Power Generation

Shipboard Power System Fundamentals

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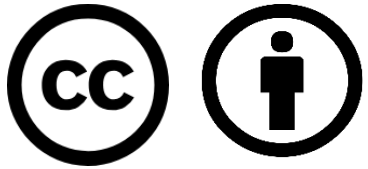
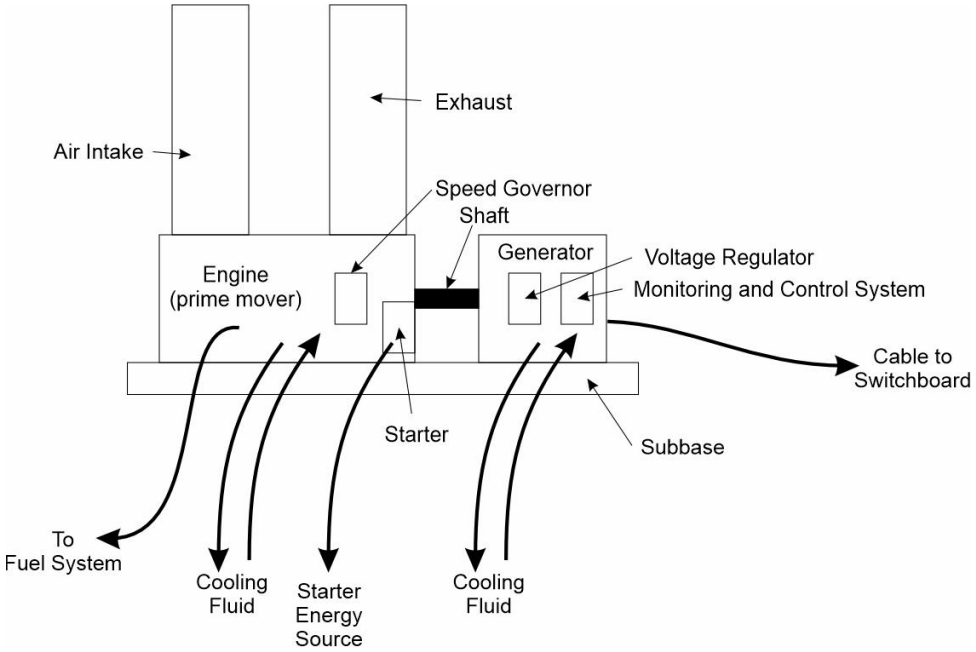


Essential Questions

What prime movers are used onboard ship and why?	Understand
What components comprise Power Generation?	Remember
What fuels do the prime movers use and why?	Understand
How is the fuel rate calculated using an sfc curve?	Apply

Introduction

- Power Generation
  - Converts energy (not of electrical origin) into electrical energy.
  - Source of energy is typically chemical in the form of “fuel”
  - Other sources of energy
    - Steam (thermal)
    - Waste heat (thermal)
    - Solar (radiation)
    - Wind (kinetic energy)
- Generator Set
  - Most common implementation of Power Generation
  - Prime mover (usually gas turbine or diesel engine)
  - Synchronous generator
  - Supporting auxiliaries and controls
- Uncommon implementations of Power Generation
  - Fuel cells
  - Photovoltaic systems
  - Waste heat systems
  - Wind turbines

