FUTure PRopulsion and INTegration
towards a hybrid-electric 50-seat regional aircraft

A reduced battery system model and sizing algorithm for future hybrid electric airplanes architectures studies

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CEA

FutPrInt50

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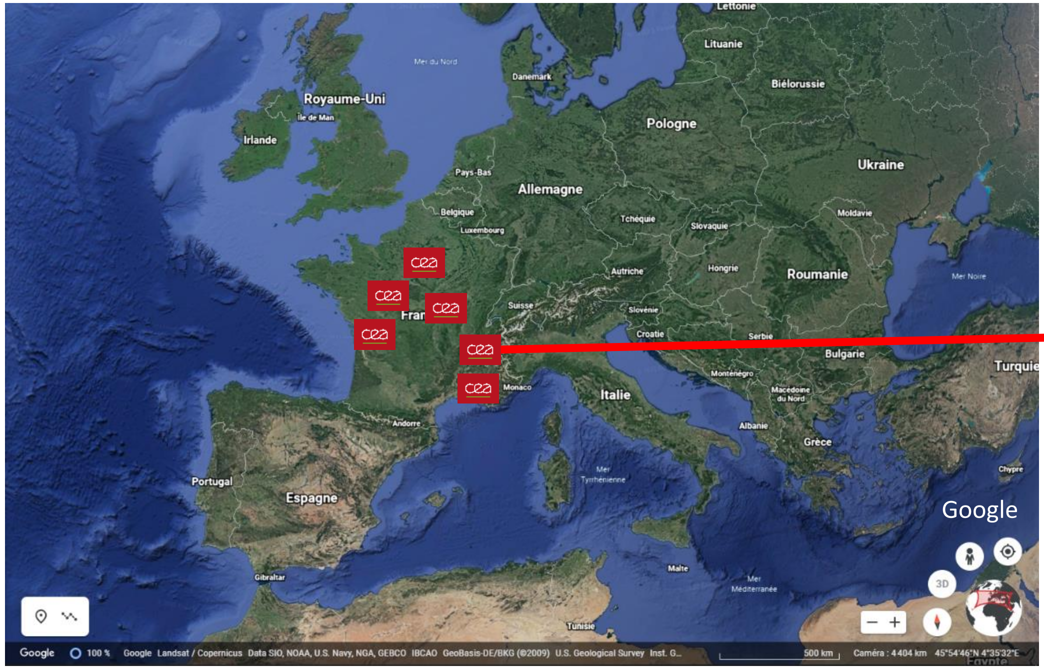
European Commission

The FUTPRINT50 project

FutPrInt50 is an **EU** funded collaborative research project set out to **identify** and **develop** technologies and configurations that will accelerate the entry-into-service of a commercial **hybrid-electric aircraft** In a class of up to 50 seats by **2035/40**.

FutPrInt50 focuses on **energy storage**, **energy recovery** and the **thermal management** of hybrid systems. In addition to improving existing technologies, it will research and share an **open-source tool** for **designing new hybrid-electric aircraft**, hybrid-electric aircraft designs and reference data sets

The French Alternative Energies and Atomic Energy Commission (CEA)



French public research organization with 20 000 employees

Defense and security, low carbon energies (nuclear and renewable energies), technological research for industry, fundamental research in the physical sciences and life sciences.

Energy storage

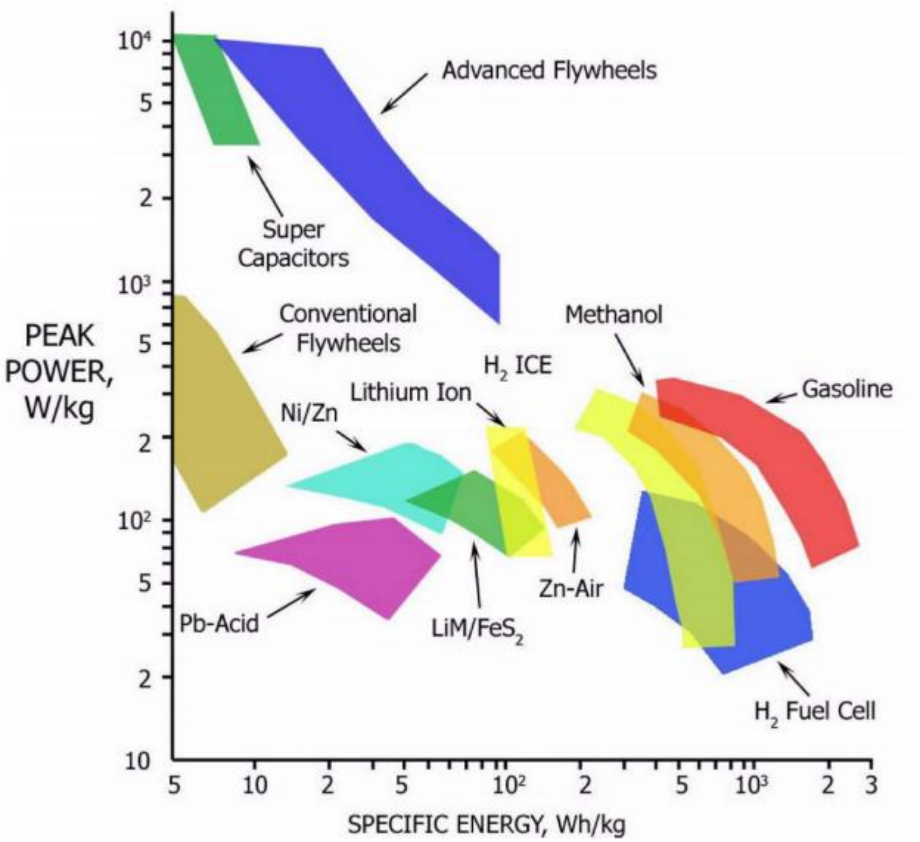
Energy storage is the capture of energy produced at one time for use at a later time (Wikipedia)

