Transportation Electrification
Land and Air

Dr. Kaushik Rajashekkara

March 30, 2018
EV to PHEV to EV
Electric Drive System Components

- Electric motor – converts electrical energy to mechanical power for motive power
- Inverter – converts high voltage direct current to varying pulses that control and power the electric motor
- Charger – modifies and controls electrical energy to re-energize the battery
- Converter(s) – increases the battery voltage for the traction drive system and decreases the voltage for the accessories

Integration of components will reduce electric drive system cost and improve efficiency
GM Impact 1990

- The Impact prototype was powered by two induction motors, one driving each front wheel. The battery pack consists of 32 compact 10-volt Delco Remy lead-acid batteries, connected in series. The inverter for converting the battery voltage to ac has 288 MOSFETs, each leg consisting of 24 parallel connected devices, switching at about 20 KHz. The slip frequency of the AC current was varied to maintain the highest possible efficiency throughout the RPM range. Each motor's output is transmitted to the tires via a 10.5:1 planetary gear unit.

  - Motor Type: Three phase induction motor
  - Max. motor output: 57 bhp @ 0 to 6600 rpm (per motor)
  - Motor speed at 60 mph: 9500 rpm
  - Top speed: 100 mph (rev. limited to 75 mph)
  - Torque: 47 lb-ft @ 0 to 6600 rpm (per motor)
  - Inverter type: Dual MOSFET inverter
  - Frequency range: 0-500 Hz
  - Battery type: Lead acid, 32, ten volt batteries in series.
  - Capacity: 42.5 amp. hour, 13.6 KWh
  - Battery weight: 395 Kg
  - Battery charger: Integral with dual inverter package
  - Recharge Time: 2 hrs (80%)
  - Range: 120 miles @ 55 mph
  - Acceleration (0 to 60 mph): 8 seconds
  - Vehicle weight: 1000 Kg

- GM's Impact was the first production intent EV announced by a major car manufacturer. Impact technology led to the production of EV1 electric vehicles.
Today - Hybrids

- Toyota Prius
- Lexus GS 450h
- Camry Hybrid
- Highlander Hybrid
- Lexus RX400h

Hybrid targets for early next decade: 10 models & 1.0 million/year sales
Toyota Hybrid System II
With two-stage motor speed reduction device

Diagram showing the components of the Toyota Hybrid System II, including the engine, hybrid transmission, power split device, generator, motor, battery, inverter, boost converter, and power control unit. The diagram also includes a graph showing the output in low gear position and high gear position.
Toyota Prius Hybrid Synergy Drive Control
Integrated Starter Generator (ISG) Architecture

• Features
  – Engine stop at vehicle stop; Engine cutout at coast and deceleration
  – 10 to 20% fuel economy gain in urban driving cycles

• Impact
  – Removal starter motor,
  – Requires energy management system
  – Increases length of the power train
**Tesla Roadster**

- Top Speed – 125 mph
- 2 Speed Transmission
- Range – 220 miles
- Full charge in 3.5 hrs (with 70 amp home charging station)
- Shaft Drive
- Weight – 2690 lbs
- 6,831 Lithium Ion batteries (laptop)
- Each cell is independent
- 100,000 mile life expectancy
- 3-phase, 4-pole electric induction motor, 215 kW
- Propels car 0 – 60 mph in under 4 seconds
- 85% – 95% efficient

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**Now in Production**

- 100% electric
- 0 to 60 mph in 3.9 seconds
- 13,000 rpm redline
- 256 mpg equivalent*
- 220 miles per charge*
- less than 24 per mile*

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*Discontinued*
**Powertrain:**
Model S is a rear wheel drive electric vehicle. The liquid-cooled powertrain includes the battery, motor, drive inverter, and gear box. Microprocessor controlled, 60 kWh lithium-ion battery (230 miles range, It is 300 miles with 85 kWh), Three phase four pole induction motor with copper rotor (310 kW, 600 N·m ), Inverter with variable frequency drive and regenerative braking system , and Single speed fixed gear with 9.73:1 reduction ratio.

