GE GLOBAL RESEARCH

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Electric Motors for Hybrid/Electric Aviation – Technology Developments & Challenges

GRCTHINK

Introduction

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BSEE Clarkson University (‘90)
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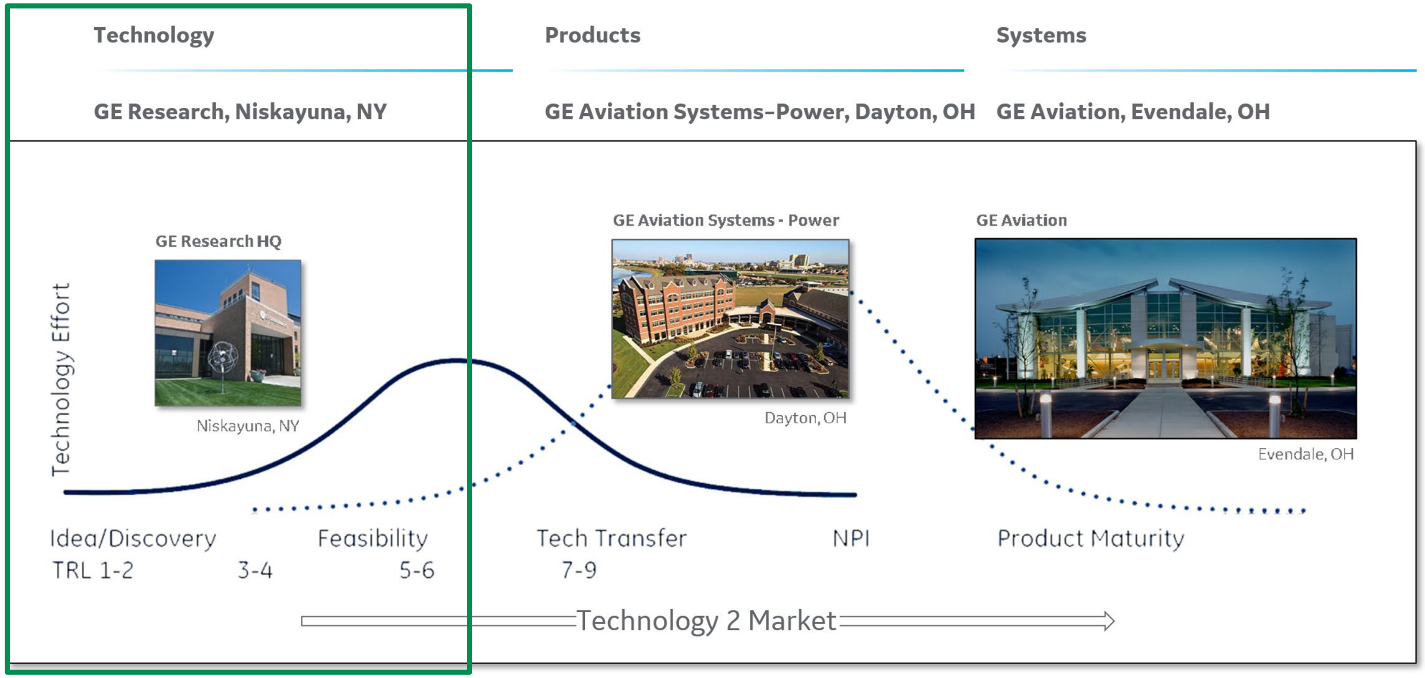
GE Power 1990 – 2018

- Large turbo-generator design (40-1500MW)
- Stator Manufacturing Quality
- High speed, PM motors for O&G (5-15MW)
- New product development & systems integration

GE GRC 2018 - now

- Supporting GE Aviation Hybrid Electric Team
- Armature development & Prototypes
- IEEE Senior member
- Vice-Chair of the Power & Energy Society Electric Machine Committee