Units:

- Power [W]
- Energy [kWh] = 1000 W × 1 h = 1 W × 1000 h = 3.6×10^6 J

Figures of Merit:

- Power density [W/kg] [W/L] (specific power)
- Energy density [Wh/kg] [Wh/L] (specific energy)



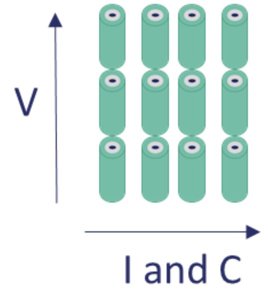
DOI: 10.5772/13062

Batteries

A **battery** is a device that converts **chemical energy** directly to **electrical energy.**

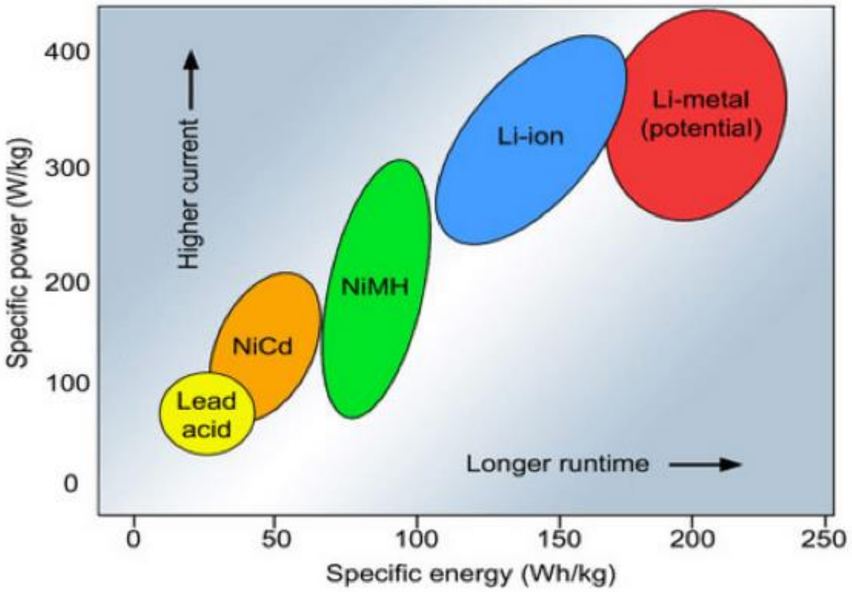
Key figures:

