Planes, Trains and Stationary Power
Outline

• Product Portfolio
• Thermodynamic Cycles (Gas Turbine, Diesel, Natural Gas)
• Fuels Perspective / Renewables
Outline

• Product Portfolio
• Thermodynamic Cycles (Gas Turbine, Diesel, Natural Gas)
• Fuels Perspective / Renewables
## GE Commercial Aviation Portfolio

<table>
<thead>
<tr>
<th>Thrust Level</th>
<th>CF-34</th>
<th>CFM-56</th>
<th>CF6</th>
<th>GP7200</th>
<th>GEnx</th>
<th>GE-90</th>
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<td>10 klbs thrust</td>
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<td>~ 24,000 lbs/hr at TO</td>
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<td>20 klbs thrust</td>
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<td>100 klbs thrust</td>
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<td>110 klbs thrust</td>
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GE Transportation Product Portfolio

- Multiple configurations available (I6, I8, V12, V16)

<table>
<thead>
<tr>
<th>kW</th>
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<td>2000</td>
<td>3000</td>
<td>4000</td>
<td>6000</td>
<td>10000</td>
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</table>

1500 lbs/hr at Notch 8

- GEVO/250: 1500 – 4664 kW (2010 – 6250 bhp)
- V228: 1308 – 3052 kW (1753 – 4090 bhp)
- P616: 2750 kW (3685 bhp)
Jenbacher Product Portfolio

- Lean-burn combustion systems

<table>
<thead>
<tr>
<th>Type</th>
<th>Electrical Efficiency</th>
<th>Thermal Efficiency</th>
<th>Range (kW)</th>
<th>Horsepower (bhp)</th>
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<tbody>
<tr>
<td>Type 2</td>
<td>Up to 45%</td>
<td>Up to 50%</td>
<td>200 – 600</td>
<td>272 – 814</td>
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<tr>
<td>Type 3</td>
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<td>300 – 1000</td>
<td>394 – 1426</td>
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<tr>
<td>Type 4</td>
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<td>400 – 2000</td>
<td>560 – 1430</td>
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<td>Type 6</td>
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<td></td>
<td>1000 – 4000</td>
<td>1323 – 5399</td>
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<tr>
<td>Type 9</td>
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<td>7000 – 10000</td>
<td>9200 – 12730</td>
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</table>

Electrical Efficiency up to 45%  Thermal Efficiency up to 50%

Type 9: 8550 – 9500 kW (11457 – 12730 bhp)
Type 6: 1990 – 4029 kW (2667 – 5399 bhp)
Type 4: 634 – 1426 kW (850 – 1911 bhp)
Type 3: 418 – 1067 kW (560 – 1430 bhp)
Type 2: 294 – 335 kW (394 – 449 bhp)
Waukesha Product Portfolio

• Multiple configurations available
• Lean-burn and rich-burn combustion systems

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<thead>
<tr>
<th>kW</th>
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- **275GL™**
  - 1887 – 3605 kW (2529 – 4831 bhp)
- **VHP®**
  - 273 – 1467 kW 366 – 1978 bhp)
- **APG™**
  - 1000 – 3200 kW (1340 – 4288 bhp)
- **VGF®**
  - 119 – 880 kW (159 – 1179 bhp)
Outline

- Product Portfolio
- Ideal Cycles (Gas Turbine, Diesel, Natural Gas)
- Fuels Perspective / Renewables
Bypass Ratio = \frac{\text{Mass Flow Rate } \_ \_ \_ \text{Bypass Air}}{\text{Mass Flow Rate } \_ \_ \_ \text{Core}}
From conservation of momentum
1) Power Required to Propel Aircraft =
$$\text{mdot}(V_{\text{exit}} - V_{\text{flight}}) \times V_{\text{flight}}$$

From first law
2) Power Delivered to Exhaust Jet =
$$\text{mdot}(V_{\text{exit}}^2 - V_{\text{flight}}^2)/2$$

Efficiency is more than just thermal efficiency......Propulsive Efficiency

Target High Bypass Ratio Engines
Thrust from HIGH mdot, LOW delta V.
Big, Low pressure ratio fans
Gas Turbine Basics

Run Engines to high pressure ratios for efficiency

Run engines hot for high efficiency and power density
Gas Turbine Cycle (Brayton Cycle)

Aircraft Engine Cycle is not a Brayton Cycle but the basics still drive efficiency

- Increase Thermal Efficiency - Pressure Ratio, Temperature Ratio
- Increase Propulsive Efficiency - Bypass ratio
- Increase Component Efficiencies - LPT
- Reduce Component Cooling - HPT
Increase Propulsive Efficiency..Open Rotor

What is open Rotor?

- Means of getting ultra high bypass ratio / high propulsive efficiency
- Resembles a turboprop
- Two counter-rotating blade rows
- Acoustics is a challenge
What is Pulsed Detonation?

