IMPROVING ENERGY EFFICIENCY OF AUXILAIRIES

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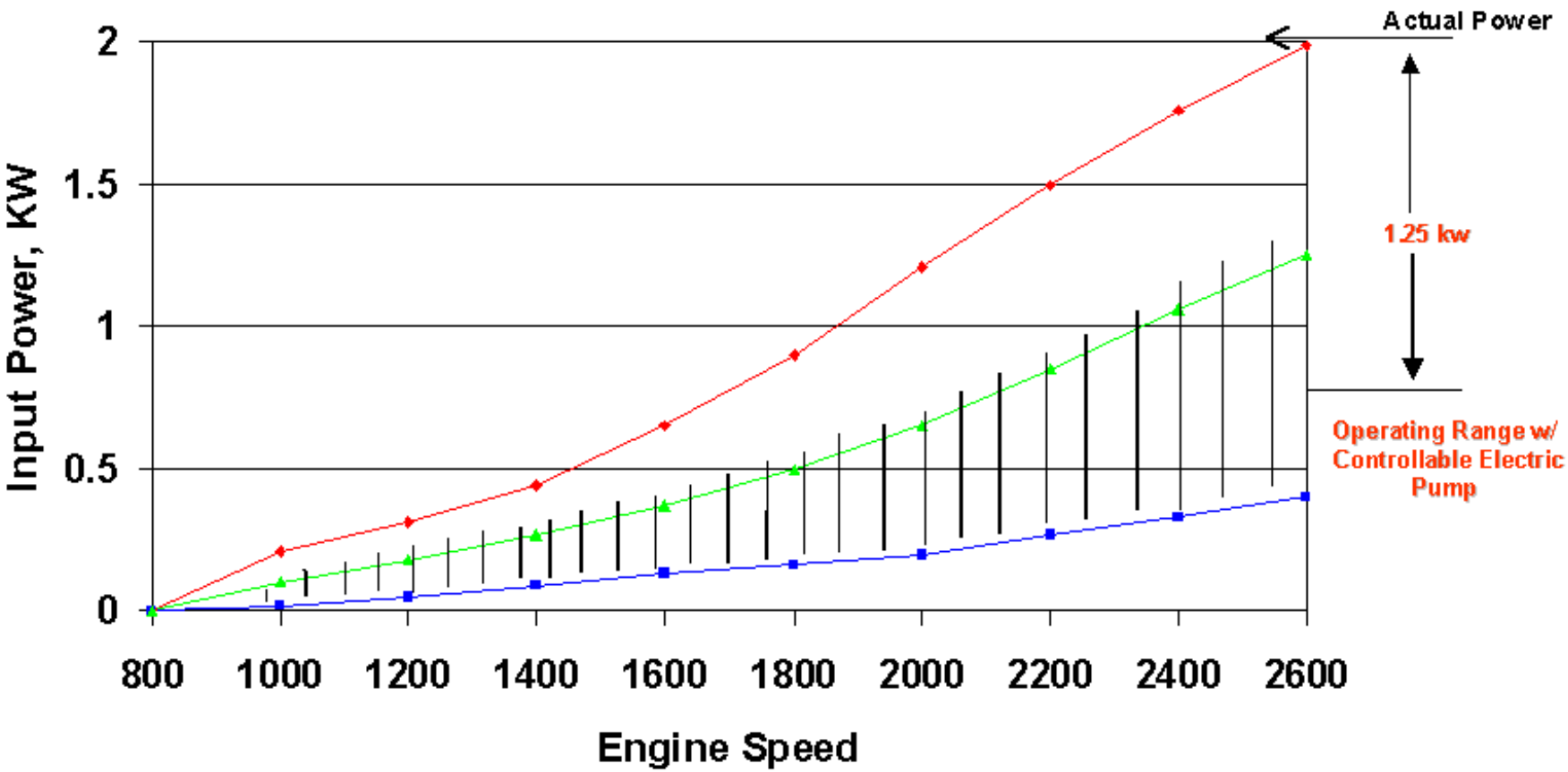
Electrically Powered Auxiliaries

