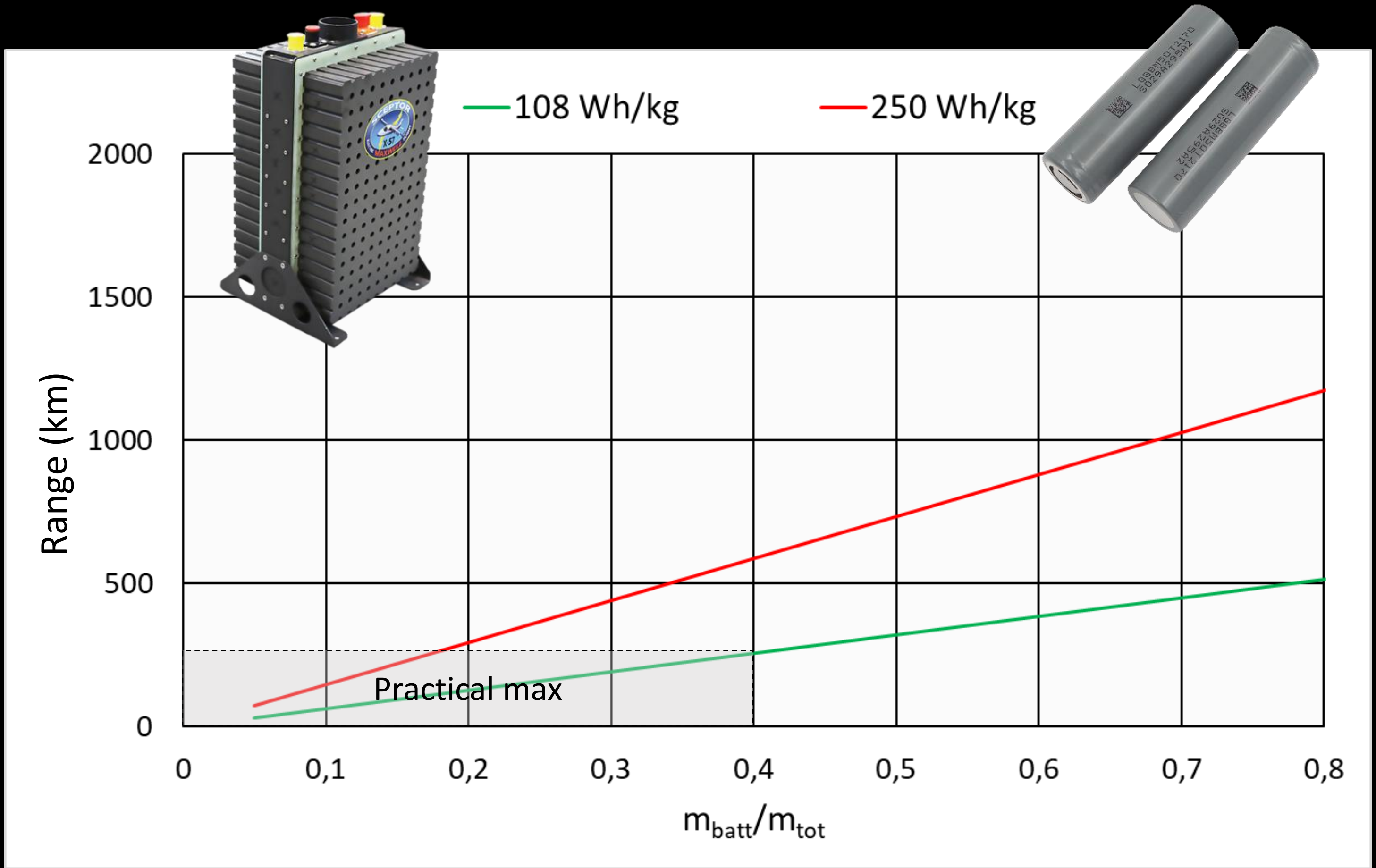
$$R = \boxed{E_{batt}} \cdot \boxed{\frac{m_{batt}}{m_{tot}}} \cdot \boxed{\frac{L}{D}} \cdot \boxed{\eta_p} \cdot \frac{1}{g}$$