**Charging:**
* 10 kW capable on-board charger with the following input compatibility: 85-265 V, 45-65 Hz, 1-40 A (Optional 20 kW capable Twin Chargers increases input compatibility to 80 A)
* Peak charger efficiency of 92%
* 10 kW capable Universal Mobile Connector with 110 V, 240 V, and J1772 adapters
### 2017 BMW i3 EV (Range Extender)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor type</strong></td>
<td><strong>Hybrid synchronous motor</strong></td>
<td><strong>Range</strong></td>
<td><strong>231-240 miles</strong></td>
</tr>
<tr>
<td>Motor power output</td>
<td>125kW</td>
<td>Battery Type</td>
<td>Li ion</td>
</tr>
<tr>
<td>Motor torque</td>
<td>250Nm</td>
<td>Battery Energy</td>
<td>27.2kWh</td>
</tr>
<tr>
<td>Top Speed</td>
<td>150 kmph</td>
<td>Charging time @ 125A 50kW DC</td>
<td>&lt;40min</td>
</tr>
<tr>
<td>Acceleration (0-100kmph)</td>
<td>8.1s</td>
<td>Charging time @ 16A</td>
<td>7.5 hrs</td>
</tr>
</tbody>
</table>
Hybrid Powertrain Topology

- **Conventional**
- **Electric Motor**
- **Engine**
- **Battery**
- **Series Hybrid**
- **Parallel**
- **Mild Hybrid**
- **Full Hybrid**
- **Electric Vehicle**
- **Range extender**
- **Series**
- **Fuel Cell**

Models mentioned:
- Smart
- Buick LaCrosse
- Toyota Prius
- Nissan Leaf
- Chevy Volt with Plug-in capability
- Honda FCX
2020 European ‘CAFE’ Prospective

Breakthroughs are a necessity

To reach 95g, ICE and transmissions efficiency is not enough. Hybrids and EVs will be necessary.

Valeo

October 2013
48/12 Volt Architectures

- There are 2 basic Architectures for 48/12 Volt Systems, which can be functionally identical within the power range of an accessory belt drive
  
  - Belt-Alternator-Starter
    - Advantageous when other powertrains are used on the same vehicle since the basic engine & transmission configuration is common.

  - Integrated Starter-Alternator
    - Does not have large starter-alternator external to the powertrain
    - Can transmit more power since it is not limited by belt drive.
    - Packaging tradeoff at the expense of serviceability
Plug-in Hybrid Vehicle

**EV:** Electric Vehicle  
**BEV:** Battery-only Electric Vehicle  
**PHEV:** Plug-in Hybrid Electric Vehicle  
**EREV:** Extended Range Electric Vehicle
CHEVROLET VOLT
YEAR: First introduced in January 2011
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Battery(KWh)</td>
<td>18.4 (2017 Models)</td>
<td></td>
</tr>
<tr>
<td>Total Energy</td>
<td>18.4kWh</td>
<td></td>
</tr>
<tr>
<td>All Electric Range</td>
<td>40 miles (2015 model)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>53 miles (2017 model)</td>
<td></td>
</tr>
<tr>
<td>Gasoline Engine (Opel’s Family)</td>
<td>1.4L 4-cylinder engine</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>80hp (60KW)</td>
<td></td>
</tr>
<tr>
<td>Fuel Tank Capacity</td>
<td>9.3 US Gallons</td>
<td></td>
</tr>
<tr>
<td>Generator/Motor 2</td>
<td>48kW (Ferrite)</td>
<td></td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>100 miles per hour (160 km/h)</td>
<td></td>
</tr>
<tr>
<td>Motor 1 Type</td>
<td>Permanent Magnet</td>
<td></td>
</tr>
<tr>
<td>Motor Power (Peak)</td>
<td>87kW</td>
<td></td>
</tr>
<tr>
<td>Torque</td>
<td>370Nm</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>Range with a full tank of gasoline and a fully charged battery is 379 miles (609.9 km)</td>
<td></td>
</tr>
</tbody>
</table>
## Energy and Power Needs