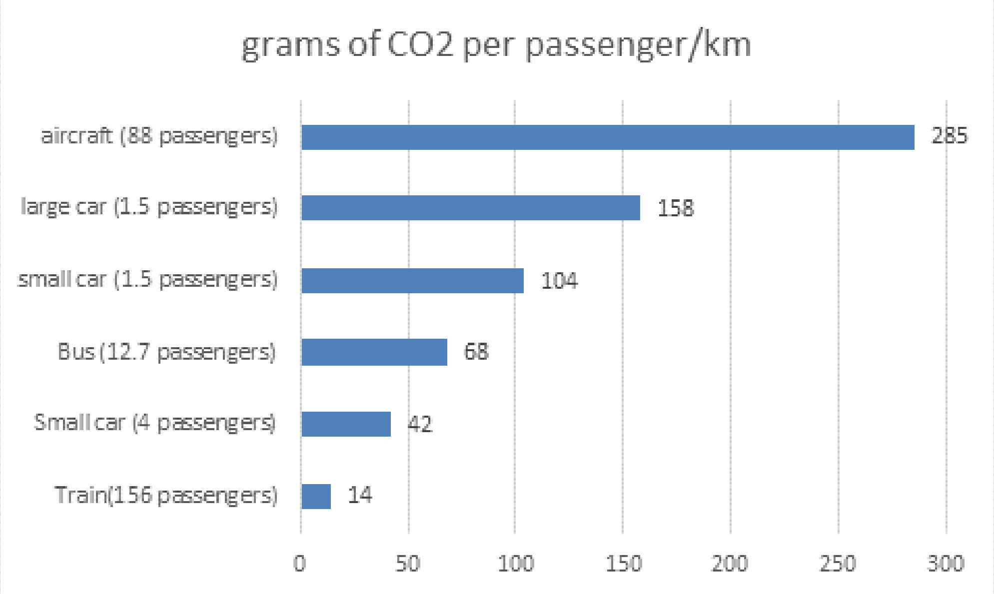
- **Part of GE team that spans technology development through maturation and productization**
- **Exciting opportunity to help transform an industry**

Hybrid Electrification of Narrow-Body Aircraft

Key in decarbonization of transportation sector

- As power sector switches to low emission technology, - Transportation sector taking lead in US CO_2 emissions[(1)]
- Within Transportation, Aviation has highest emissions per passenger/mile and is fastest growing segment[(2)]
- Narrow body segment (Regional + Single Aisle) consumes 60%+ of commercial aviation fuel[(3)]
- Hybrid architecture w/embedded generators & tail-cone propulsor can deliver significant fuel burn reduction[(3)]

(1) https://rhg.com/research/preliminary-us-emissions-estimates-for-2018/ , Table 4.
(2) https://www.eea.europa.eu//publications/progress-of-eu-transport-sector-1, Fig. 1; EEA report: Focusing on environmental pressures from long distance transport, doi: 10.2800/857401, Fig. 5.3
(3) https://www.grc.nasa.gov/vine/wp-content/uploads/sites/91/Rodger-Dyson-NASA-Hybrid-Electric-Aircraft-Propulsion-10-4-2017-FULL.pdf