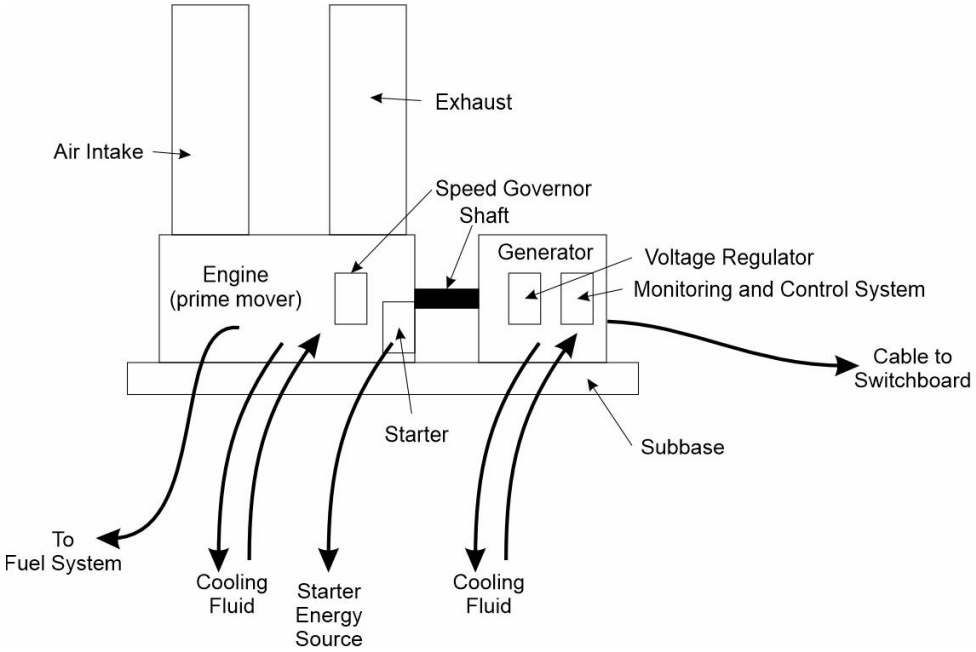


Prime Movers

- Diesel Engines
  - Tend to be large and heavy
    - Usually located low in ship
  - Good fuel efficiency
  - Often used to satisfy endurance conditions
- Gas Turbines
  - Smaller and lighter than diesel engines
    - Usually located low in ship, but may be located higher in ship.
  - Not as good fuel efficiency as diesel engines
  - May be used to achieve sustained speed conditions
    - If significantly higher power levels than endurance conditions
  - May employ reduction gear to reduce high shaft speed of gas turbine (>3000 rpm) to 1800 rpm to enable use of 4 pole synchronous generator for 60 Hz operation.