<table>
<thead>
<tr>
<th>Storage technology</th>
<th>Energy density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-acid batteries</td>
<td>100 kJ/kg (30 W-h/kg)</td>
</tr>
<tr>
<td>Lithium-ion batteries</td>
<td>600 kJ/kg</td>
</tr>
<tr>
<td>Compressed air, 10 MPa</td>
<td>80 kJ/kg (not including tank)</td>
</tr>
<tr>
<td>Conventional capacitors</td>
<td>0.2 kJ/kg</td>
</tr>
<tr>
<td>Ultracapacitors</td>
<td>20 kJ/kg</td>
</tr>
<tr>
<td>Flywheels</td>
<td>100 kJ/kg</td>
</tr>
<tr>
<td>Gasoline</td>
<td>43000 kJ/kg</td>
</tr>
</tbody>
</table>
Nissan Leaf battery pack
Lithium ion batteries

Li-ion systems get their name from their unique cathode materials. The lithium-ion family is divided into three major battery types, so named by their cathode oxides, which are cobalt, manganese and phosphate. The characteristics of these Li-ion systems are as follows.

- **Lithium-ion-cobalt** or *lithium-cobalt* (LiCoO2): Has high specific energy with moderate load capabilities and modest service life. Applications include cell phones, laptops, digital cameras and wearable products.
- **Lithium-ion-manganese** or *lithium-manganese* (LiMn2O4): Is capable of high charge and discharge currents but has low specific energy and modest service life; used for power tools, medical instruments and electric powertrains.
- **Lithium-ion-phosphate** or *lithium-phosphate* (LiFePO4): Is similar to lithium-manganese; nominal voltage is 3.3V/cell; offers long cycle life, has a good safe record but exhibits higher self-discharge than other Li-ion systems.
# Figures of Merit of Advanced batteries

<table>
<thead>
<tr>
<th></th>
<th>Lead-Acid</th>
<th>Nickel-Metal Hydride</th>
<th>Lithium-Ion</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>SLI</td>
<td>Advanced</td>
<td>HEV</td>
</tr>
<tr>
<td>Nominal Cell Voltage V</td>
<td>2.0</td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Energy Density Wh/l</td>
<td>60</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Specific Energy Wh/kg</td>
<td>25</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Power Density W/l</td>
<td>1200</td>
<td>600</td>
<td>2000-2500</td>
</tr>
<tr>
<td>Specific Power W/kg</td>
<td>500</td>
<td>250</td>
<td>1000-1300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>HEV</th>
<th>PHEV-BEV</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3.3-3.8</td>
<td>3.3-3.8</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>200-400</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>120-200</td>
</tr>
<tr>
<td></td>
<td>3500-9000</td>
<td>800-2200</td>
</tr>
<tr>
<td></td>
<td>2000-4000</td>
<td>500-1200</td>
</tr>
</tbody>
</table>

- Values are shown for cells.
- System values can be reduced by as much as half (more for HEV).
Electric Vehicle

No engine
Only battery, power electronics, and electric motor
PHEV Fast Charging

- DC-fast charging (DCFC) enables a direct connection to the DC leads to the vehicle battery for the very fastest rate charging.
- DCFC is typically most useful for battery electric vehicles (BEVs) that have no gasoline engine backup for intercity travel.
- DCFC is most often associated with the fastest charging rates possible in an attempt to approach the rapid energy transfer rate of gasoline refueling.
- DCFC charge rates of 100kW+ require grid connections that are only typically available in commercial or industrial sites (and not homes).
- While DCFC still delivers slower than the energy transfer at the gas pump, DCFC can get the electric vehicle driver back on the road conveniently to provide a substantial amount of range.
- For an intercity trip, a rough estimate is that a large battery BEV (such as an 85kWh Tesla Model S) can acquire enough charge for about 2.5 hours of highway driving in 30 minutes at the fastest Tesla Supercharger DCFC station.