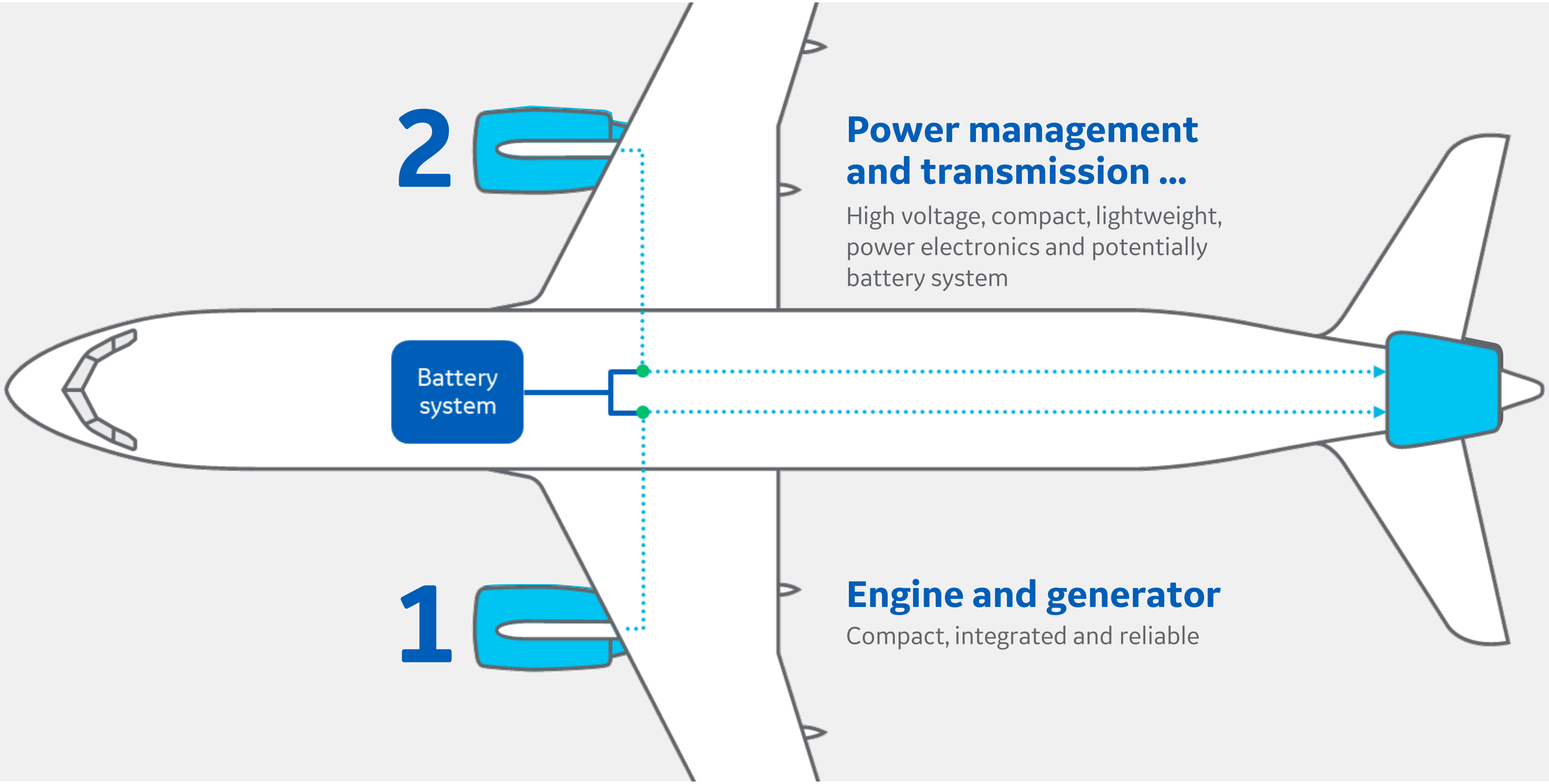


Adapted from EEA report: Focusing on environmental pressures from long distance transport, doi: 10.2800/857401, Fig. 5.3 [(2)]

Focus technology, component & system development on narrowbody architectures

Elements of Tail-cone Propulsion Hybrid System

MW level, high voltage distributed power providing new propulsion lever



Power management and transmission ...

High voltage, compact, lightweight, power electronics and potentially battery system

Engine and generator

Compact, integrated and reliable

System Characteristics

- ❑ System-level optimization
- ❑ Highly integrated, altitude-capable components
- ❑ High-voltage bus(es)
- ❑ Direct/ Embedded-cooling
- ❑ Prime reliability

