

GE
Aviation
Systems

Electrification and roadmap for future

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GE Proprietary Information

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For Internal Use Only



Fuel and emission ... drivers for change

Industry

Fuel

55B gallons / \$230B

- 13% of fossil fuel in transportation
- 35% of operating cost (change from loss to profit)

Emission

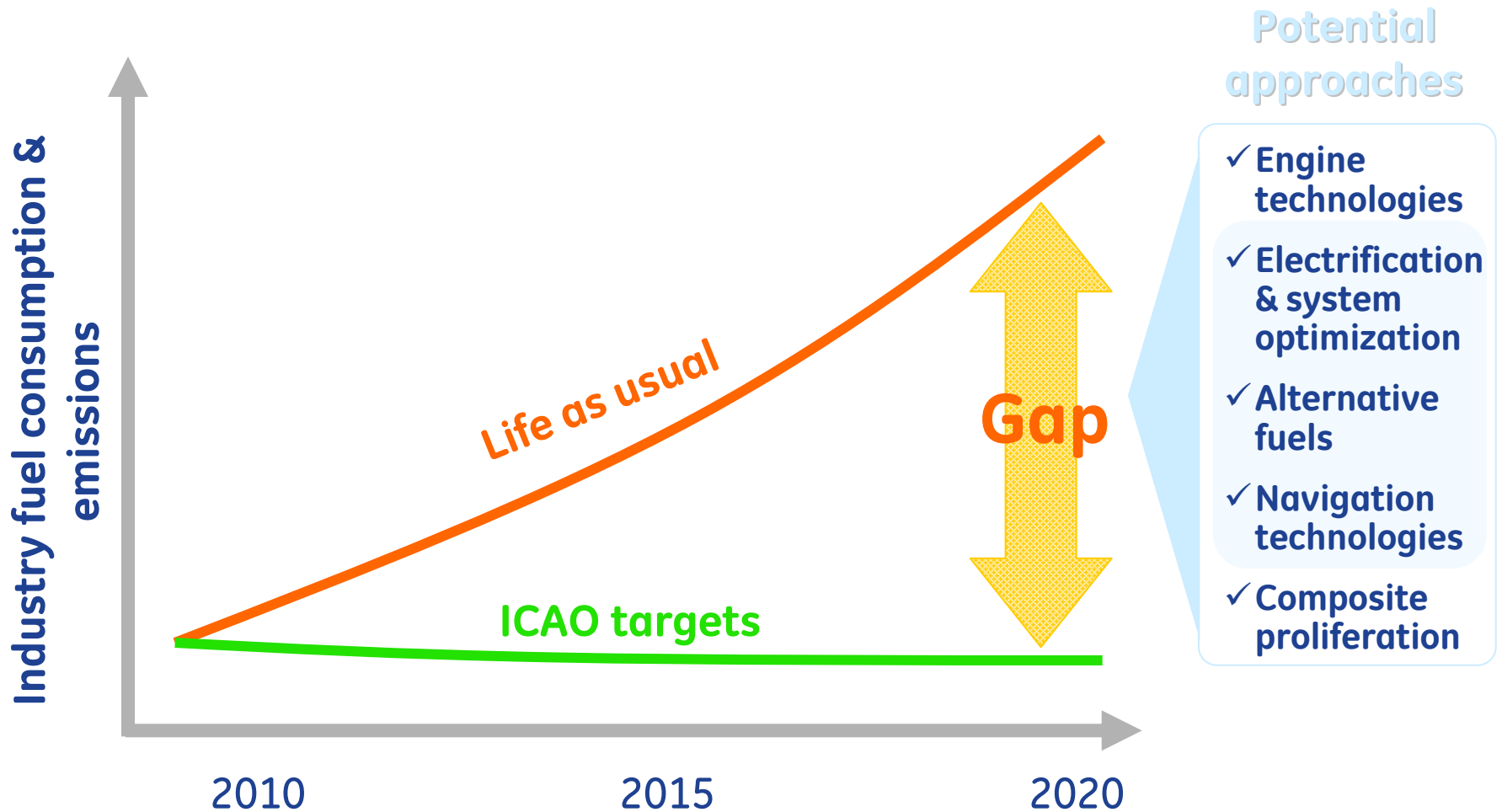
540M tons CO₂

- 8% of global CO₂ emission in transportation

ICAO responded responsibly by setting targets for industry ...