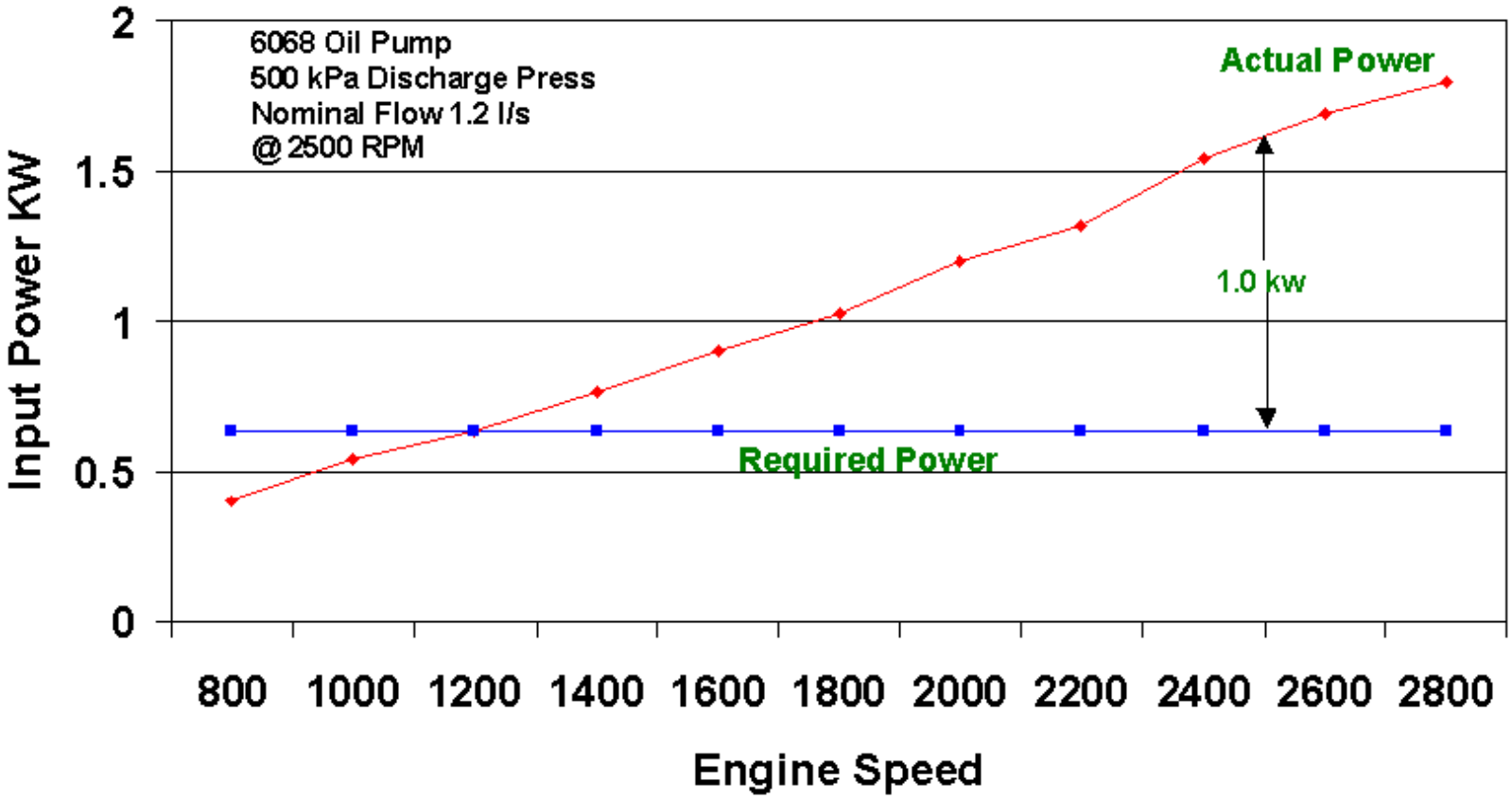
Includes: Oil Pumps, Coolant Pump, A/C, Fans, Air Compressors, and 100/220V AC

- Improved Efficiency
  - Packaging Constraints Removed by Localizing
    - Streamlined Flow
    - Pumping Losses Reduced
  - Improved Control w/Electronics
    - Speed Control Allows Press & Temp Modulation
    - On/Off Operation Eliminates Idle Losses
    - Constant Speed Pumps Can by Downsized
  - Improved Efficiency Reduces Cooling Loads