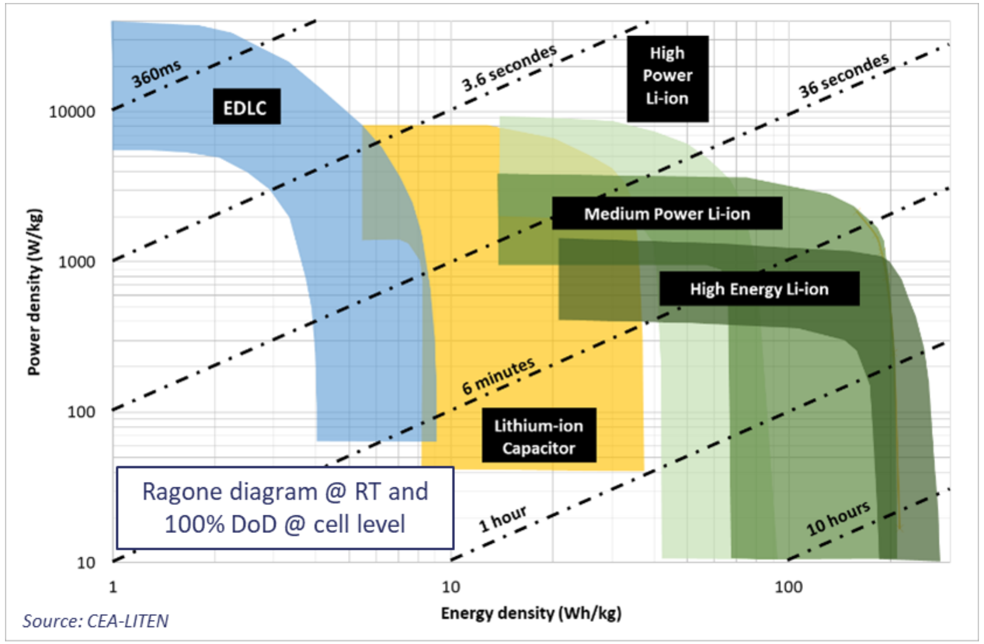
- Capacity [Ah]: quantity of electricity stored: 1 Ah = 3600 A.s = 3600 C
- Charge/discharge rate (C-rate) [1/h]
  xC is a rate that allows a battery to be charged/discharged in x hours under a constant current
- Mass, volume, temperature range, aging…



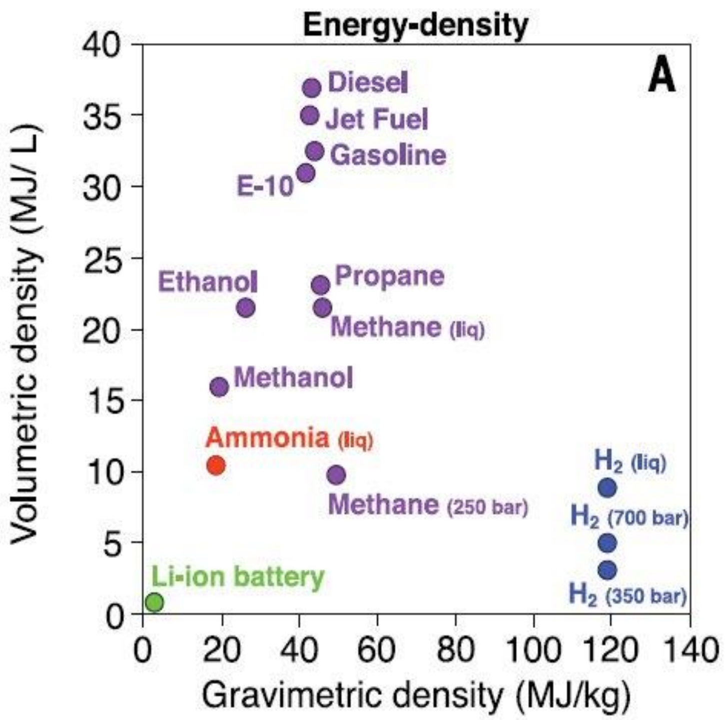
$E = V*C$

$P = V*I$

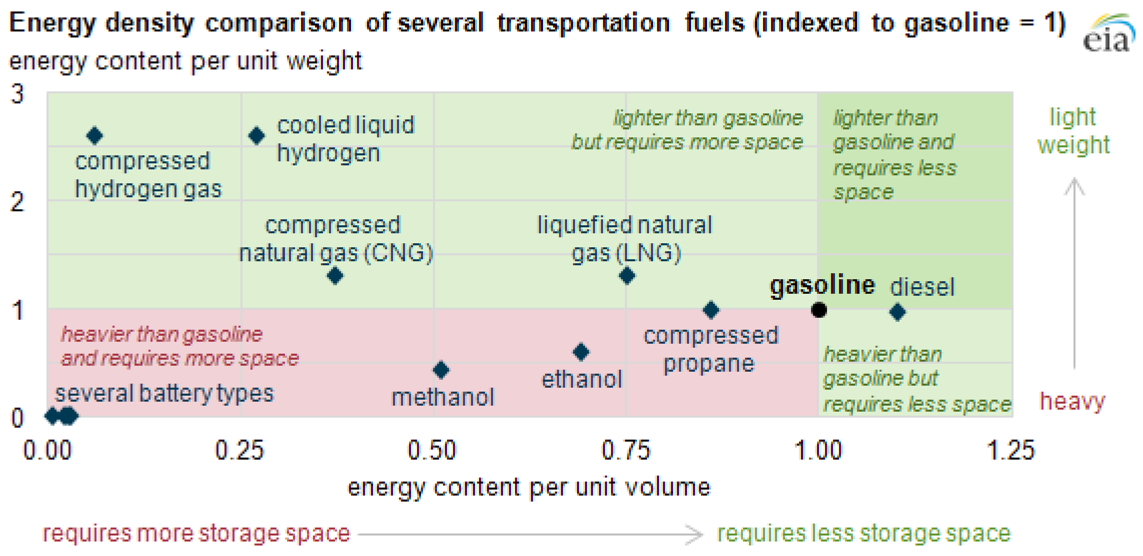




Why don't we have electric aircrafts yet ?