- **1.5% fuel efficiency by 2020**
- **Carbon neutral growth by 2020**
- **50% CO₂ reduction by 2050**

Requires step change in approach



Note: Life as usual ... 5% industry growth



Electrification ... a valuable lever

Strategy

Efficiency through Essentials ... only supply the power essential to your needs only when you need it

- During both in-use and idling
- Optimization / sys. analysis

Mechanical to electrical auxiliary load transformation

Alternative power strategies provide electricity

- Hybridization ... multiple sources
- Waste energy recovery
- Energy storage
- Alternative fuel ... i.e. fuel cell, solar, grid pwr.



Efficiency



Maintainability



Reliability/redundancy



Power system flexibility & Utility



Availability



Power management



Reduced power extraction



Reduced life cycle costs



Lower emission



imagination at work

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Electrification-to-date

'10s & '20s

1913: 1st flight with **electric compass**

1914: 1st magneto produces current using perm. magnets

1920's: 1st electric generator

1920's: Planes started carrying radios and nav. gear powered by DC batteries

'40s

Convair B-36

1945: 1st constant Speed drive

1946: 1st AC 400Hz Generator (Convair B-36)

'60s

Concorde

1969: 1st civil **fly-by-wire** aircraft (Concorde)

'70s

1970's: 1st electronically controlled **VSCF 400Hz generator**

1972: 1st digital fly-by-wire aircraft

'80s

A320

1984: 1st civil airliner with digital fly-by-wire flight controls (A320)

'90s

B777

1995: 1st airliner with **integrated power mgt** and distribution (B777)

1996: 1st Civil aircraft **VF generator** (Global Express)



imagination at work

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Electrification ... most improvements in '00s

'00s ... a decade of step change

JSF

A380

B787

2005: 1st business jet with fly-by-wire flight controls (Falcon F7X)

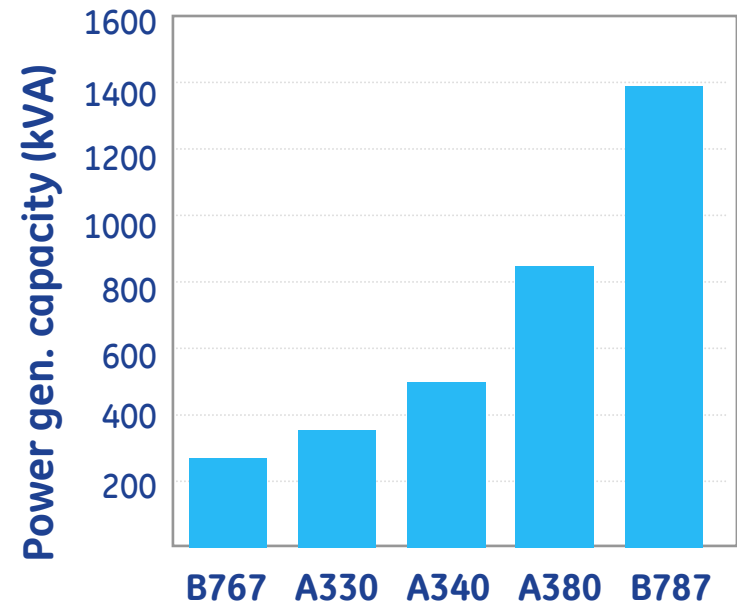
2006: 1st 270 VDC starter generator system (F-35)

2007: 1st electric airplane to receive certificate of airworthiness (France)