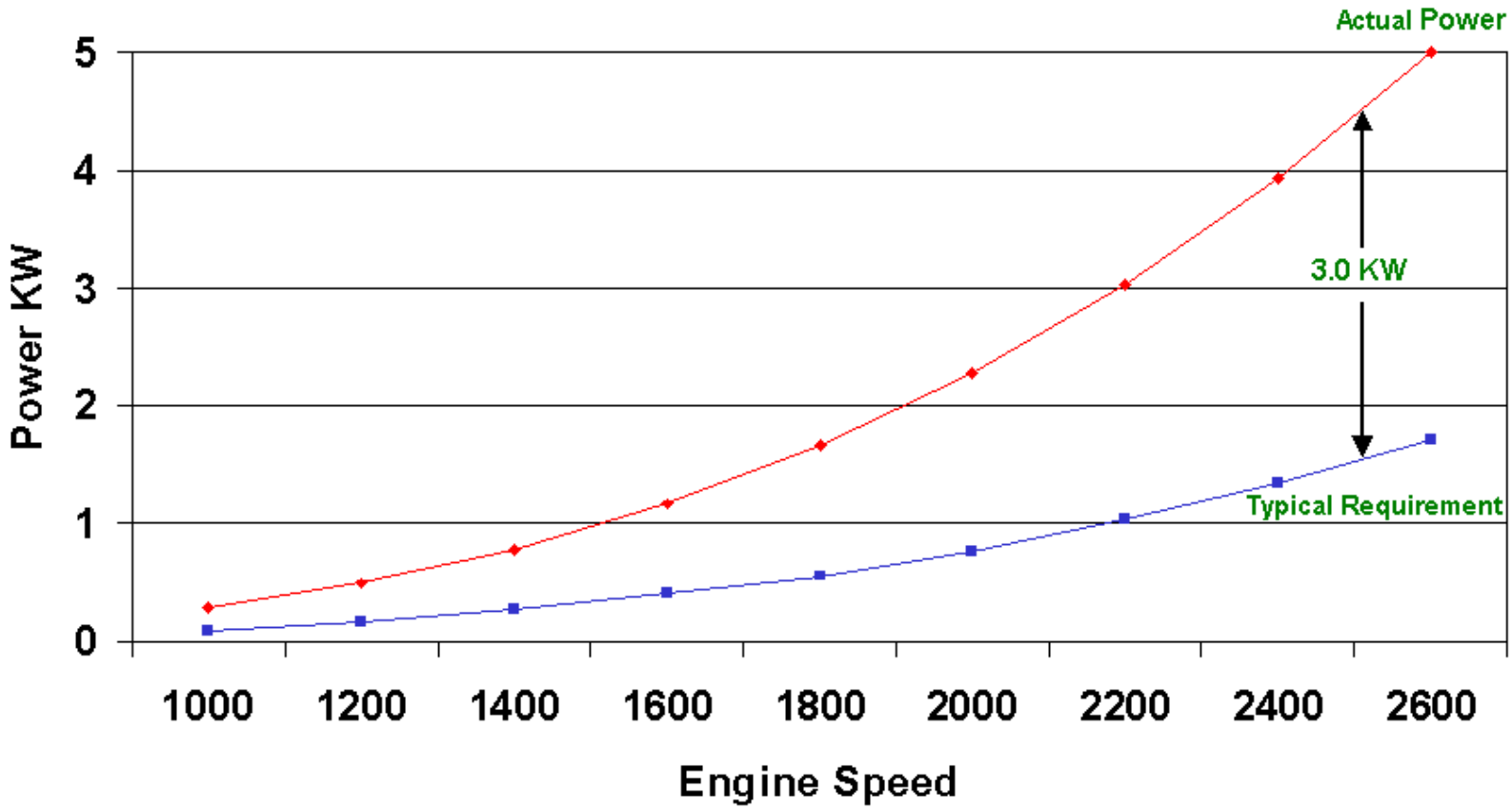
Water Pump Power Requirement



Oil Pump Power Requirement



Fan Power Requirement



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Electrically Powered Auxiliaries

- Improved Vehicle Functionality
  - Increased Cab Comfort
  - Improved Performance
  - Improved Vehicle Architecture