Specific energy

Structures

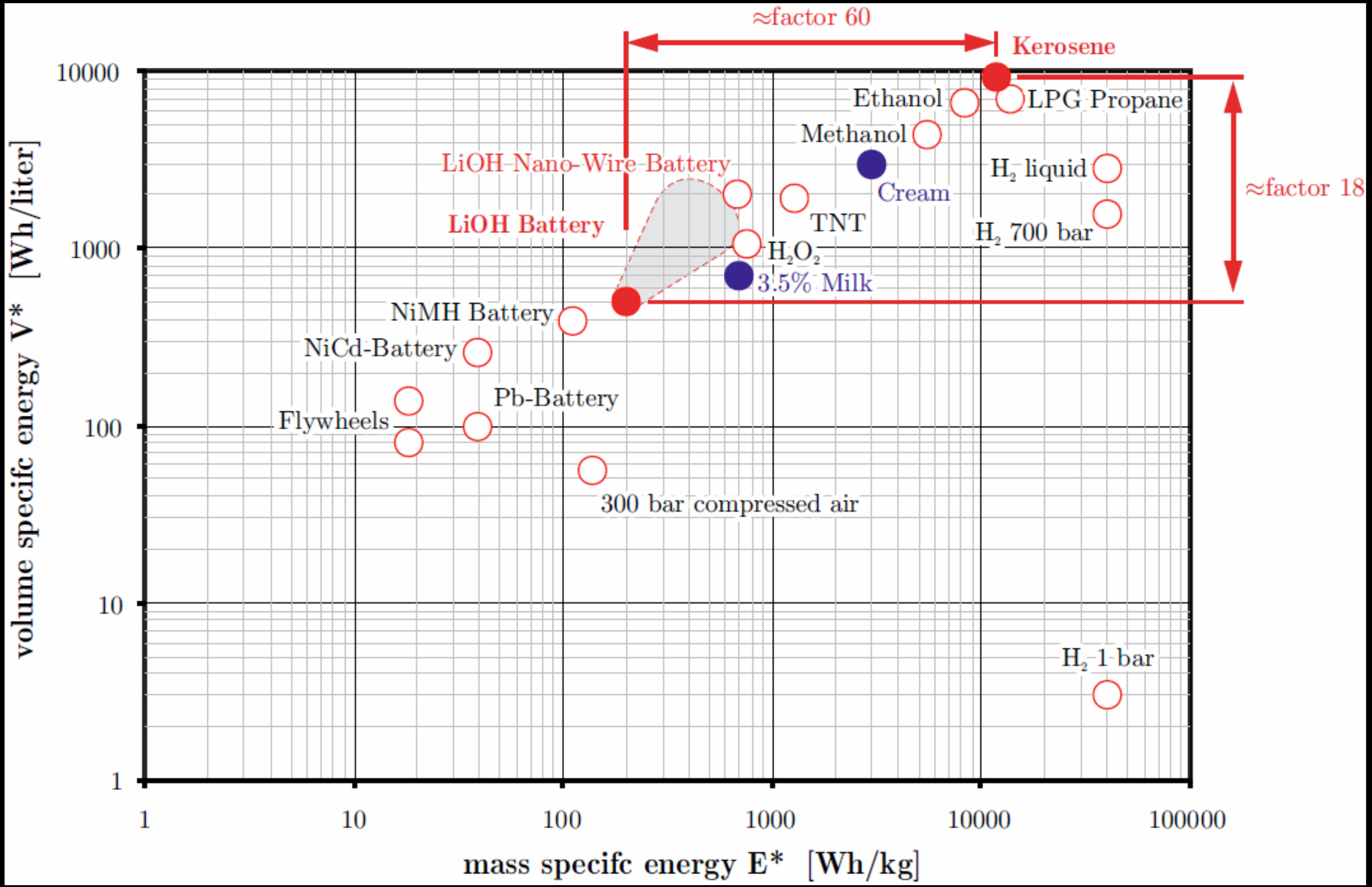
Aerodynamics 20

Systems 0.8



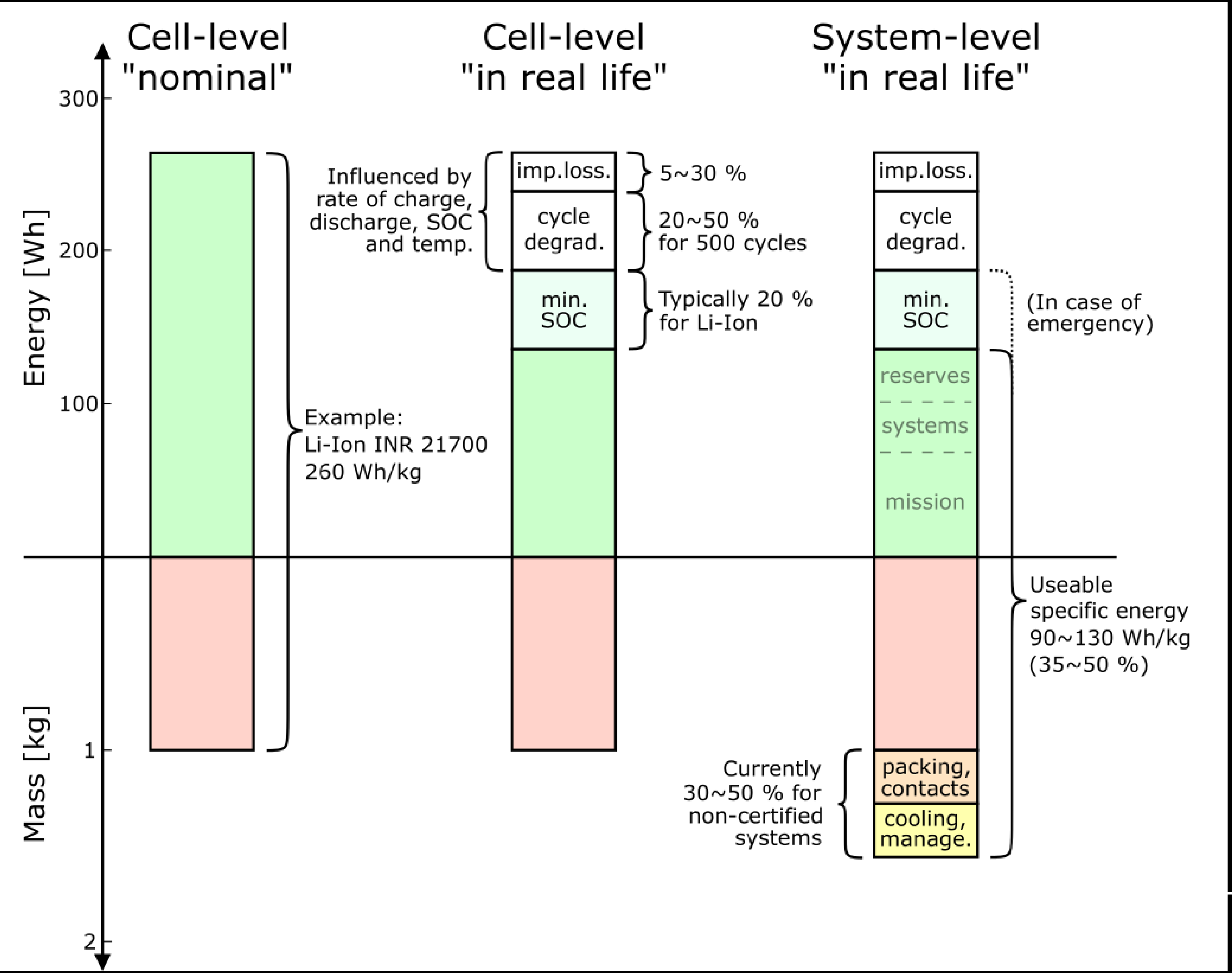
Energy storage

- lower [Wh/kg] (affects mass)
- lower [Wh/m³] (affects L/D)
- **cell energy ≠ useable energy!**