2009: 1st high voltage AC Starter/Generator system & E-ECS/MEA (B787)

2009: 1st aircraft with smart modular power tiles (G650)

Onboard electrical power capacity

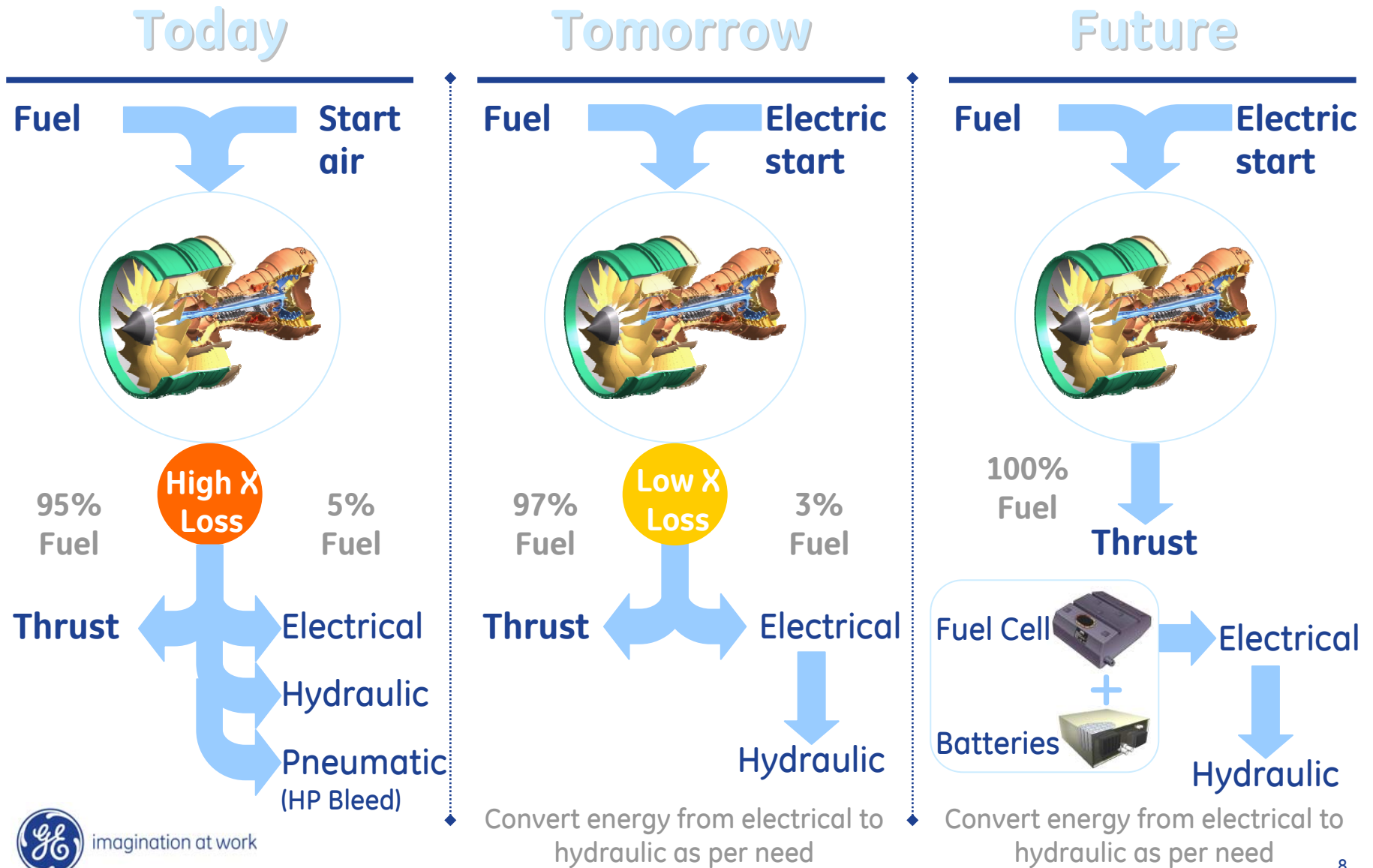


Tomorrow

SmartGrid on Aircraft

- 1 Efficient power extraction
- 2 Power source management for efficiency
- 3 Active load management & localized control
- 4 Active energy management based on mission