Generator Requirements

- High Efficiency (>85%)
- High Power Output (10 - 75 kW)
- High Voltage (42V for light loads only)
- Multiple Voltages Likely Required
- Compact Packaging
- Improved Reliability & Durability
- Fail Safe w/Backup

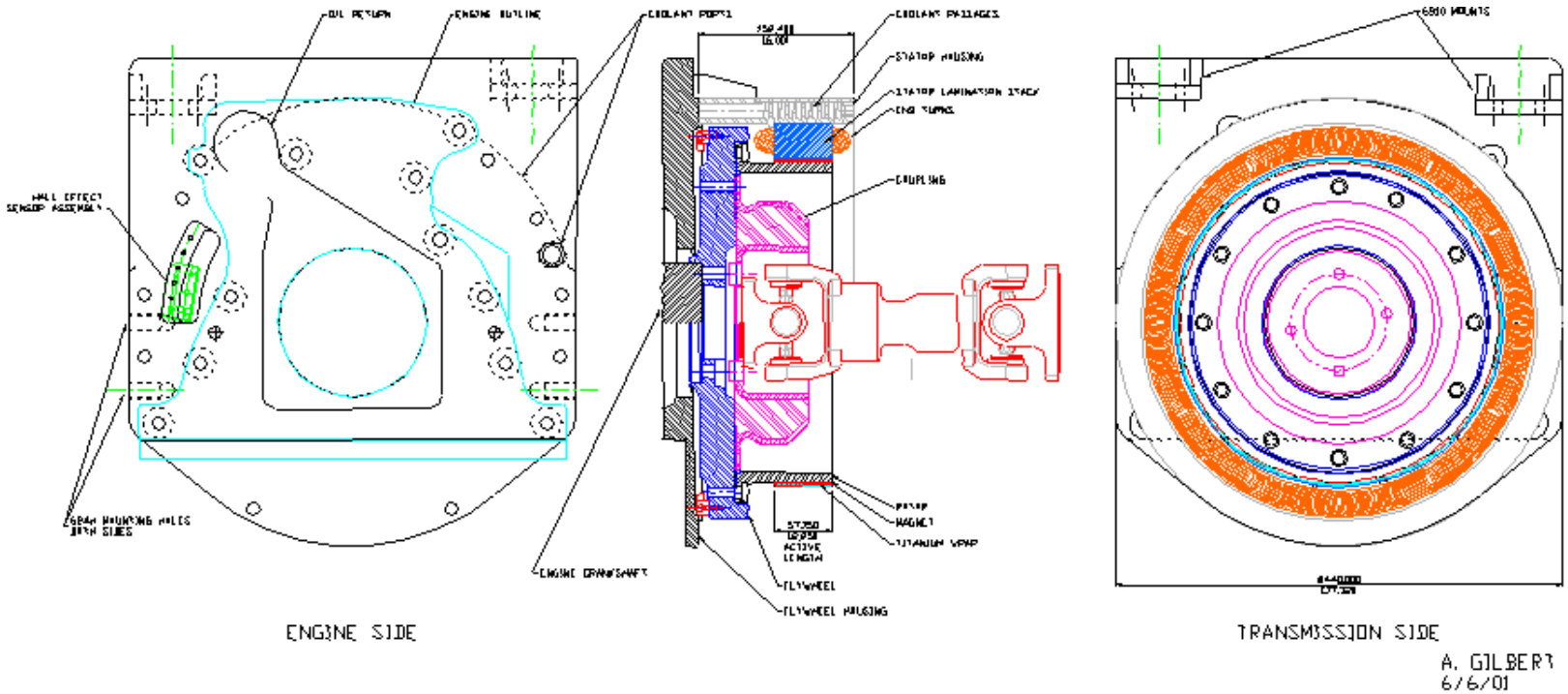
Generator Options

- Large Flywheel Mounted Motor/Generator
  - Advantages
    - 90% Efficiency Demonstrated
    - Compact Packaging
    - High Power Capacity
    - Simple Hardware w/Excellent Reliability Potential
    - Known Technology