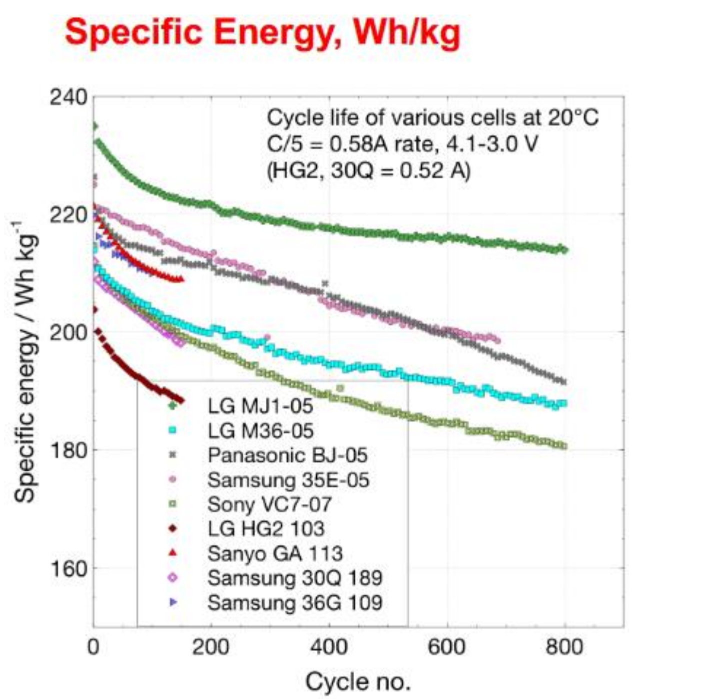


source: M. Hepperle. Electric flight - potential and limitations. In Energy Efficient Technologies and Concepts of Operation, NATO, Lisbon, Oct. 2012