3 Motor-driven fan

Compact, light, integrated with fuselage

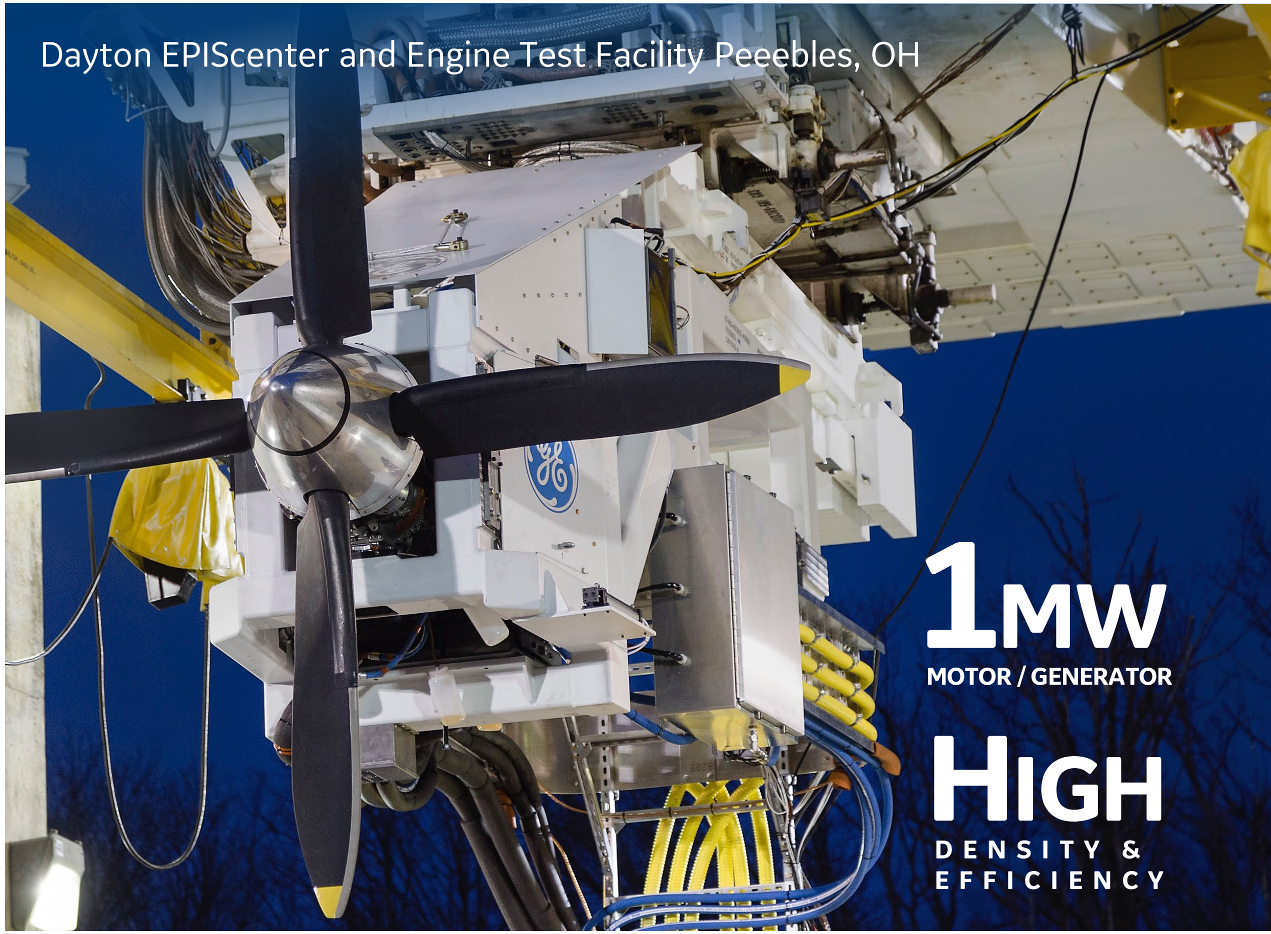
4 Thermal Mgmt. Syst.