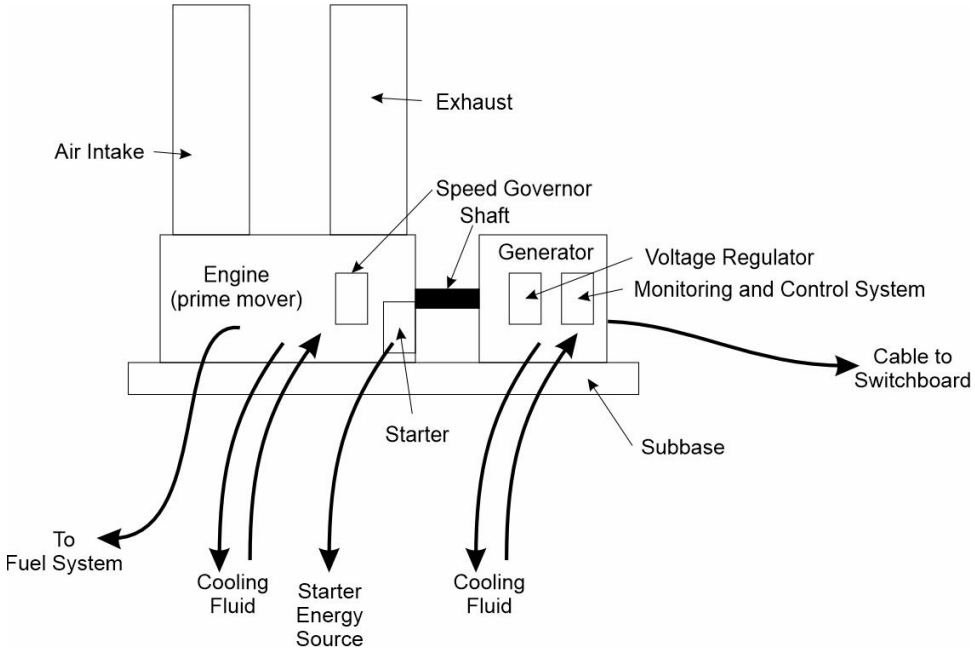
Generator Set Components

- Engine (prime mover)
  - Diesel or Gas Turbine typical.
- Synchronous generator
  - For 60 Hz output, RPM is a sub-multiple of 3600 (1800 and 1200 rpm are common).
    - May require gearbox for gas turbine
  - Higher frequency (200 to 300 Hz) output desirable for direct conversion to d.c.
- Subbase
  - Rigid structure for other components.
  - Enable construction, alignment and testing before installation.
- Voltage regulator
  - Controls excitation current in the field winding of the synchronous generator to regulate the output voltage.
- Speed governor
  - Regulates the shaft speed of the prime mover and generator by controlling the fuel rate into the prime mover.
- Starter
  - Provides the mechanical means to start the engine.
  - Example technologies include air motors and electrical motors.



Generator Set Components (Continued)

- Air Intakes and exhaust
  - Air intakes provide combustion air and cooling air.
    - Can include a cooling air fan.
  - Exhaust conveys combustion products and heated air to the exterior of the ship.
- Fuel system
  - Day / Service Tank.
  - Filters and water separators.
  - Fuel pumps.
- Cooling system
  - Engines are typically cooled by oil or fresh water (with glycol).
    - Seawater – oil or Seawater-freshwater heat exchanger transfers heat to the exterior of the ship.
  - Generators often Totally Enclosed Water – Air cooled (TEWAC).
    - Air cools the generator.
    - Seawater – air heat exchanger cools the air.
- Monitoring and Control System
  - Coordinates generator set components.
  - Communicates with external systems.
- Rectifier (d.c. output only)
  - Creates d.c. voltage for integration into d.c. power systems.

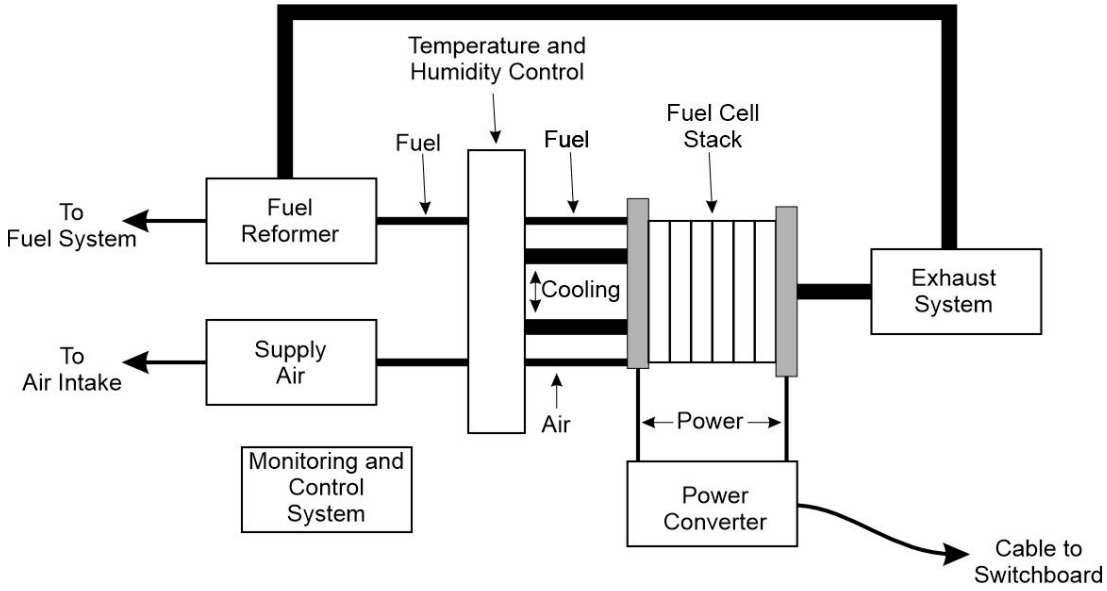


Fuel Cells

- Advantages
  - Clean exhaust – reduce or eliminate NO_X, CO_2, SO_X, and particulate emissions
  - High efficiency
  - Modularity
  - Low noise and vibration
- Disadvantages
  - Traditional fuels (F76 or MGO) cannot be directly used – must be reformed
  - Slow dynamic response to transients
    - Usually require additional energy storage to support required dynamics
  - Limited industrial base