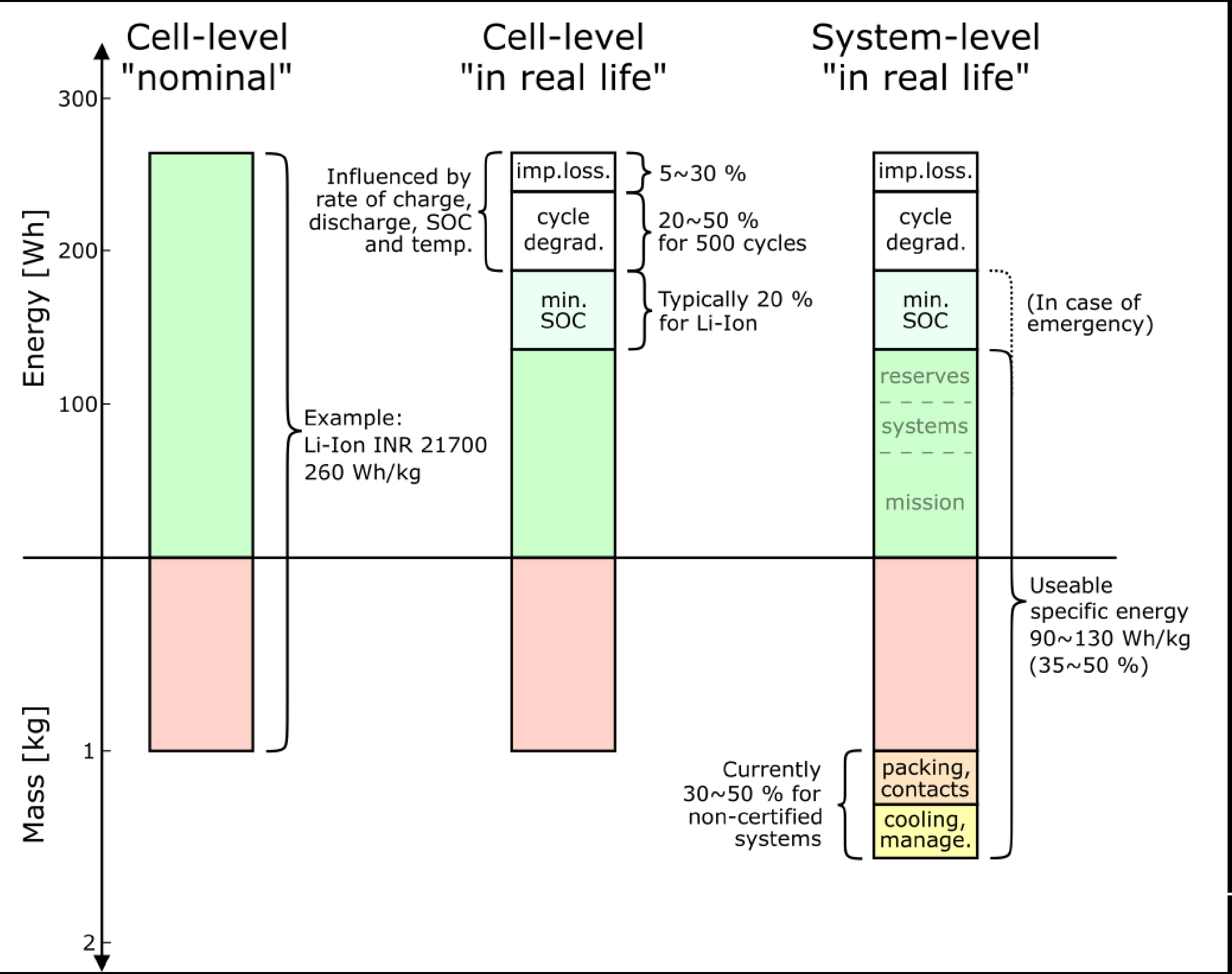
Energy storage



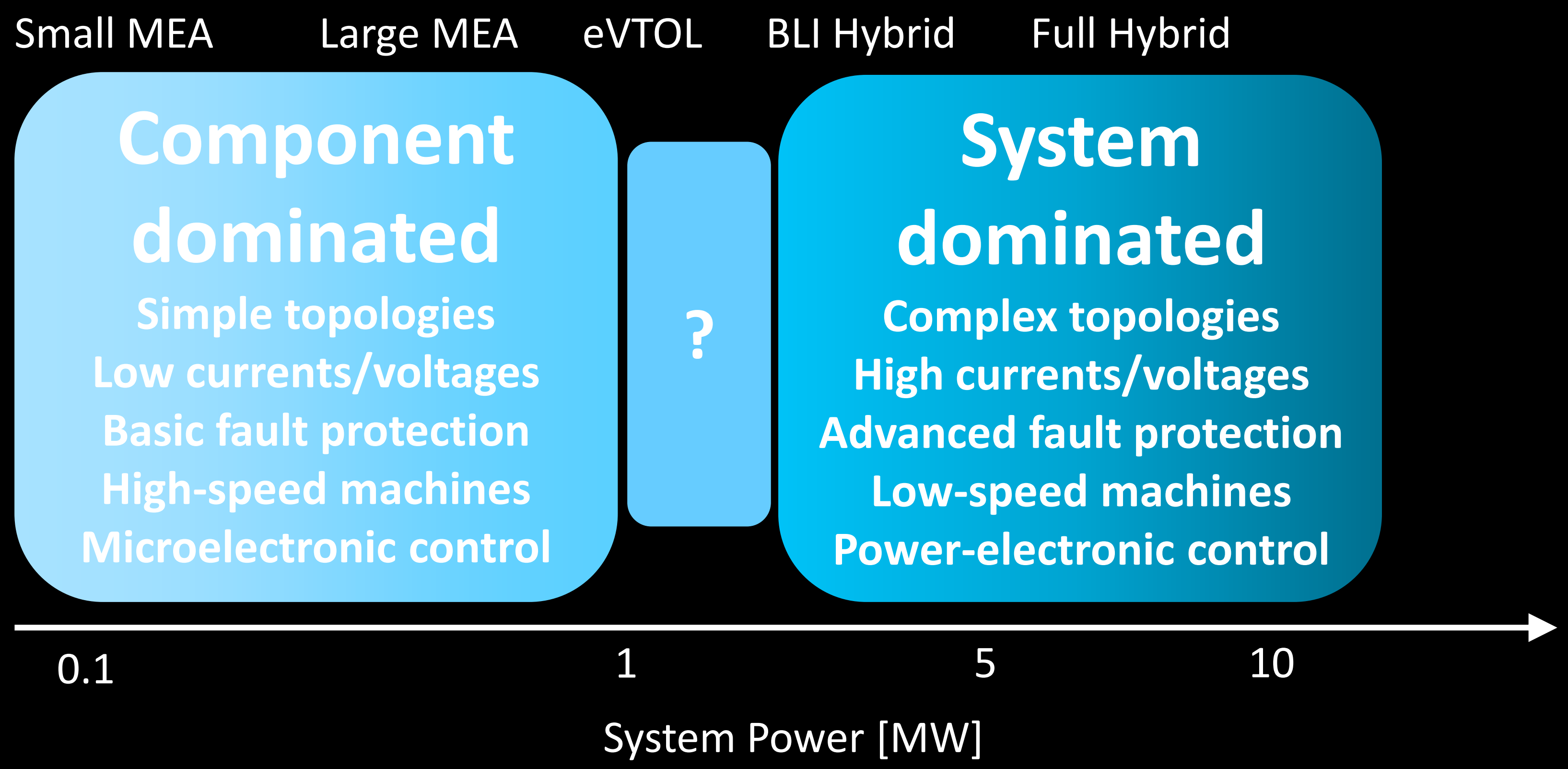
Energy storage



source: Perf of Commercial Hi Energy & Hi Powr Li-Ion Cells in Jovian Missions, NASA Battery Workshop, 2019