1. Efficient power extraction



2. Power source management

Two considerations: (1) redundancy (2) efficiency

Today

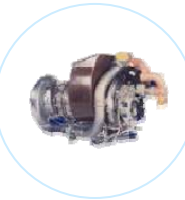
Future

Engine(s)



- During taxi
- In flight
- 40% efficiency in cruise
- Inefficient at take-off

APU



- On ground
- In flight for redundancy
- Avg. 20% efficiency

RAT



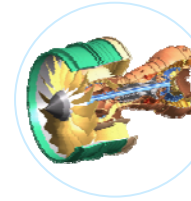
- Emergency power

Battery
(High Power)



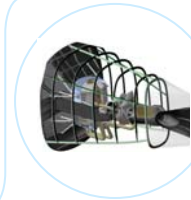
- Electrical back-up power & S/G
- Power quality

Engine(s)

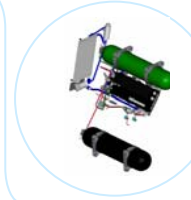


- 40% efficiency in cruise

Fuel Cells



- ~70% efficiency
- Distributed & modular



	Density (Wh/kg)
Engine/APU	1,700
Fuel Cell	1,500
Battery	275

Battery
(High Energy)



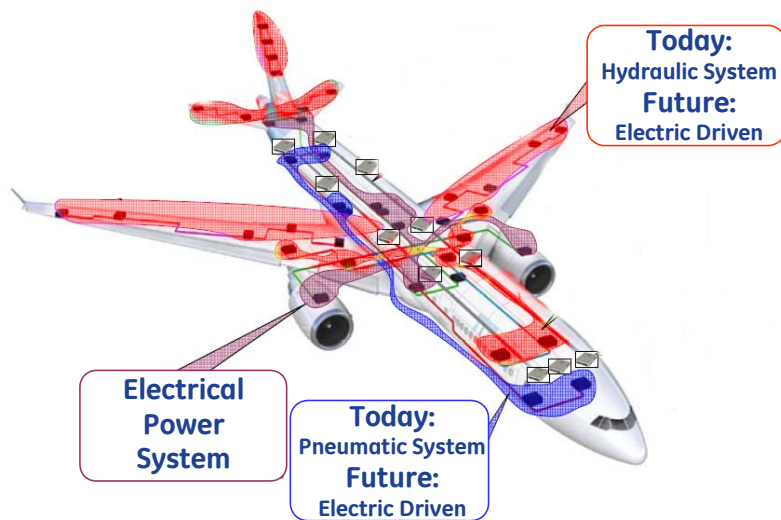
- ~90% round-trip efficiency
- First charge at terminal