DOI: 10.1126/science.aas9793

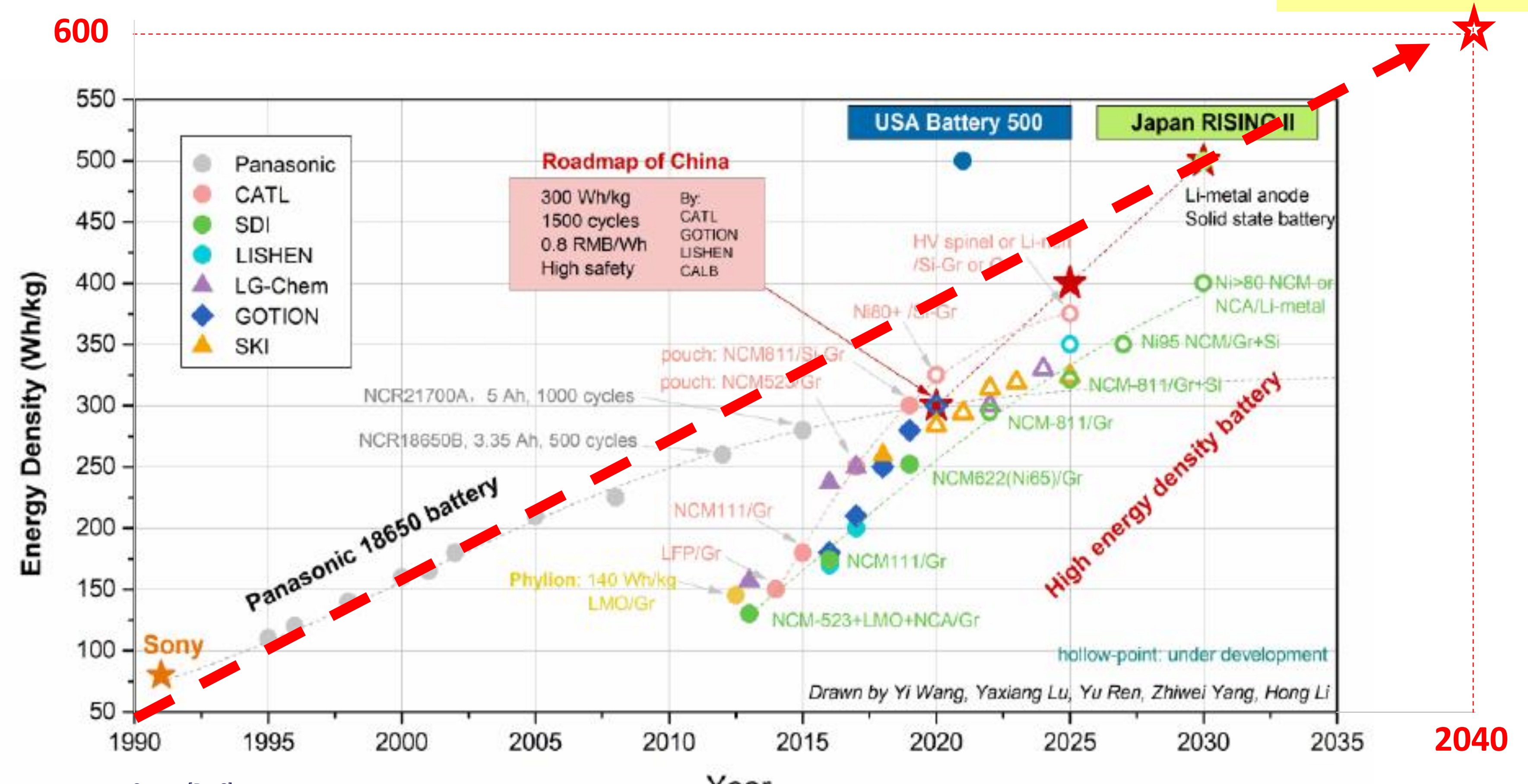


https://www.eia.gov/todayinenergy/detail.php?id=9991

Kerosene: 13000 Wh/kg
LiB cell: 400 Wh/kg

Future battery (roadmap for energy)

Cell level:
600Wh/kg???