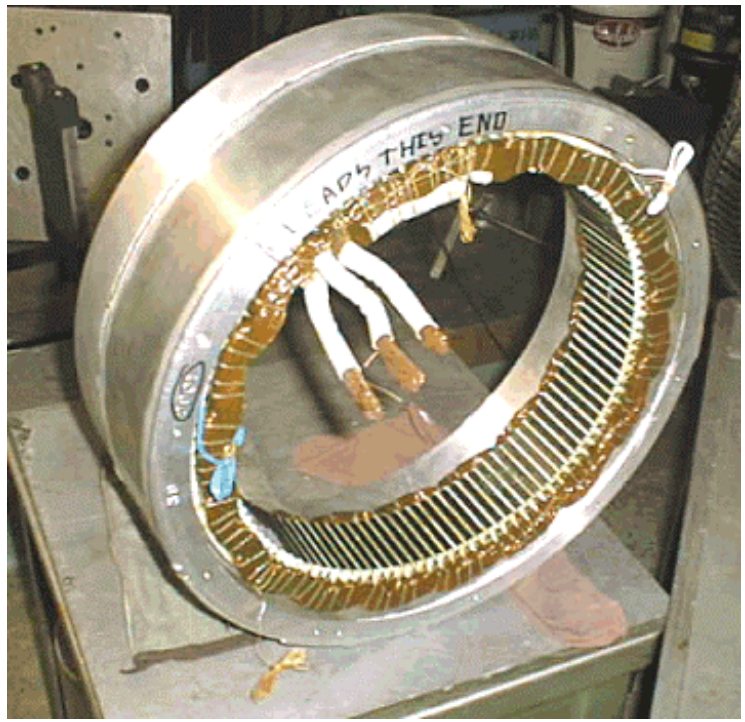
Generator Options

- Large Flywheel Mounted Motor/Generator
  - Disadvantages
    - Increased Cost (Infrastructure Needed)
    - Unique Application Specific Hardware
    - Safety Protocols Needed
    - Requires Electric Auxiliaries