Energy management

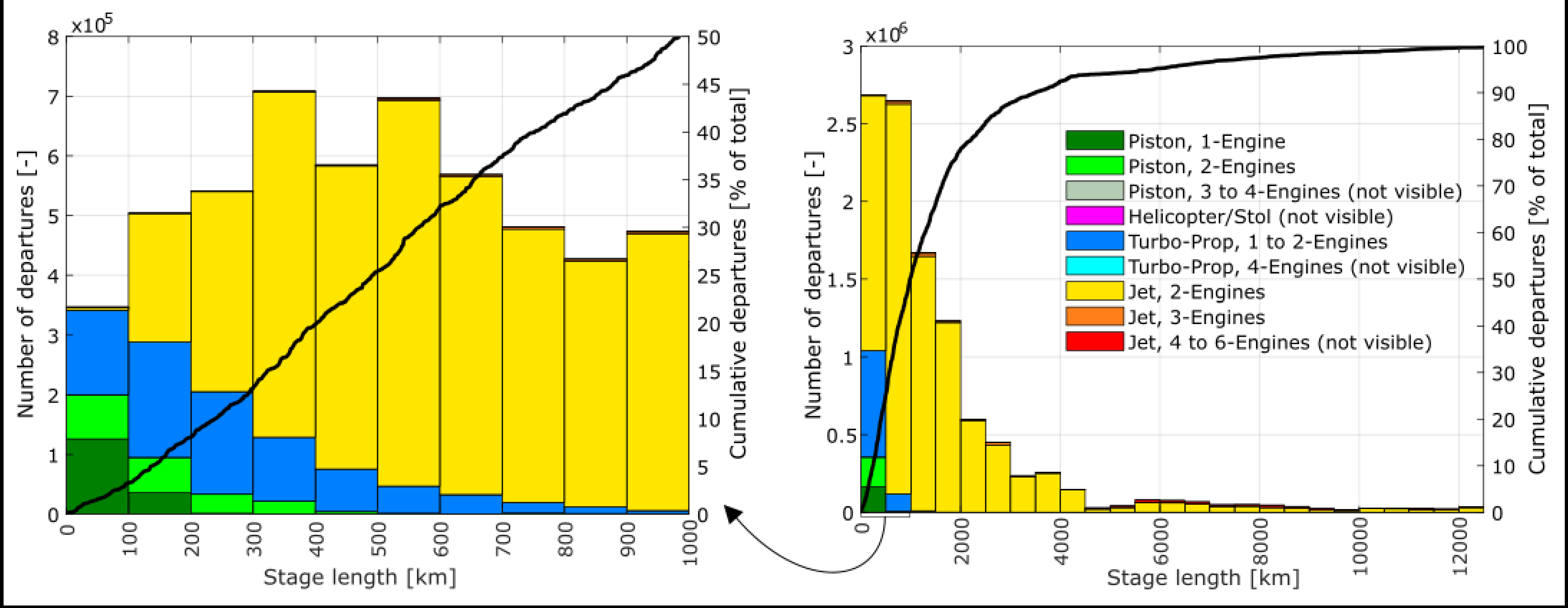


* source: adapted from P. Malkin, Newcastle University, 2019

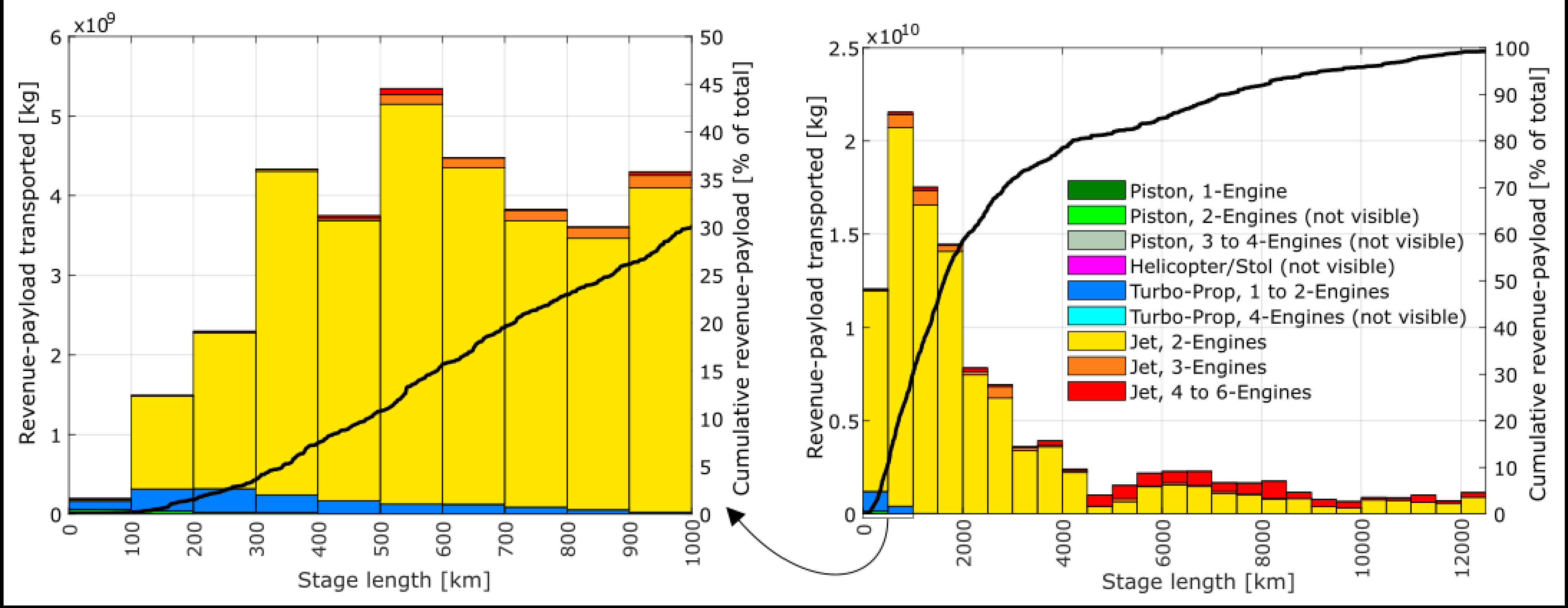
Commercial aviation today (yesterday?)

- Data from the U.S. Department of Transportation
- Reporting U.S. air carriers + other carriers with operations to, from, and inside the U.S.
- Data from years 1998 – 2017
- “Photograph” of year 2017
- Stage length (great-circle distance)
- Assumption: U.S. ≈ global market