Source [Bat6]

Mash-up of China / USA / Japan / Europe roadmaps

Two competitive challenges for flying batteries

In order to fly batteries, we must (objectives):

- Decrease **mass**
- Increase **safety**
- (Without forgetting aging and TCO optimization…)

Four key architectures (constraints and decision variables):

- Mechanical architecture
- Electrical architecture
- Thermal architecture
- BMS: Battery Management System

One optimization…

Fixed data

- Expected lifetime (year)
- Sizing profiles (electro-thermal)
  - $P_{elec\_(W)} = f(t_{\_(s)})$
  - $T_{amb\_(°C)} = f(t_{\_(s)})$
- Sizing profiles (ageing):
  - $P_{elec\_over\_24h\_(W)} = f(t_{\_(s)})$
  - $T_{amb\_over\_24h\_(°C)} = f(t_{\_(s)})$
- Pack voltage limits :
  - Udc min
  - Udc max
- Module max volume, mass, voltage
- Safety constraints (no thermal runaway propagation, DO311, degassing or not, failure rates requirement)
- Cold source (Q, Tinput_coolant)

Pack optimization method

Decision variables*

- Cell :
  - type/chemistry/grammage and electrode area
  - or reference
- Cooling-heating techno
- Distance and material between cells, module geometry
- Module casing shape and material
- N modules in series / N modules in parallel
- N cells in series / N cells in parallel
- 'Architecture' for electrics (fuses…)
- 'Architecture' for safety (?)

Iterative simulations

BATTERY PACK MODEL

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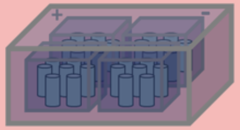


(*) each decision variable is:
- restricted
- discrete, continuous or from database

Optimal decision variables

Cell, thermal management technology, etc.

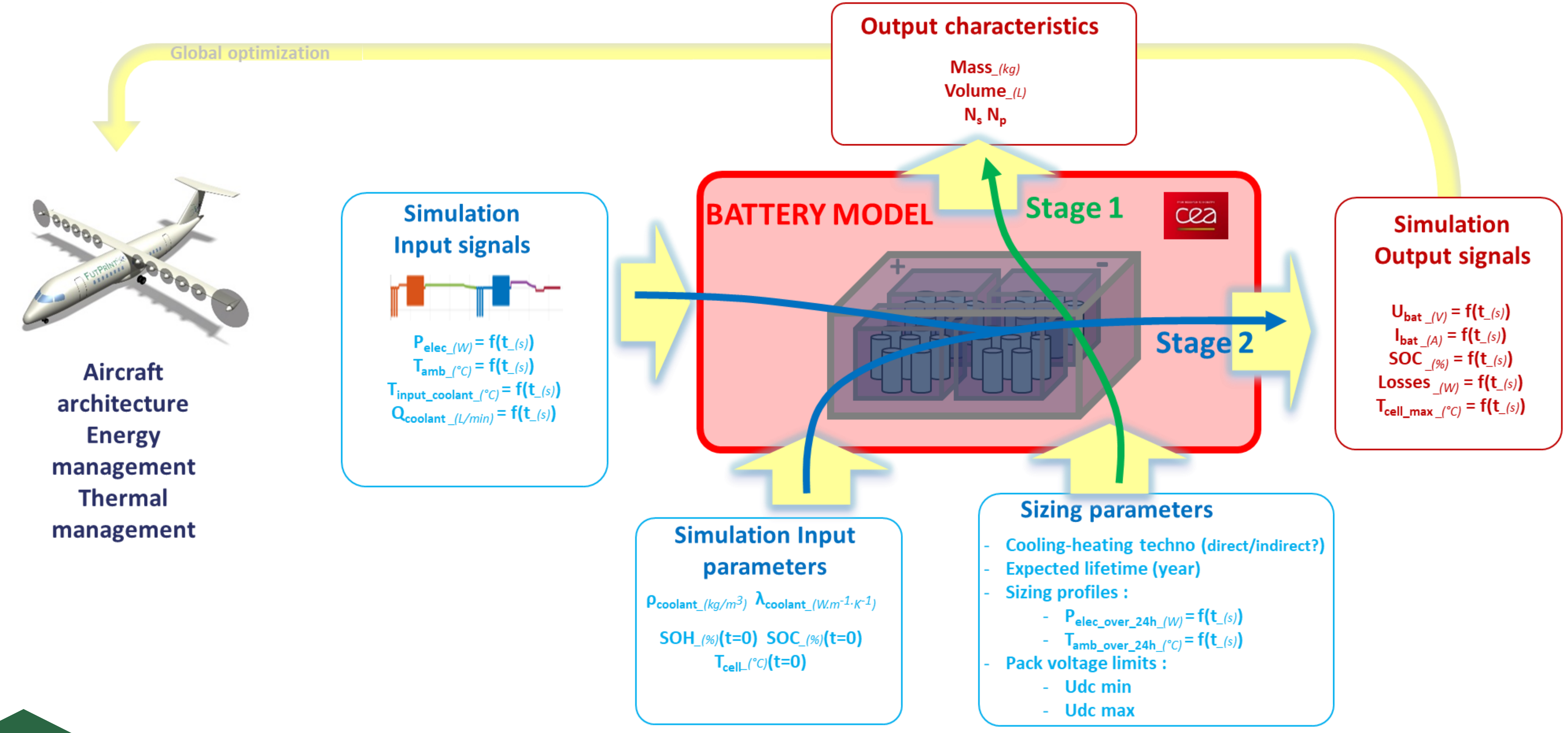
Output variables (either objectives, constraints or information variable)