DC Fast Charging

Miles per 30 minutes of charging

<table>
<thead>
<tr>
<th>Level 1</th>
<th></th>
<th>3.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Level 1 = 1.7 kW  
0.5hr * 1.7kW/hr * 4mi/kWhr = 3.4 miles

Level 2 = 6 kW  
0.5hr * 6.0kW/hr * 4mi/kWhr = 12 miles

Level 3 = 50 kW  
0.5hr * 50.0kW/hr * 4mi/kWhr = 100 miles
DC Fast Charging

The Fleet solution: Sarge

Product Overview

Sarge - 50 kW Networked Fast Charge Station

Power Requirements: Max Draw 67A 480/3 Phase

Designed, Engineered & Manufactured in VA, USA

CHAdEMO certified (December 2010)

UL certification (January 2011)

Future Proof – SAE 1772 DC Coupler

Touch Screen Interface

Tamper-proof enclosure

Vertical cable to avoid tipping hazards
DC Fast Charging - Fuji Electric

DC Quick Charging
- 3Φ 208V
- 300-500V DC + CAN
- 25-50 kW
- 16-24 kWh
- 3 phase 208V AC is Converted to DC.
- DC is sent directly to the EV Battery.
- BMS commands charging current via CAN

Level 2 AC Charging
- 1Φ 208V
- 1Φ 240V
- 3-6 kW
- 3-6 kW 16-24 kWh
- 208V AC is sent through the charger to the Vehicle
- The On-Board Charger converts the AC to DC
- DC Charging is limited to the Power of the On-Board Charger
How CHAdeMO Quick Charging Works...

- BMS Decides the Charging Rate Based on Battery Conditions
- The Charger is Given the Proper Voltage and Rate to Charge via CAN
- The Charger Pre-charges the Circuit to the Voltage given by the BMS and Limits Charging to the Specified Rate
- Improvements in battery technology can be implemented without a change to the charger. The BMS can specify a higher charging rate to the existing infrastructure.
The ZEFIRO is the latest class of very high speed (VHS) trains from Bombardier.

It is one of the fastest sleeper trains in the world and is currently being operated in China. Operating speed of 250kmph to 380kmph

- The ZEFIRO features sustainable technologies and an aerodynamic design that generates 20% energy savings.
- It requires the lowest energy consumption per seat in its segment. It also offers the highest service speed among the ZEFIRO class of trains
- Power:
  - Voltage/frequency nom.: 25 kV-50 Hz; min. 17.5 kV; Max 30 kV,
  - Asynchronous motors, forced cooling
  - Distributed drives
  - 20 MW (16 cars, 380 kph)
Boeing 787

Hybrid AC and DC Primary Distribution Systems
(230 Vac, 115 Vac, ±270 Vdc, 28 Vdc)

Power Conversion from 230 Vac to ±270 Vdc

Remote Power Distribution System

Variable Frequency Generation at 230 Vac
- 2 x 250 kVA per Engine
- 2 x 225 kVA on APU

Liquid cooling of Conversion and Motor Controllers

Current Return Network

APU Starter / Generator System

Forward E/E Bay

Conventional 115 Vac Ground Power Sources

Aft E/E Bay

Electric Engine Start

Adjustable Speed Motors and Motor Controllers

787 Systems and Performance by Tim Nelson
With this no-bleed airframe, the ECS, cabin pressurization system, wing anti-icing system, and other conventionally air-powered subsystems are all electrically powered.

A380 System

- Generator: VFG (150 kVA) replace IDG (≤ 115 kVA)
- Variable frequency (f = 360…800 Hz) replace Fixed frequency (400 Hz)
- Electrical actuators (EHA…) replace Some hydraulic actuators
- Electrical RAT replace Hydraulic RAT
- AC-DC Converter: BCRU (300 A) replace TRU (200 A)
- Electronic circuit breakers (up to 15 A) replace Thermal circuit breakers
In a traditional airplane, the jet engine is designed to produce thrust and to power the pneumatic, hydraulic and electrical systems.
Airbus 330 Engine off take loads