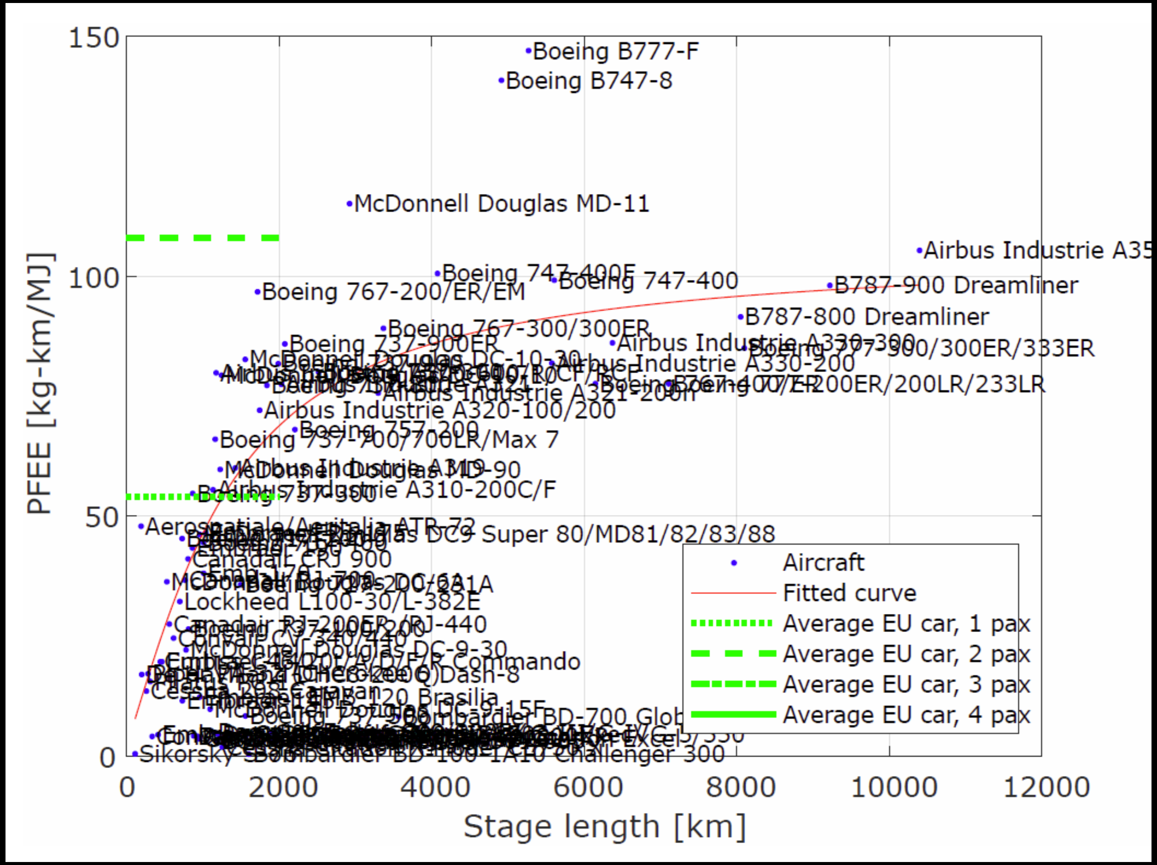
Departures vs stage length (U.S. 2017)

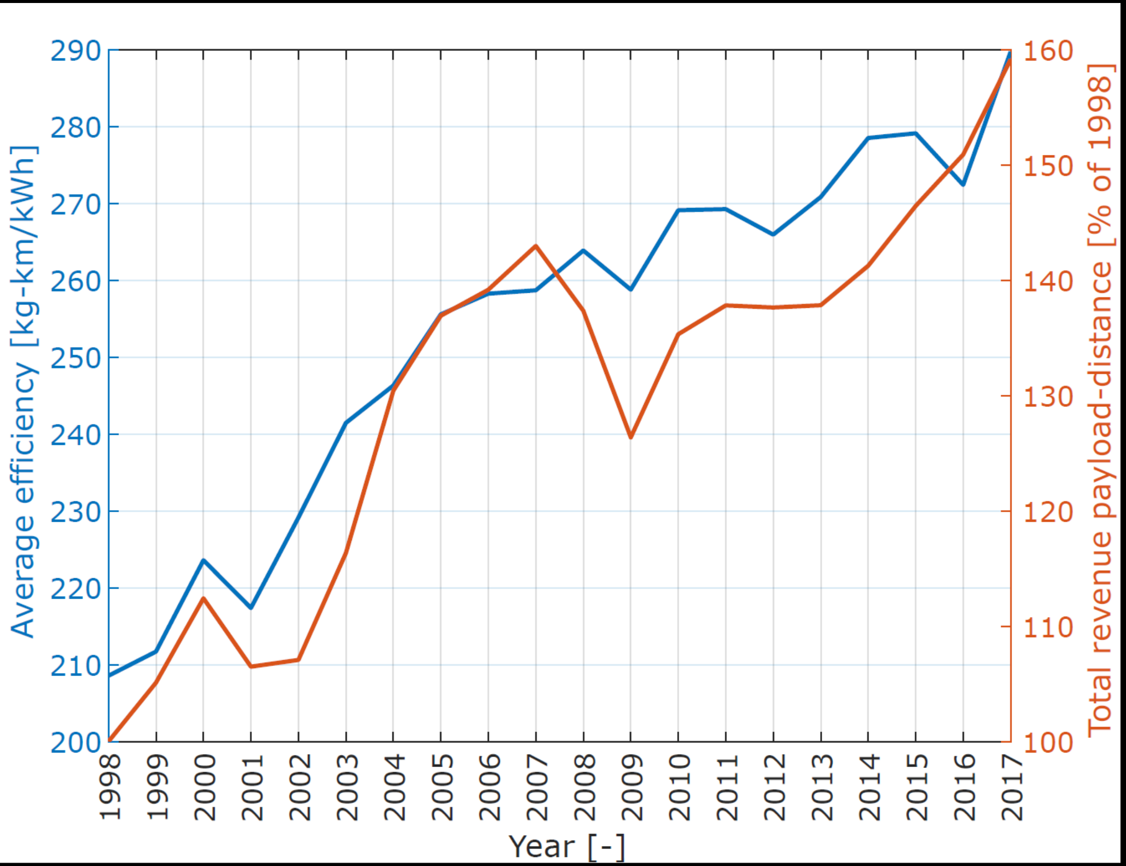


Revenue-payload vs stage length (U.S. 2017)