Integrated with overall system

2016/2017: Demonstrators

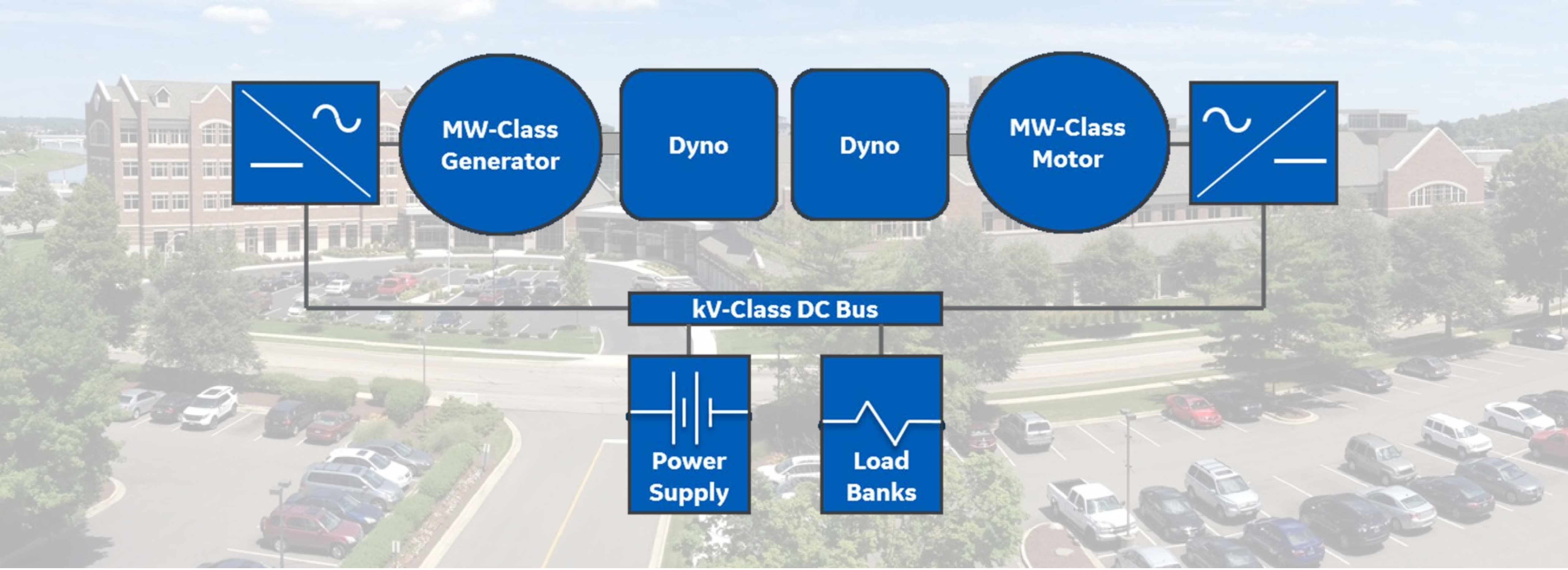
F110-GE-129 dual-spool engine

Electric motor/generator



2018: Component characterization and system testing

Ground level tests at GE's EPIScenter in Dayton, Ohio



2018: Inverter technology

Component/System test at GE Research and the GE EPIScenter

1MW

SiC INVERTER

HIGH

POWER DENSITY AND EFFICIENCY

Preparing the technology building blocks

Challenges

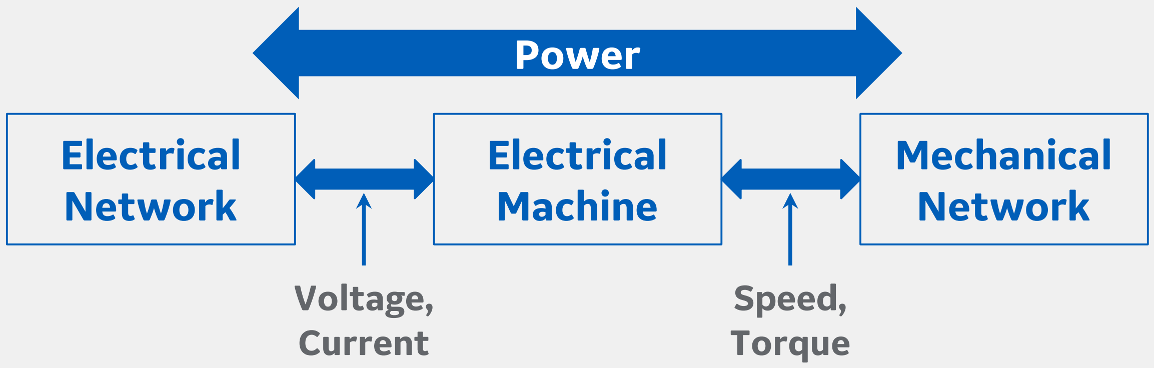
- Higher voltage systems at altitude
- Performance and HALT testing at altitude
- Prime Reliable subsystems
- System-Level power densities

Enabling technologies

- Integration concepts and technologies
- Altitude-ready HV machines and inverters
- Advanced cooling & thermal systems
- New materials and additive manufacturing
- Compact energy storage technology

Enabling technologies for motor / generator - Physics

Energy Conversion Principles



$$P \propto n\, L\, D^2\, \sigma\, \beta$$

Utilization Factors

***Magnetic*: Flux density**
- Magnetic Materials

***Thermal*: Heating from current**
- Insulation Materials
- Cooling systems

***Kinetic*: Material Strength**
- Machine architecture
- Magnetic / Structural Materials

Thermal & Weight Budgets

- Electric machine max temperature often limited by insulation & magnetic material capabilities
- Higher operating temperatures reduce:
  - Weight through higher power density
  - Thermal management system (TMS) weight & drag

Technology Levers for Power Density

- Machine Architecture & Subsystem integration
- Embedded cooling & thermal systems
- High temperature Electrical Insulation
- Magnetic Materials

System level integration & interdisciplinary design required

Opportunities for Technology Development

Materials

- ❑ Alternatives to mica-based insulation
- ❑ Alternatives to soft magnetic alloys

- ✓ Altitude capable, kV-class, 230C+, PD-resistant, higher thermal conductivity & breakdown strength
- ✓ Higher strength, temperature
- ✓ Additively manufactured

Motor Architecture & Thermal Management

- ❑ System & machine configurations
- ❑ Alternate cooling fluids & components

- ✓ Fully integrated fan, converter, TMS
- ✓ Direct / embedded cooling
- ✓ Optimized thermal management

Subsystem & System Demonstrators

- ✓ Machines at scale (power, voltage)
- ✓ Performance & HALT testing at altitude

A mature, viable HEP system requires technology breakthroughs on all fronts.

With support, the industry can transform commercial aviation in a carbon-constrained world.