Dynamic source power and energy capacity mgt



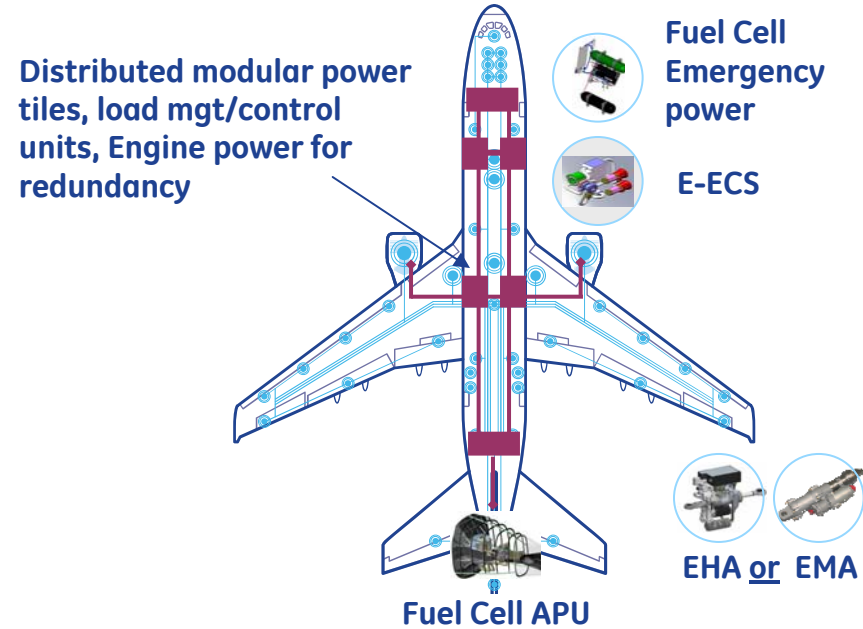
3. Active load management

Today



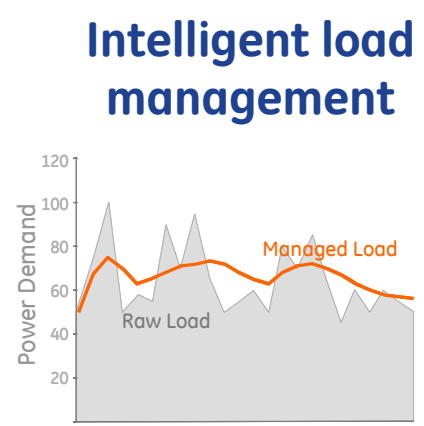
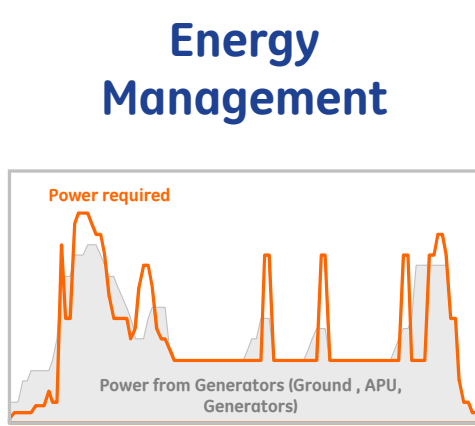
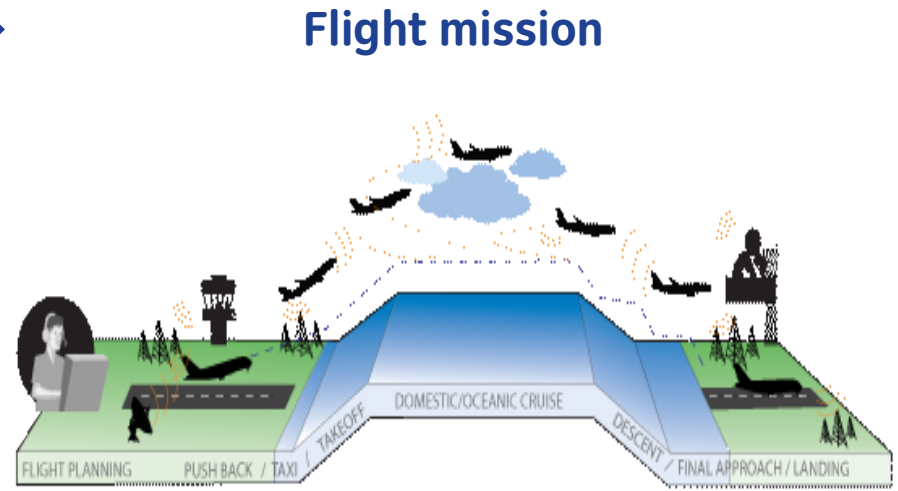