- Unsteady Combustion Process
- Unlike gas turbine, pressure rises across the combustor
- Traveling shock wave propagates through fuel air mixture
- Potential step change in thermodynamic efficiency

Video
Beyond Gas Turbines...Hybrid

Hybridization for Aircraft
- Concepts are being actively researched
- Gas turbine for takeoff
- Electric Motor utilization depending on range

Image (NASA/ The Boeing Company)
Outline

• Product Portfolio
• Thermodynamic Cycles (Gas Turbine, Diesel, Natural Gas)
• Fuels Perspective
Modern Diesel Cycle different from ideal cycle but...

Improved cycle efficiency comes from
- Increasing the expansion ratio. Extreme Miller Cycle, Two Stage Turbocharging
- Reducing air handling losses
- Reducing heat transfer losses

P-v Diagram for Diesel Cycle (Example)

T-s Diagram for Diesel Cycle (Example)
Hybrid Loco

recover and store wasted dynamic braking energy
save fuel & increase power

10-15% fuel savings
also...
+2,000 HP boost

Technology Highlights...
• Locomotive power management
• Battery charging & power control
• Advanced batteries: all-temp, long life
Electric Turbocompounding?

Waste Heat Recovery via mechanical means
Save fuel & increase power

5% fuel savings
also...
+500 HP boost

Technology Highlights...
• Increases total expansion downstream of engine
• Reduces thermodynamic losses that take place at exhaust valve opening
• Speed of auxiliary turbine can be regulated by load and optimized for efficiency
• Provides overall BSFC reduction
Outline

• Product Portfolio

• **Thermodynamic Cycles (Gas Turbine, Diesel, Natural Gas)**

• Fuels Perspective / Renewables
Natural Gas Engines

SI NG engine resembles an Otto cycle. Improved cycle efficiency comes from:

- Extreme Miller Cycle with High Compression Ratio and Two-Stage Charging
- Combustion optimization including Pressure Based Controls
- Waste heat recovery
Natural Gas Engines - Operability Range
Natural Gas Engines - J920 Rapid Burn Pre-Chamber Combustion

- Ultra lean rapid burn combustion
- Low NOx emissions
- High efficiency
- High stability – low sensitivity
Natural Gas Engines- Two Stage Turbocharging

- **Type 2**: PR ~ 3.5
- **Type 3**: PR ~ 4.5
- **Type 6**: PR ~ 5.1

Charging efficiency vs. time

- J 624 TSTC PR ~ 10
- J 920 PR ~ 10

Engine models and specifications.
Clean Cycle is a production waste heat recovery system

Clean Cycle™ 125 kW generator converts waste heat into electricity with no additional fuel or emissions

The Clean Cycle™ is based on an organic rankine cycle.

Similar to a steam cycle except that it uses an organic fluid in place of water.

Organic fluid allows the product to capture low-temperature heat.
Outline

- Product Portfolio
- Thermodynamic Cycles (Gas Turbine, Diesel, Natural Gas)
- **Fuels Perspective / Renewables**
Fuel Price Outlook

Up cycle continues

Oil ($/bbl)

Crude oil: Brent

N. Am. NG Disconnect

Natural Gas ($/MMBtu)

NG: Europe Border Index
NG: US Henry Hub

Widening Spreads

Normalized ($/MMBtu)

Crude Oil: WTI
NG: US H. Hub
Coal: US CAPP

With higher oil prices... look for oil substitution

Source: GE Energy, Fuel COE, May 2011
Renewable energy

- Through 2010: 5-10%* — “Tolerate to accommodate”
- 2010 to 2020: 10-20% — “Accommodate to embrace”

Source: GE Energy Analysis, EIA, DOE

* Percentage of total energy use
Hybrid Power Plant

Fuel Flex 50 Combined Cycle Power Plant
- Developed from ground up for quick load response to grid demands and renewable swings
- 61 % combined cycle efficiency

Sun Tower (E-Solar technology)
- Concentrated Solar Thermal
- Array of mirrors focus energy on tower to boil water
- Produces steam to augment combined cycle power plant

Integrated Plant announced in Turkey for 2015
Rethinking the role of gas

“Bridge Fuel”

- Role of gas temporary ‘bridge’ to low carbon economy
- US gas supply constrained
- US facing future of high import dependency

Old way of thinking

“Destination Fuel”

- Role of gas key long term solution to achieving a low carbon economy
- US gas supply abundant
- US facing a more secure energy future

New way of thinking
Summary

GE provides a wide range of engine technology including gas turbines, steam turbines, wind turbines, and recips.

Thermal efficiencies will continue to be driven largely by first principals (higher pressure ratios, temperature ratios, faster & leaner combustion, etc).

But, efficiencies beyond “thermal” are a large focus:
• Aircraft- Propulsive Efficiency
• Loco- hybrid systems, greater electrification
• Stationary Power Recips- Waste heat recovery
• Stationary Power (General)- Flex Efficiency

GE’s strategy regarding next generation engines / fuels is tied with renewables.
Natural Gas Engines- Fuel Flex and tailor-made solutions

- Landfill gas
- Sewage gas
- Associated petroleum gas
- Biogas
- Special gases
- Island mode
- Coal mine gas
- Cogeneration (Natural gas)
- Greenhouse applications
- Cogeneration (Natural gas)