System Definition: Motor/Generator



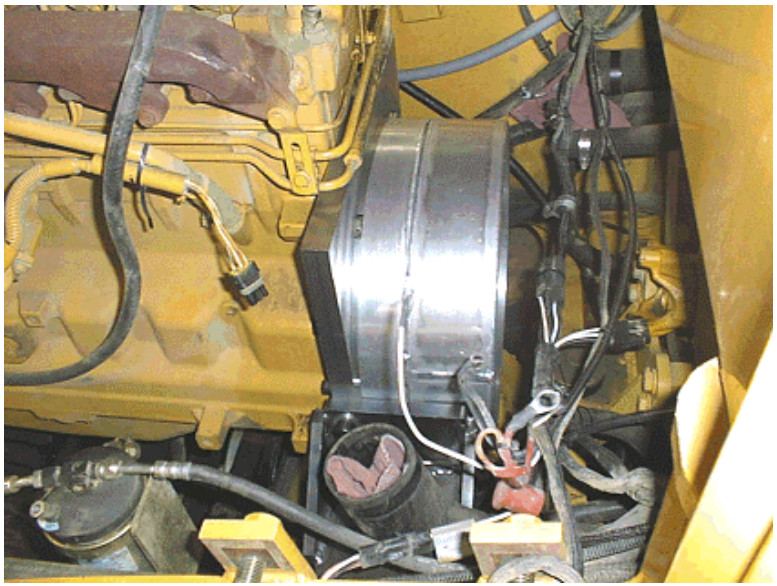
Flywheel/Coupling/Rotor Assembly

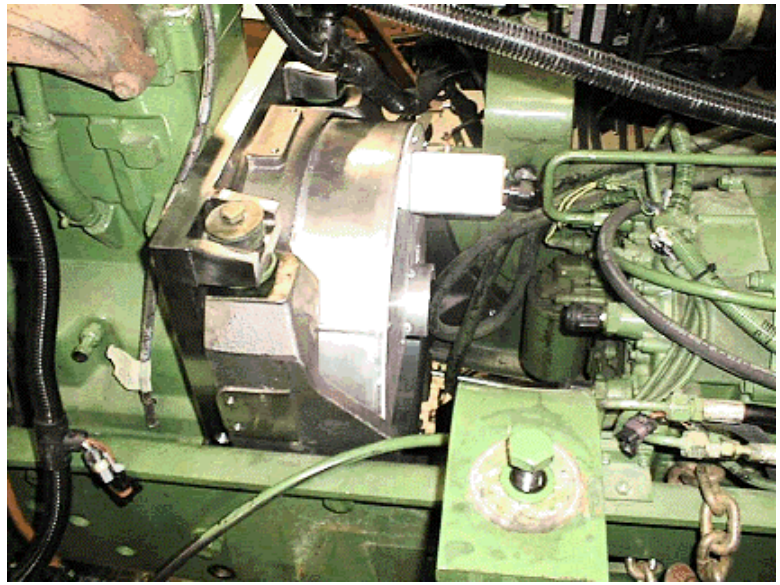


Stator and Housing Assembly

Integration into Vehicles

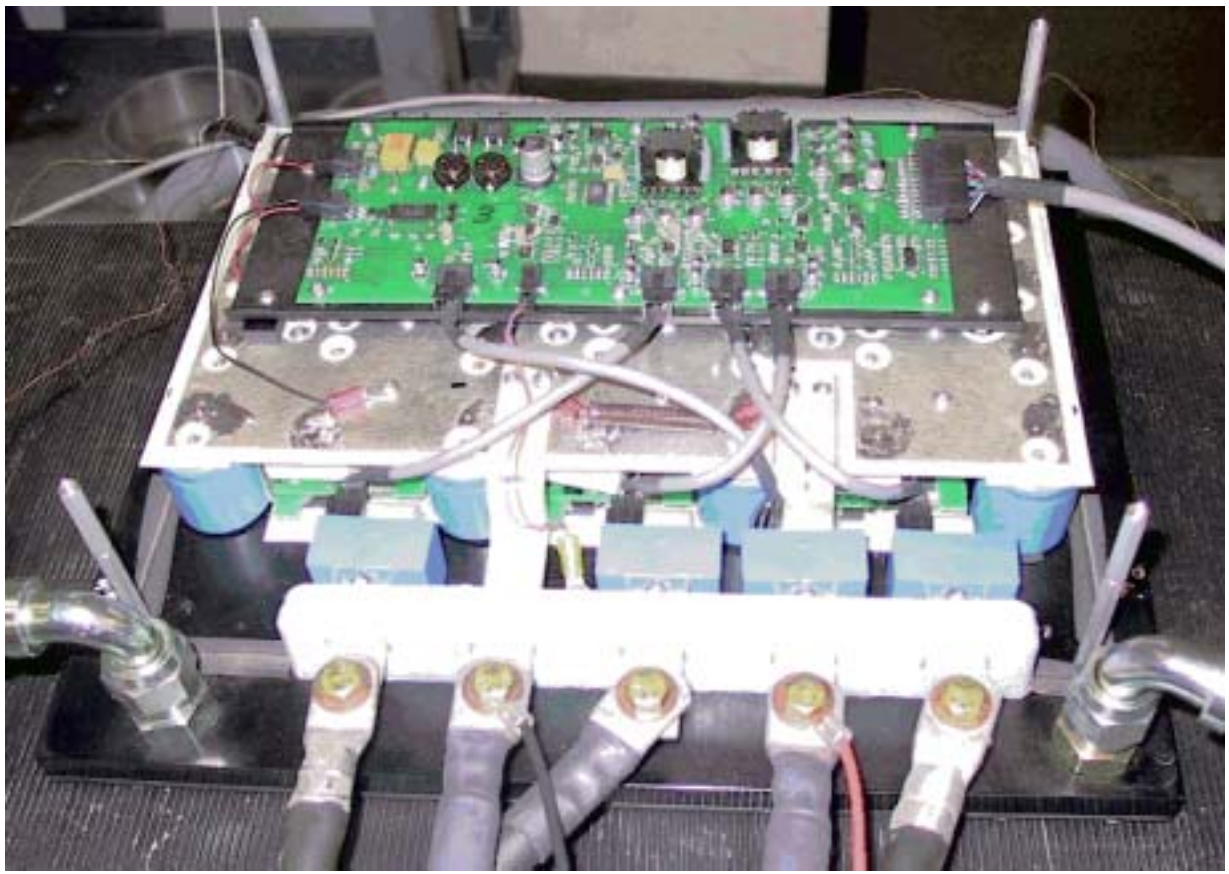
624H Loader





6910 Agricultural Tractor

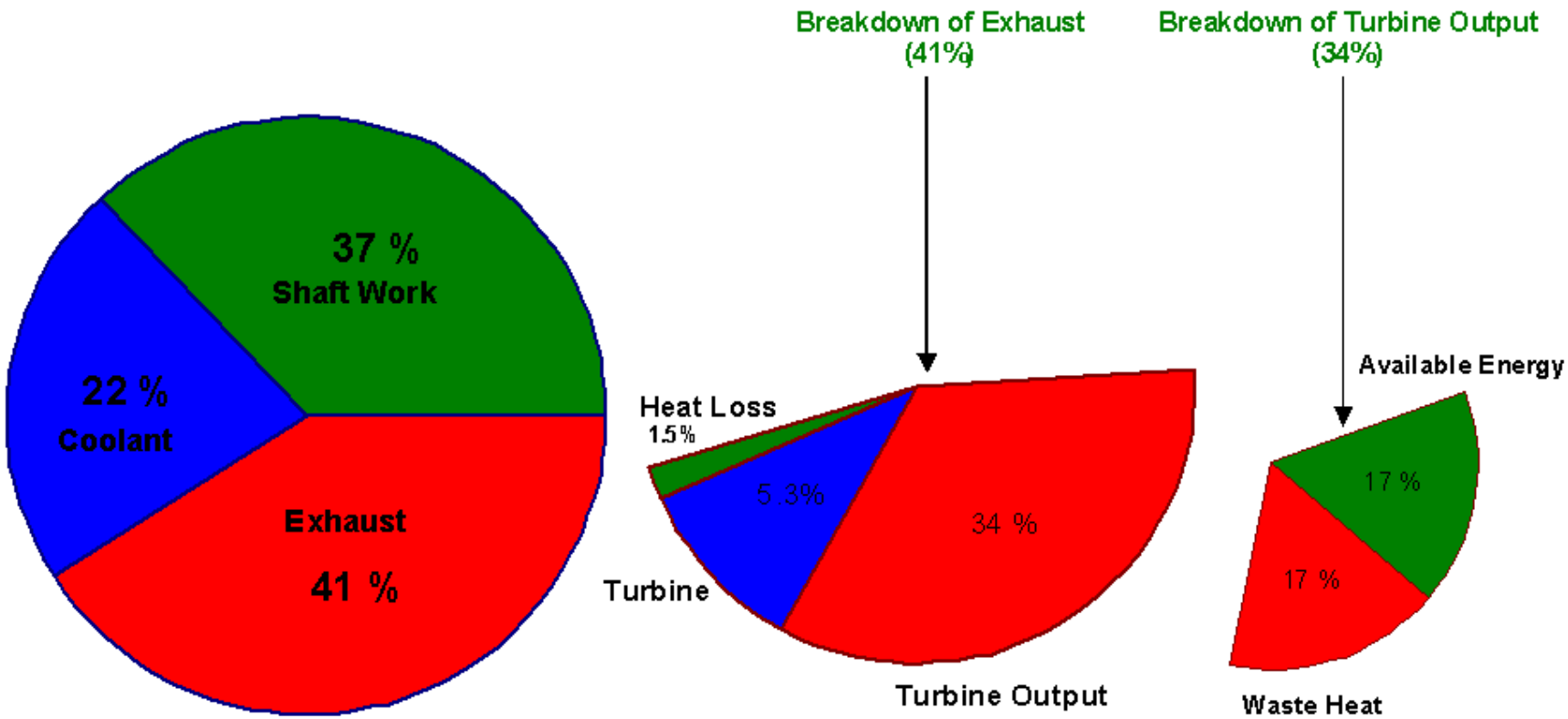
Inverter/Controller Assembly



Generator Options

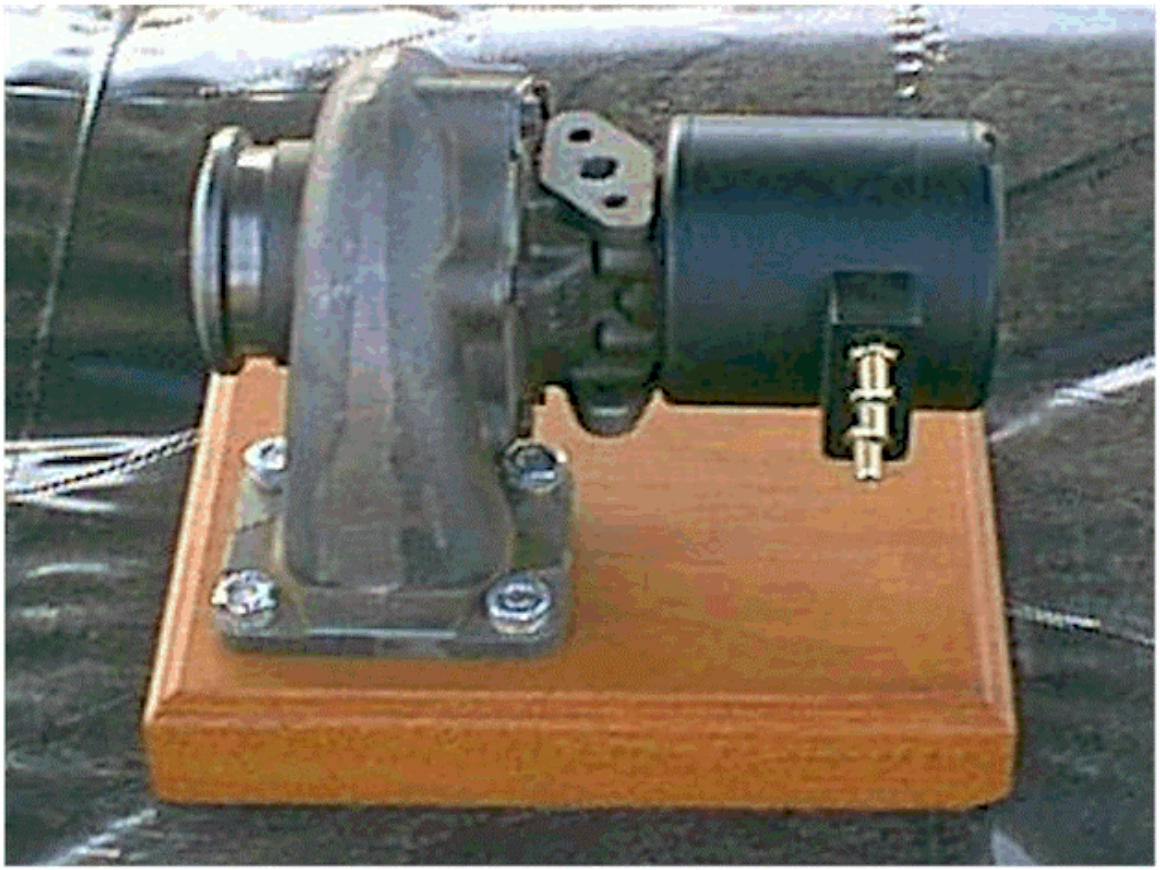
- Turbo Generation
  - Advantages
    - Provides Supplementary Power (20%) Using Waste Exhaust Heat
    - Compact Unit
    - Existing Technology
    - Could be Combined w/Combustor for Engine-Off Power and Heat