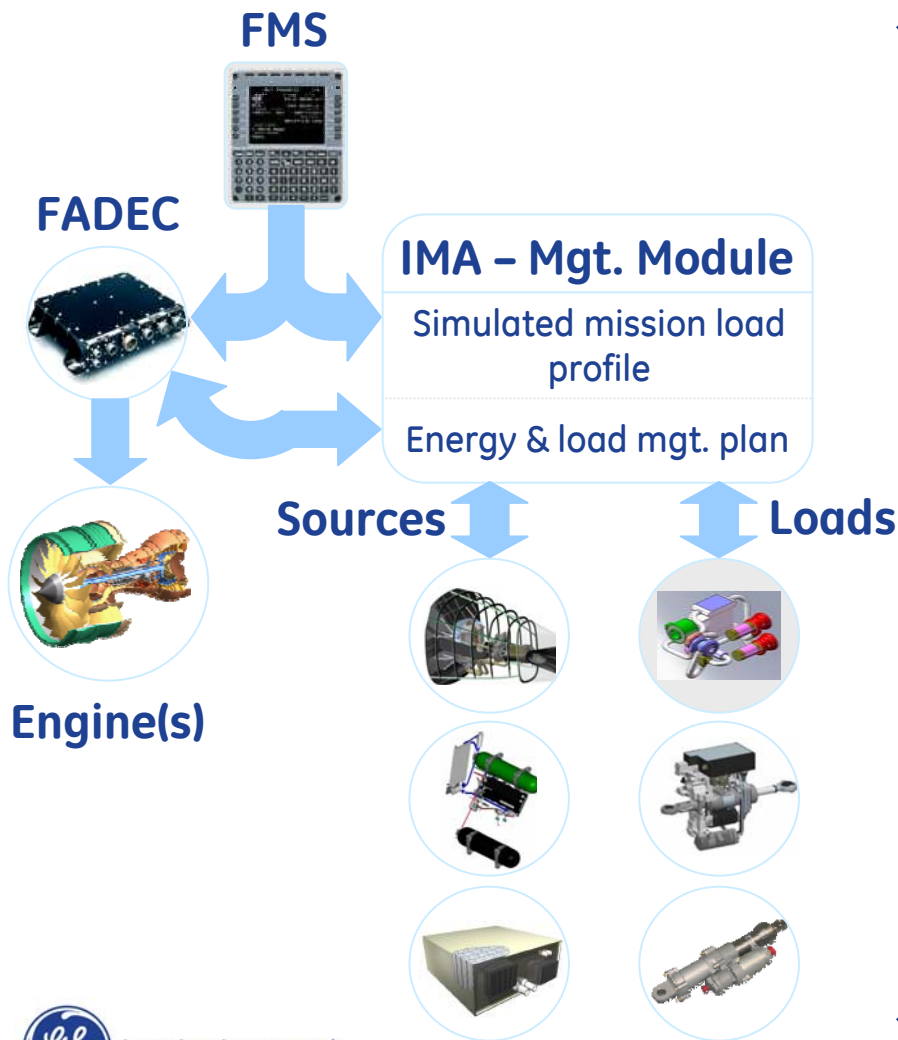
- 3 separate power lines (ele., hydr., pneu.) throughout aircraft
- Separate power and controls
- Tough to match power needs with source
- ↑ weight, ↑ maintenance; ↓ reliability