- Mass
- Volume

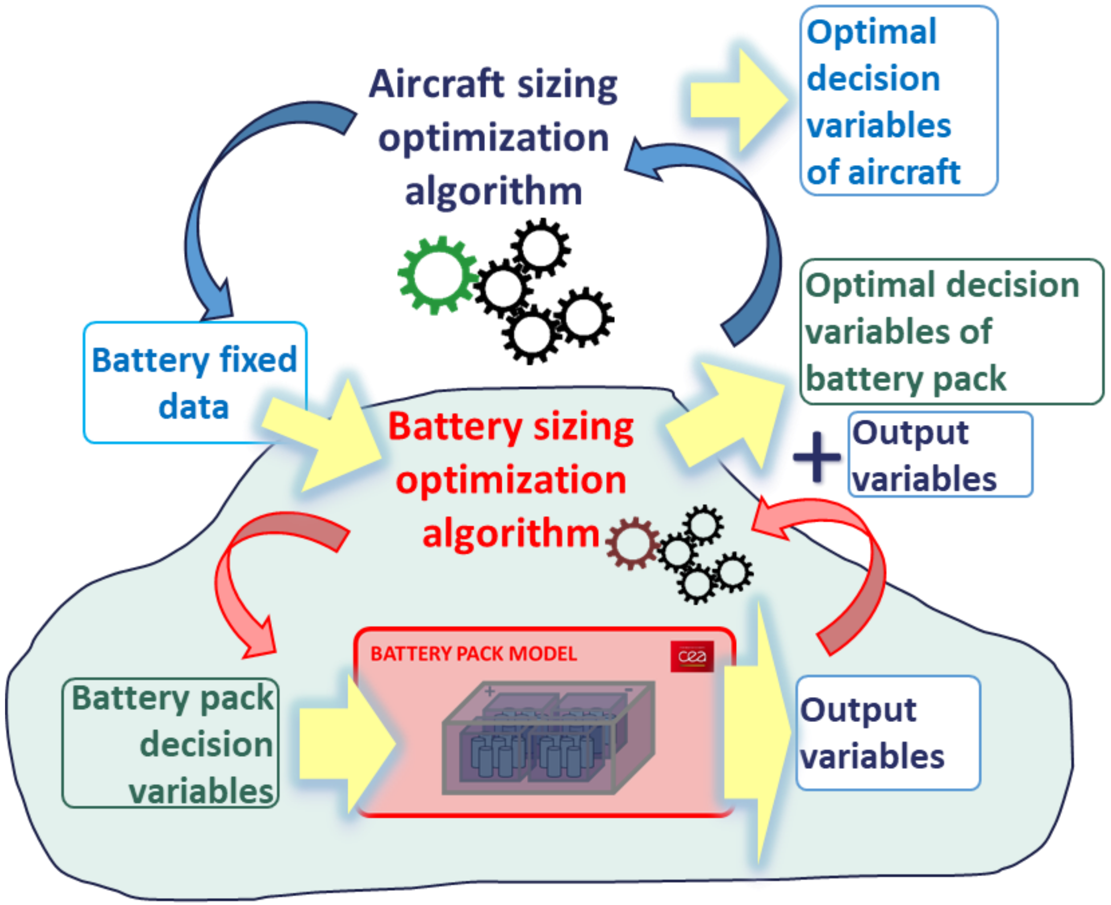
- **Specifications are reached or not** (for each <u>fixed parameters as inputs</u>)?
  - Ex failure rate

- **Internal variables for information**
  - Ex Gaz pressure during thermal runaway (info)
  - Ex Module casing max T during thermal runaway
  - Ex Pack energy
  - Ex Pack max power