Example: Power used on A330

**Electrical power**
- Avionics
- Commercial
- Pumps
- De-icing
- Lights
- ......

**115VAC-230kVA**

**Hydraulic power**
- Flight Controls
- Landing gear
- Braking
- Reverse
- Doors

**240kW-206bars**

**Mechanical power**
- Engine Fuel Pump
- Engine Oil Pump
- Engine start

**200kW (peak)**

**100kW (local)**

**Pneumatic power**
- Air conditioning
- Pressurisation
- Ice Protection
- Engine start

**From some bars up to 20bars-1200kW**

Example: Power used on A330
In a More Electric Aircraft (MEA) system, the jet engine is optimized to produce the thrust and the electric power.
Power Electronics and Power Conversion

Typical power conversion system with various loads
Hybrid Electric Aircraft
N3-X Concept Description by NASA

- TeDP-HWB: Turboelectric Distributed Propulsion– Hybrid Wing Body
- Decoupled propulsive producing device from power producing device
- Two wingtip mounted turboshaft engines driving superconducting generators
- Superconducting electrical transmissions
- Fifteen superconducting motor driven propulsors embedded in fuselage
- Two cooling schemes, cryo-cooled and LH2-cooled
Hybrid Electric Distributed Propulsion (HEDP) Aircraft

30 MW Superconductor Electrical Generator

Fuel Efficiency + 70%
Potential World-Market Pull : $400/yr saving

Superconductor Applications Needed

<table>
<thead>
<tr>
<th>Class</th>
<th>Superconductor Applications Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generators</td>
<td>30-40 MW</td>
</tr>
<tr>
<td>Motors</td>
<td>4-6 MW</td>
</tr>
<tr>
<td>Power Transmission Cables</td>
<td>5-70 MW DC ±270</td>
</tr>
<tr>
<td>Power Inverters</td>
<td>1-30 MW</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>30-40 MW</td>
</tr>
</tbody>
</table>

T.J. Haugan, “Design of SMES Devices for Air and Space Applications,” [http://www.cvent.com/events/tenth-epri-superconductivity-conference/custom-18-0ac856fa88e84a97ac2058094d0a4629.aspx](http://www.cvent.com/events/tenth-epri-superconductivity-conference/custom-18-0ac856fa88e84a97ac2058094d0a4629.aspx), October 2011
# N3-X Turboelectric Distributed Propulsion (TeDP) Vehicle Concept

<table>
<thead>
<tr>
<th>Aircraft Attributes</th>
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<tbody>
<tr>
<td>Range</td>
<td>7500nm</td>
</tr>
<tr>
<td>Payload</td>
<td>118100 lbf</td>
</tr>
<tr>
<td>$M_{\text{cruise}}$</td>
<td>&gt;0.8</td>
</tr>
<tr>
<td>Cruise alt</td>
<td>35,000 ft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Takeoff</th>
<th>Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust/Engine</td>
<td>54888 lbf</td>
<td>19293 lbf</td>
</tr>
<tr>
<td>Empty Weight (Baseline B777-200LR)</td>
<td>267400 lbf</td>
<td>(Δ73,400)</td>
</tr>
<tr>
<td>Number of Propulsors</td>
<td>14 or 15 (function of aircraft width, FPR, and net thrust)</td>
<td></td>
</tr>
<tr>
<td>Generator/engine</td>
<td>30,000 hp (22.4 MW)</td>
<td></td>
</tr>
<tr>
<td>Motor/propulsor</td>
<td>4000 hp (3 MW)</td>
<td></td>
</tr>
</tbody>
</table>

- **Increased Aerodynamic Efficiency**
  - Hybrid Wing Body Concept Aircraft
    - Blended wing body (BWB) aircraft have higher aerodynamic efficiency
    - Additional 3-7% fuel burn reduction

- **Increased Propulsive Efficiency**
  - Decouple fan and engine speeds
  - Operation at optimal fan speed
  - Effective bypass ratio > 30

- **Cryogenically Cooled Superconducting Electrical System**
  - Tasked with providing aircraft propulsion and some level of differential thrust for yaw control
Possible Future Commercial Large Transport Aircraft

Hybrid Electric

Both concepts can use either non-cryogenic motors or cryogenic superconducting motors

Turbo Electric

National Aeronautics and Space Administration
Aircraft Turboelectric Propulsion

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Power Level for Electrical Propulsion System