Future

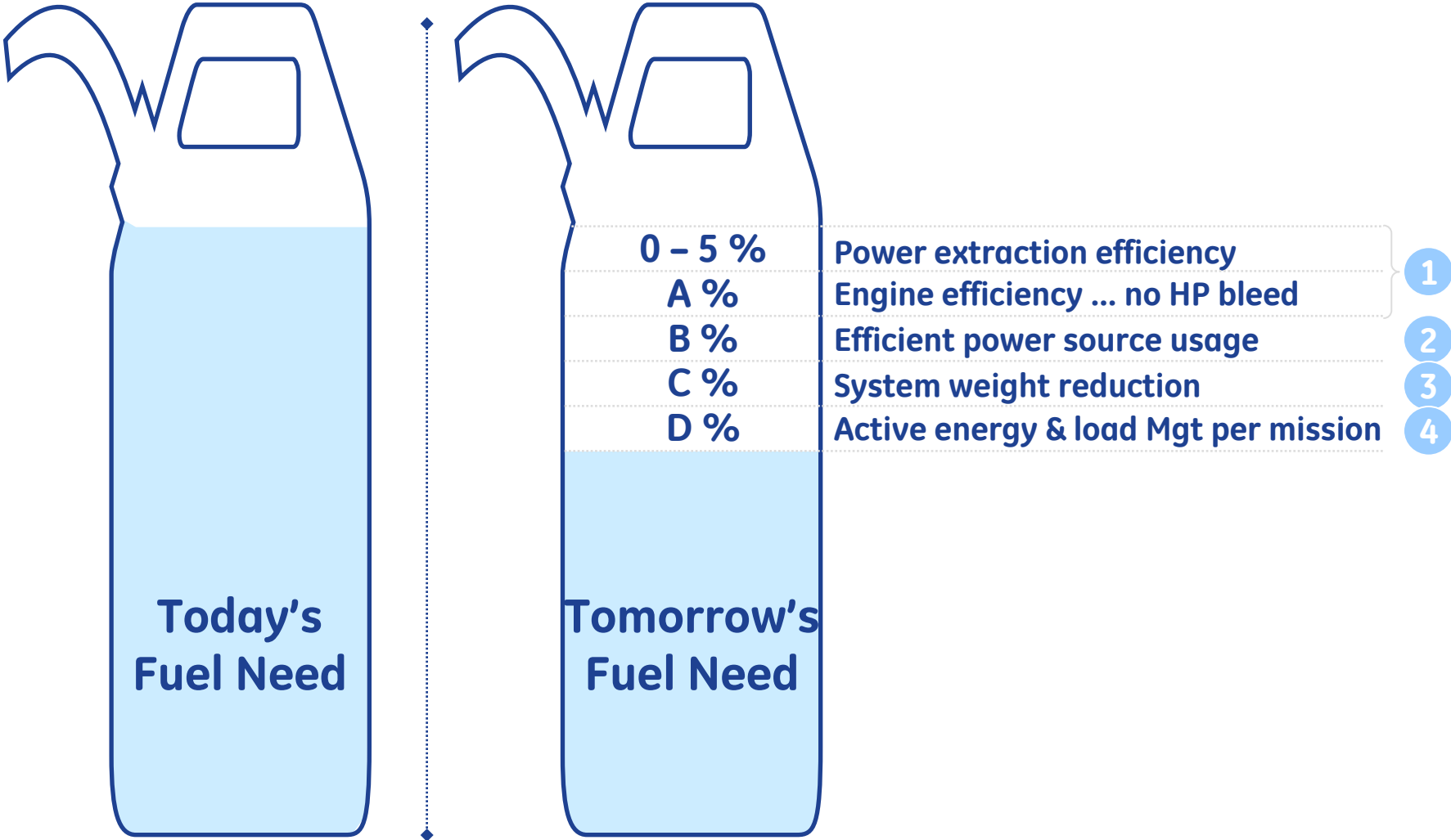


- Electric architecture ... ↓ weight from bulky mechanical structures & ↑ reliability
- Distributed modular power tile ... ↓ weight and ↑ controls (localized) for load mgt.
- High voltage power distribution ... wiring weight