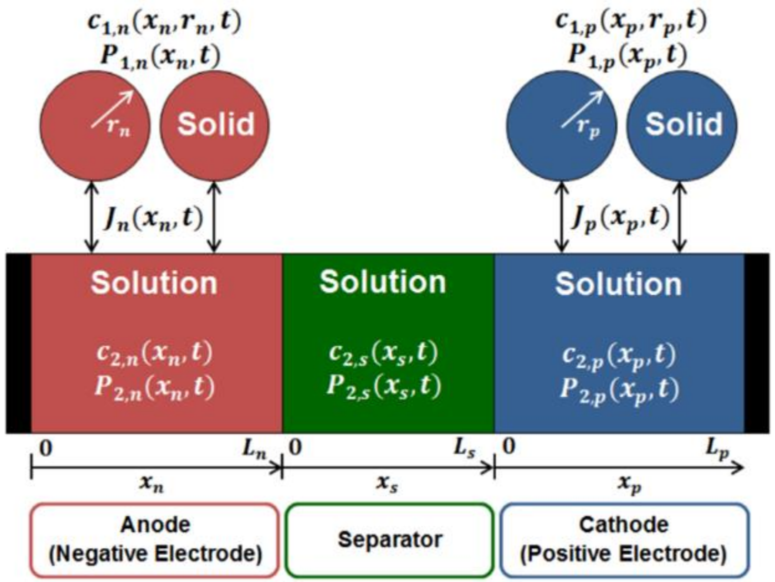
One optimization integrated into a global and complex aircraft architectures optimization



One optimization integrated into a global and complex aircraft architectures optimization

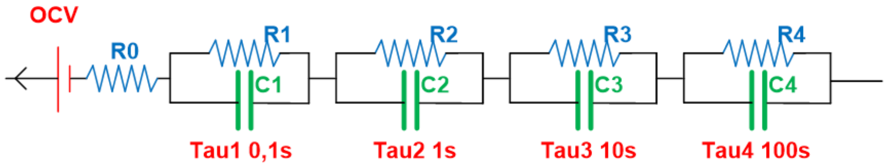


Several battery models available…



Doyle-Fuller-Newman (DFN) lithium-ion battery model

doi: 10.1109/ACC.2014.6858858



Example of empirical model

Dependencies

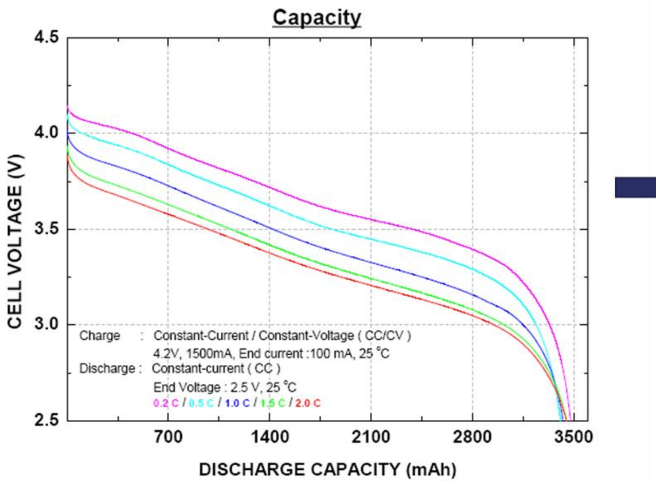
OCV = f(Tcell, SOC, SOH)

Rx = f(T, SOC, SOH)

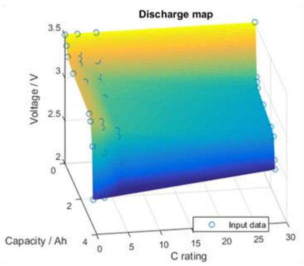
Physical model

Empirical model

Several battery models available…

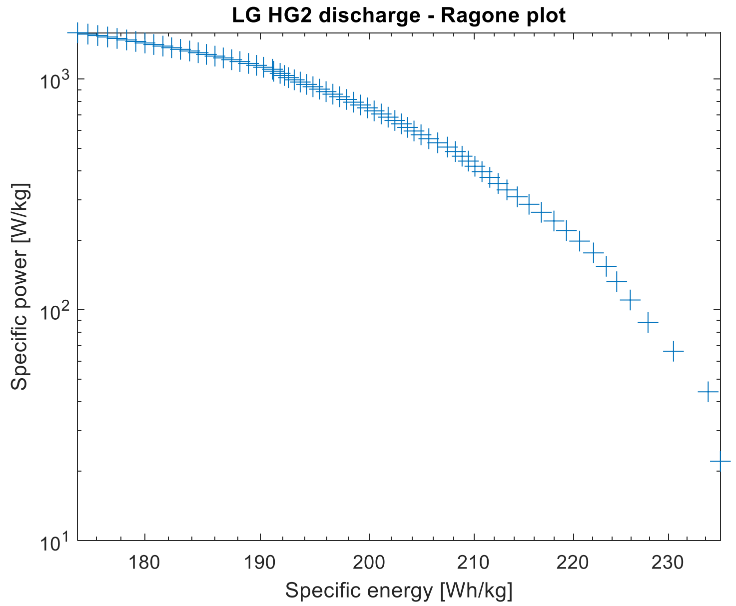


V = f(SoC,I)