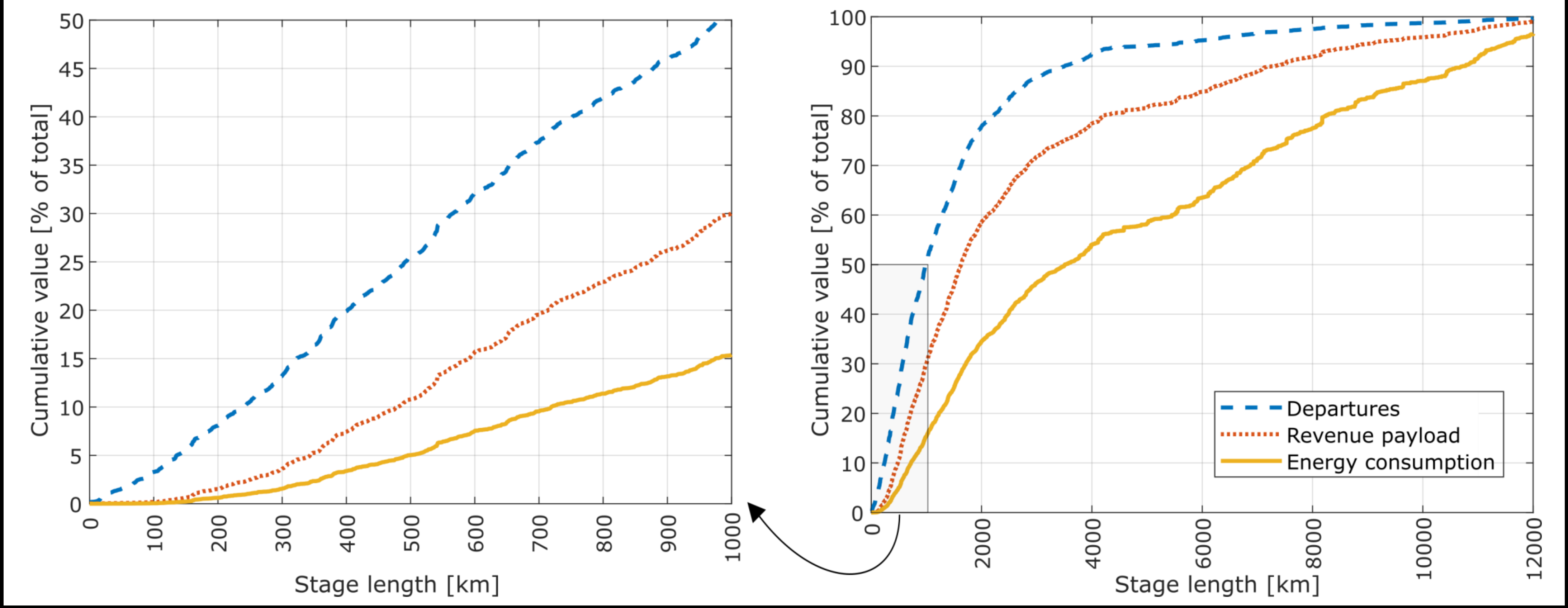


Energy consumption (further assumptions)



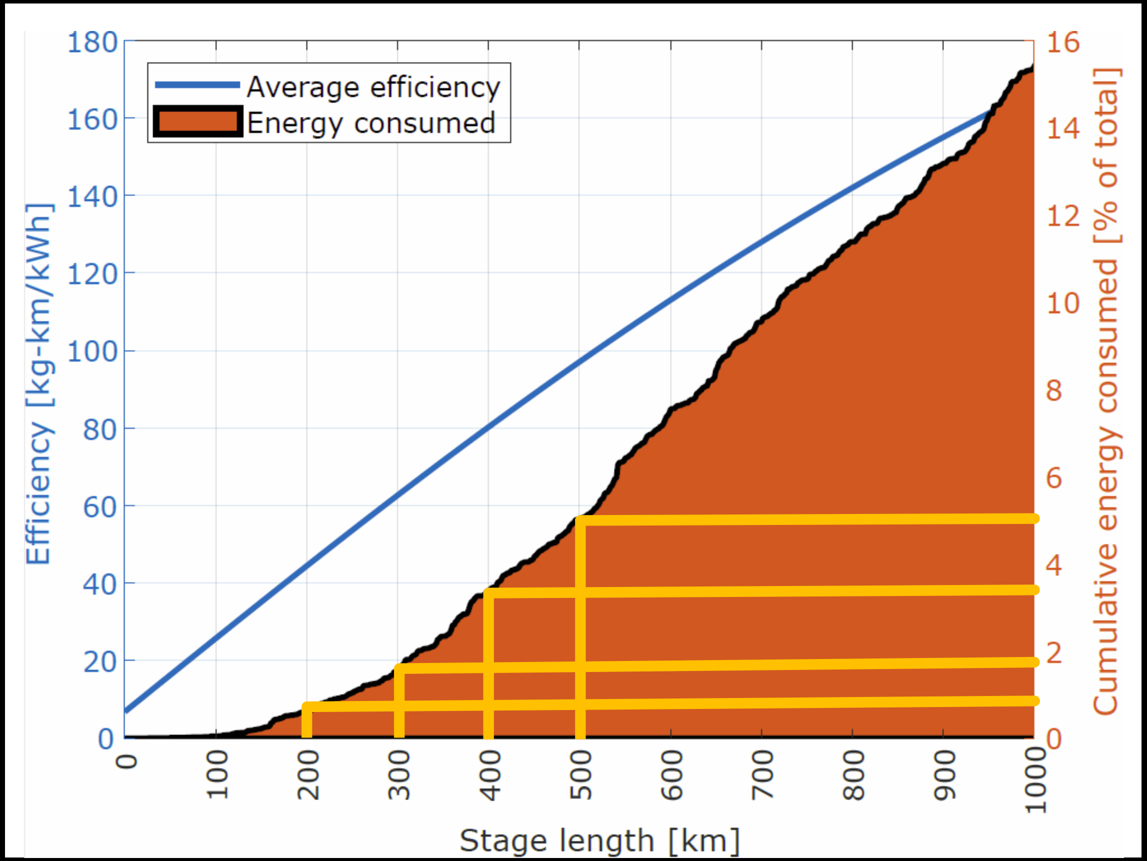


Energy consumption vs stage length (U.S. 2017)



Energy "decarbonized"

- Best scenario: electrify all flights under 500 km by 2040 ≈ 5 %
- All replaced energy should come from renewables
- Translation from energy into emissions is **not** straightforward
- Noise benefits not assessed



Key enablers

Technologies:

- Battery cycle stability
- Battery integration at system level
- Complexity jump at 1+ MW power:
    - Power electronics, weight & size
    - EMC & EMI
    - Thermal management & losses
    - Charge & maintenance

Operation:

- New approach to reserves (same safety!)
- Lower crew costs (single-pilot?)
- Mission profile optimization
- Change mindset & business model
- Charging infrastructure, energy sourcing
- Financial support (e.g. landing-fee exception, bonus-malus)

Conclusions

- May be feasible and beneficial for very short hops and niche markets
- Realistic range very limited in the short/mid term
- Even in best scenario, very limited impact on aviation’s footprint
- The country’s electricity production and allocation strategy should be prepared in advance – even short-range operations add up to a sizeable amount of energy
- The coexistence of different propulsion technologies is unavoidable, and electrification will take different forms across the market.