- kW class
  - All-electric and hybrid-electric general aviation

- 1 to 2 MW class
  - Hybrid electric 50 PAX regional
  - Turboelectric distributed propulsion 100 PAX regional

- 2 to 5 MW class
  - Hybrid electric 100 PAX regional
  - Turboelectric distributed propulsion 150 PAX

- 5 to 10 MW
  - Hybrid electric 737–150 PAX
  - Turboelectric 737–150 PAX

- >10 MW
  - Turboelectric and hybrid electric distributed propulsion 300 PAX

Spinoff Technologies Benefit
More/All Electric Architectures:
- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

Today 10 Year 20 Year 30 Year 40 Year

National Aeronautics and Space Administration
The Lilium Jet consists of a rigid winged body with 12 flaps. Each one carries three electric jet engines. Depending on the flight mode, the flaps tilt from a vertical into a horizontal position. At take-off, all flaps are tilted vertical, so that the engines can lift the aircraft. Once airborne, the flaps gradually tilt into a horizontal position, leading the aircraft to accelerate. When they have reached complete horizontal position, all lift necessary to stay aloft is provided by the wings as in a conventional airplane.
Boeing 777 to electric?

- An airplane like 777-ER uses two Trent 800 series engines, each producing about 70,000 lbs of thrust. To achieve the same capability, you need electric motors each of 45MW. This is a very big motor even if it is a superconducting motor. You need to consider the cooling system weight and volume.

- Even for regional airplanes, we need about 5-10MW of power.

- If you take about 10 kW/kg (Optimistic value), still the weight of the motor would be very high value

- The power electronics would be complicated. Again, if you consider 15kW/kg and 20kW/liter (optimistic value), the weight and volume will be very large

- **Voltage**

- In the Aerospace area, the maximum dc voltage is 270V. In Boeing 787, they use +/-270VDC. Higher dc voltages are not being used because of the corona effect. With this dc voltage, the current will be of the order of several thousands of amperes. This would require busbars, not cables.

- The fuel capacity of 777 is 31,000 gallons and that of 777-200 ER is 45,000 gallons. Even with 3000 Whr/kg (lithium-air) battery, it needs 69,000 kg of batteries. What about the volume?
Electric Airline challenges

- Jet-A has lots of energy/weight: \(\sim 11,900 \text{ Watt Hours / KG}\)
- 60,200 lbs of Jet-A has 325,000,000 Watt Hours of Energy
- Today's plug-in automotive battery module (Lithium Ion): 59 Watt Hours / KG

It takes 5.5 Million pounds of batteries to reach the same energy as 60,200 lbs of Jet-A!
NASA's X-57 Electric Research Plane (Pure Electric)

With 14 electric motors turning propellers and all of them integrated into a uniquely-designed wing, NASA will test new propulsion technology using an experimental airplane now designated the X-57 and nicknamed “Maxwell.” The X-57’s electric propulsion technology is expected to significantly decrease aircraft noise, making it less annoying to the public.
Hybrid Electric Airplane

- Hybrid Propulsion (Energy is stored in Batteries and Jet Fuel)
  - Long ranges can still be flown using jet fuel
  - Shorter ranges can be flown mostly with batteries
- Average range of a 737 is only 900 NM, allowing for significant fuel savings on most missions
- Reserve fuel can be stored as jet fuel to reduce weight
- Weight of electric propulsion system is low if it drives the same fan or open rotor as the gas turbine

Zach Hoisington, Airliners with Electric Propulsion, 4th Annual CAFE Foundation Electric Aircraft Symposium, Sonoma, CA April 23, 2010
There will be an exponential growth in electrical power demands in aircraft.

More Electric Architecture and hybrid aircraft are expected to play a significant role in the future of overall airplane system design, operation, and performance.

“More Electric” is a technology enabler for power generation, energy storage, conversion systems, and other technologies.

Power electronics plays a significant role in the advancement of MEA technologies in terms of improving system efficiency, architecture, size, etc.

The main objectives are to obtain high power and volume density, high efficiency, reliability, and the ability to withstand harsh environments.

Achieving lower weight and volume are very critical in More Electric and Hybrid Electric Aircraft systems.