Temperature context

Constant Current Cycles Linear Interpolation (3CLI)



Figures of merit (Ragone plot)

Several battery models available that are not satisfactory for complex optimizations

Computation time (physical and empirical) vs accuracy (3CLI and Ragone)

We propose a new reduced battery system model and sizing algorithm that we expect to be:

- Fast enough for complex optimizations
- Accurate enough: take into account power and energy performances, voltage dynamics, aging…

Sizing parameters

Application definition

Performance targets

→ List of « sizing » usage sequences at critical temperature → typical : coldest targeted temperature

→ Range of pack voltages to be respected

Ageing protocol

→ Typical usage description

(sequence of power profiles, pauses, charging phase → leading to typical ageing

- Distribution of ambient T°
- Target of durability

Candidate cell description

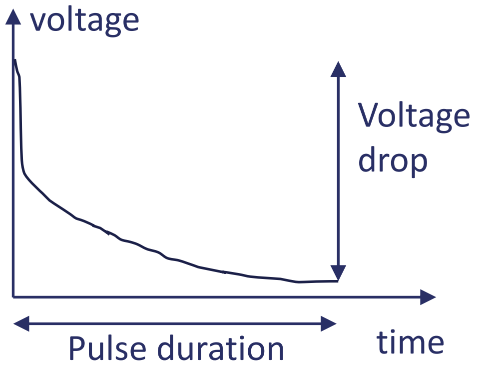
Model v1 : cell reference (fixed chemistry, fixed format, fixed specs, …)

Model v2 : parametric model based on physic → possibility to tune chemistry, format, loading (energy/power ratio)

Cell model reduction

Sizing tool based on reduced electrochemical cell model

limitation : **cell model for constant power profiles**
Objective : **very fast electrochemical model (reading in lookup table)**



Dynamic Empirical model
→ Cell voltage simulated for a high number of constant current (or power) pulses

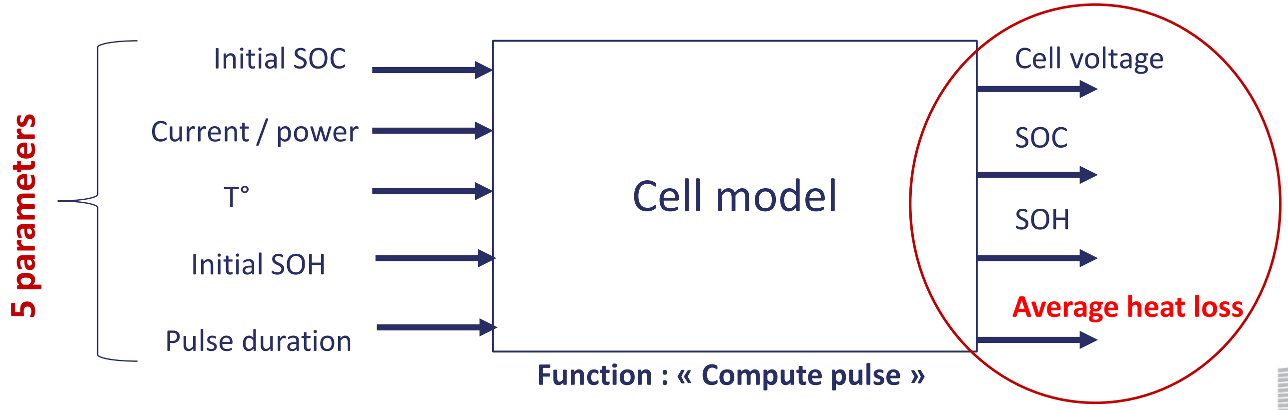
Launching dynamic simulations for different parameters :
- **Initial SOC**
- **Current or power**
- **Temperature**
- **SOH**

Making response surface

Storing information obtained at end of current pulse

Several 5D matrix, giving information at end of current pulse :
- **Cell voltage**
- **Cell SOH**
- **Cell SOC**
- **Average heat power generated**

End of pulse values



Next steps

- Results
- Integration in global aircraft architectures optimization

THANK YOU!

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