Outlook

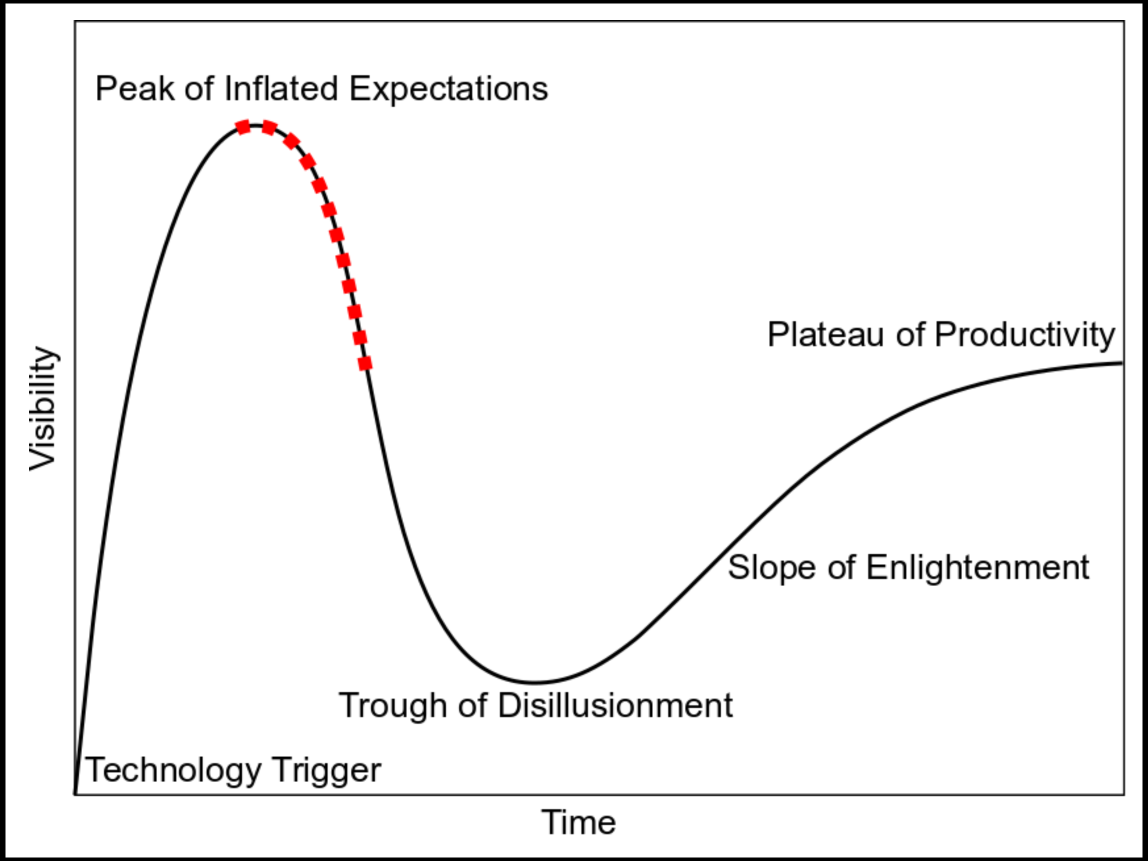
- Risk for a social & political "hype" (see Gartner's *Hype Cycle*)

BUT, from an environmental perspective:

- Any contribution is welcome
- All available concepts & technologies should be used (cleverly)

AND:

- Aviation post-corona may be different



Thanks!

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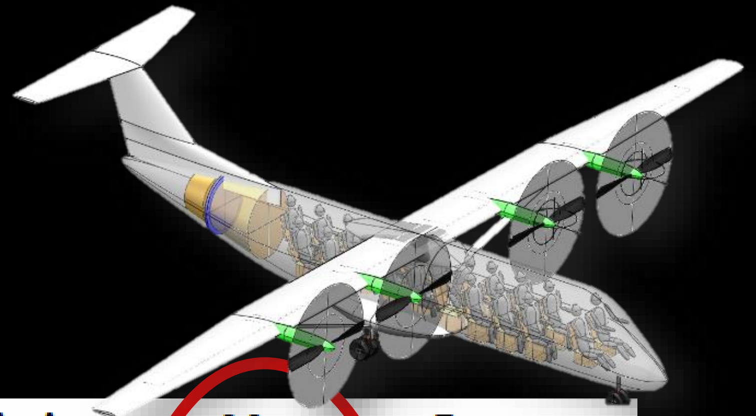
Fuel Reserves (ICAO Annex 6, Part I, section 4.3.6 "Fuel Requirements")

- Contingency fuel
  - add. en route fuel e.g. wind, ATM route changes/restrictions, typically 5%/3%/0%(*)
- Destination alternate fuel
  - missed approach & landing at alternate airport
- Final reserve fuel
  - **45 min(!) holding flight for reciprocating engines**
  - or, 30 min for jet engines
- Additional fuel
  - e.g. ETOPS fuel, MEL
- Short range operation suffer extreme from alternate/reserves (45 min! for non-jet aircraft)

CS-23 commuter study



Case ID	Specific energy cell [Wh/kg]	Specific energy system [Wh/kg]	Energy T-O + climb [kWh]	Energy cruise + others [kWh]	Mission flight time [h]	Max stage length [km]	Energy reserve + systems [%]
A	260	128	217	167	0.45	120	(20)[1]
B	260	160	217	263	0.61	177	0
C	260	200	217	383	0.81	248	0
D	?	300	217	683	1.31	427	0
E	?	400	217	983	1.81	605	0

NOTE 1: In case (A), reserve energy would be 20% if assumed that batteries can be fully depleted (100% DOD) in case of need, despite effects in battery lifespan.