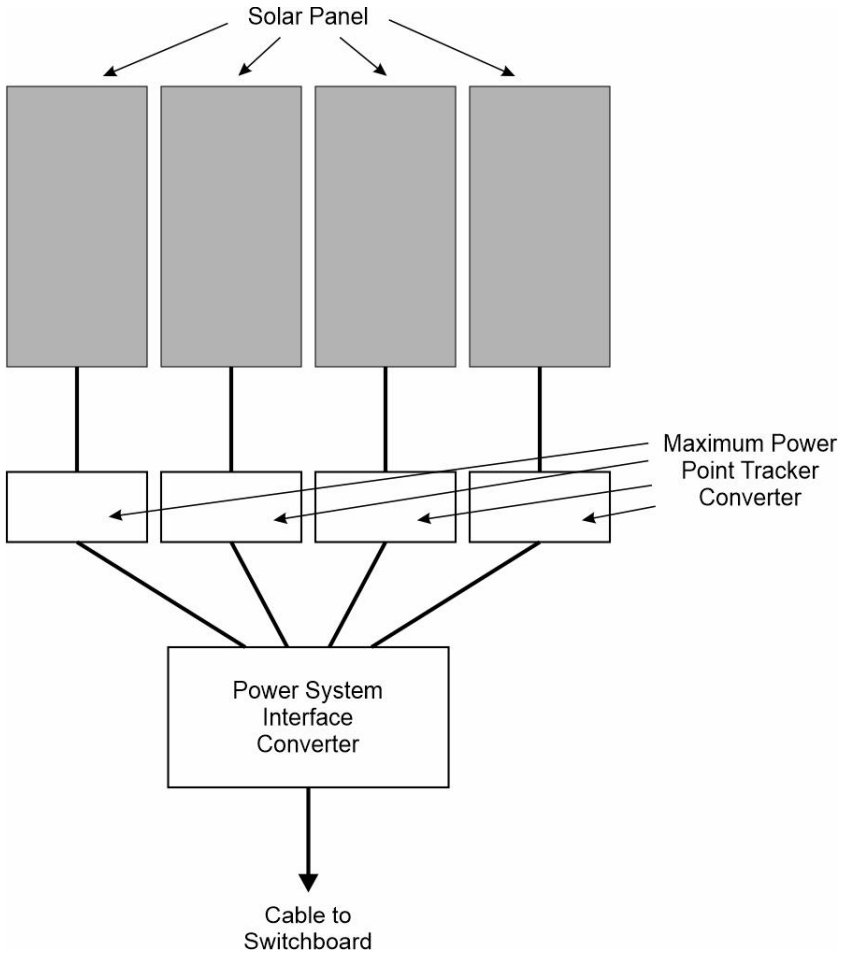
Fuel Cell Components

- Fuel cell stack
- Power converter
- Fuel reformer
- Supply air
- Temperature and humidity control
- Exhaust system
- Monitoring and control system



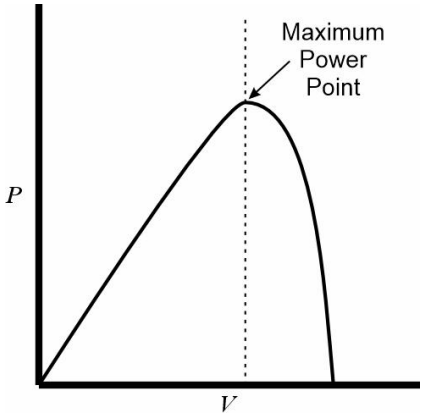
Photovoltaic Systems (Solar Panels)