4. Energy management per mission



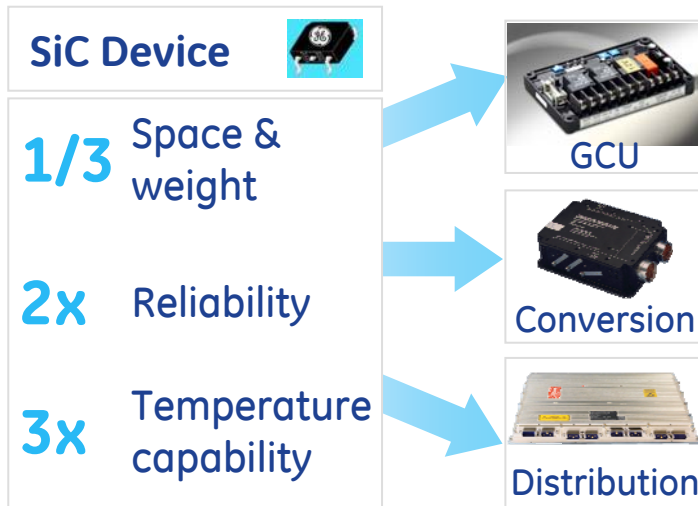
What's the potential? ... 8%? ... 10%?



Enabling technologies

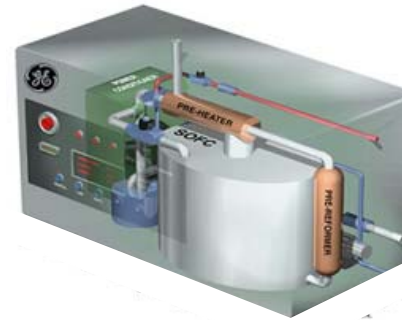
Device Level

Silicon Carbide



Subsystem Level

SOFC (Fuel Cell)



Energy Storage



Energy Conversion



(12-pulse, 18-pulse or AFE system)

Modular Power Tile



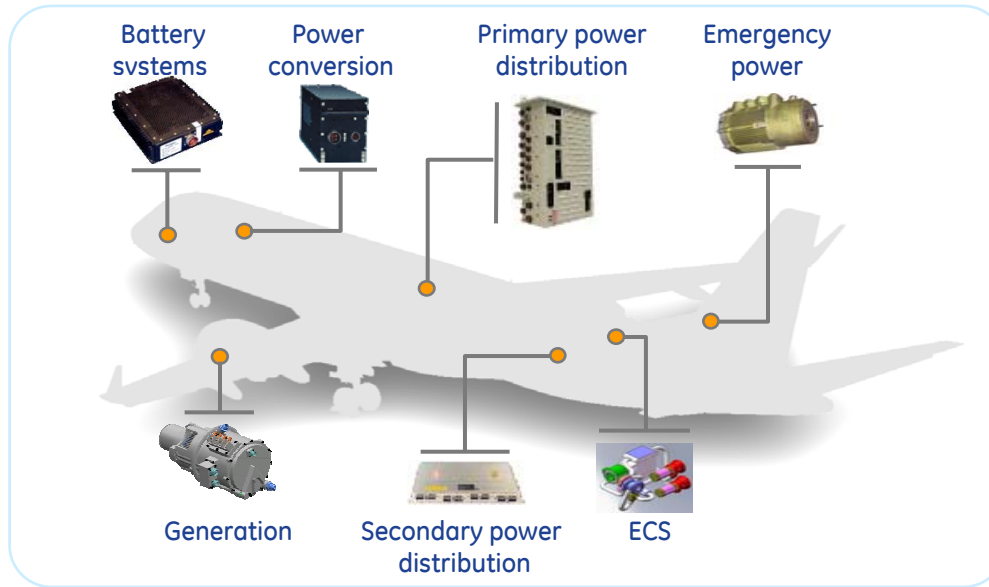
Power Panel



Distributed MPT

System integration labs in GE

Enables trade studies and energy mgt. systems



Key technologies & capabilities



Fuel Cells & Integration



Battery technologies (Li-Ion, Sodium) & integration



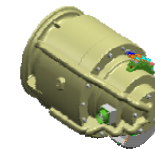
SiC



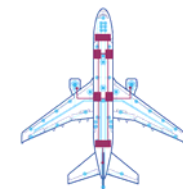
Modular power tiles



Integrated load controller



Integrated VFG



Systems trades & optimization