    - Excess Power Can Be Used for Propulsion

Energy Distribution



*All percentages based on Total Fuel Input Energy

Turbo Generator



Generator Options

- Turbo Generation
  - Disadvantages
    - Complex Controls
    - Significant Output only at High Engine Loads
    - Not a Stand Alone System

Generator Options

- Fuel Cell Powered APU
  - Advantages
    - Very High Efficiency
    - Low Noise
    - Engine-Off Power
  - Disadvantages
    - Increased Cost (Infrastructure Needed)
    - Complexity w/Reformer (Diesel)
    - Additional Technical Development Needed
    - Package Size
    - Safety Protocols Needed

Summary

- Economics Ultimately Dictates Direction
- Electric Auxiliaries Provide Solid Benefits. The Impact on Vehicle Architecture Will be Important
- Integrated Generators With Combined With Turbo Generators Can Meet the Electrical Demands of Electric Auxiliaries

Summary

- Implementation Will Follow Automotive 42V Transition
- Availability of Low Cost Hardware Will Slow Implementation
- Industry Leadership and Cooperation Needed
- Standards and Safety Protocols Will be Important

Summary

- Government Can Play an Important Role in Expediting
  - Funding Technical Development
  - Incentives for Improving Fuel Economy
  - Developing Standards, Allowing Economy of Scale
  - Providing Safety Guidelines