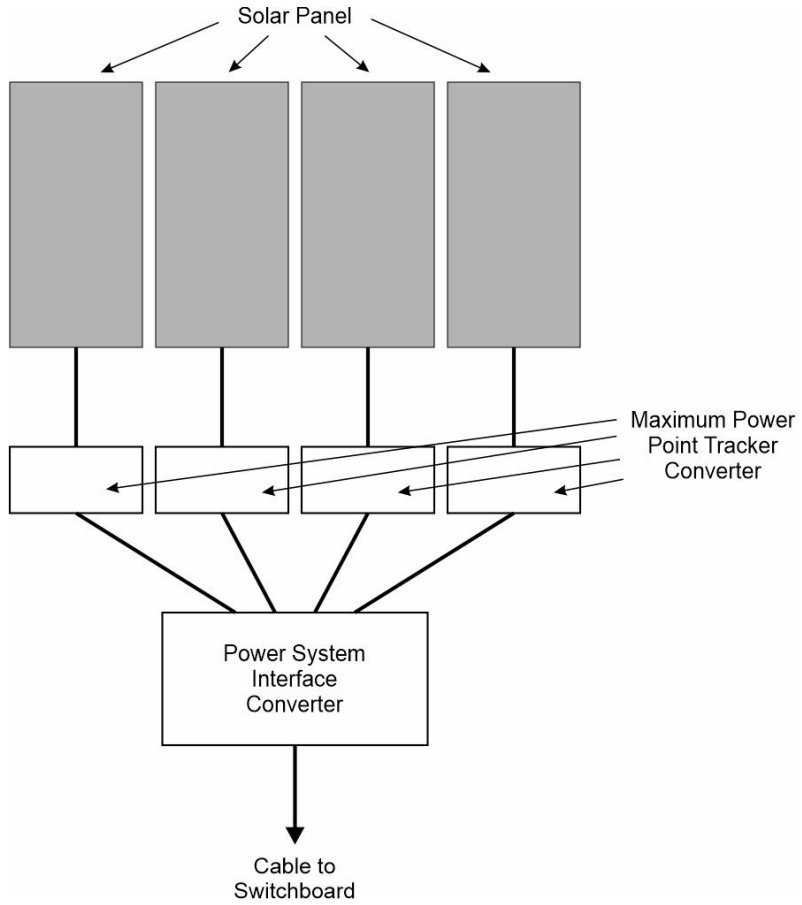
- Convert light directly into electricity
- Amount of power and energy produced is usually not large
  - Augment, rather than replace other sources of power and energy
  - Special purposes



Photovoltaic System Components

- Solar Panels
  - Typically contains a series and parallel network of solar cells.
  - Power production depends on:
    - Cleanliness of panels.
    - Intensity of light.
    - Angle between the normal angle of the panel with respect to the sun.
- Maximum Power Point Tracker Converter
  - Imposes a voltage on the solar panels to maximize the power produced.
- Power System Interface Converter
  - Converts power from the maximum power point tracker converter to the type of power needed by the power system.
  - May not be needed if the power from the maximum power point tracker converter meets the applicable interface requirements.





Fuel

- Heavy Fuel Oil (HFO)
  - Remains after crude oil refined has removed lighter components
  - High viscosity – must be preheated
  - Inexpensive
  - May require special scrubbing systems to meet environmental laws
- Distillate Fuels (MGO and F76)
  - Lower viscosity than HFO
  - More expensive
  - Easier to meet environmental laws
  - F76 (and JP5) standard fuel for U.S. Navy
- Blended Fuels (mix HFO and MGO)
  - Viscosity lower than HFO – eliminates need for preheating
- Biofuels
  - Reduces emissions of SO_X and CO_2
  - Limited shelf live (typically 1 year)
  - May require engine modifications

Fuel (Continued)

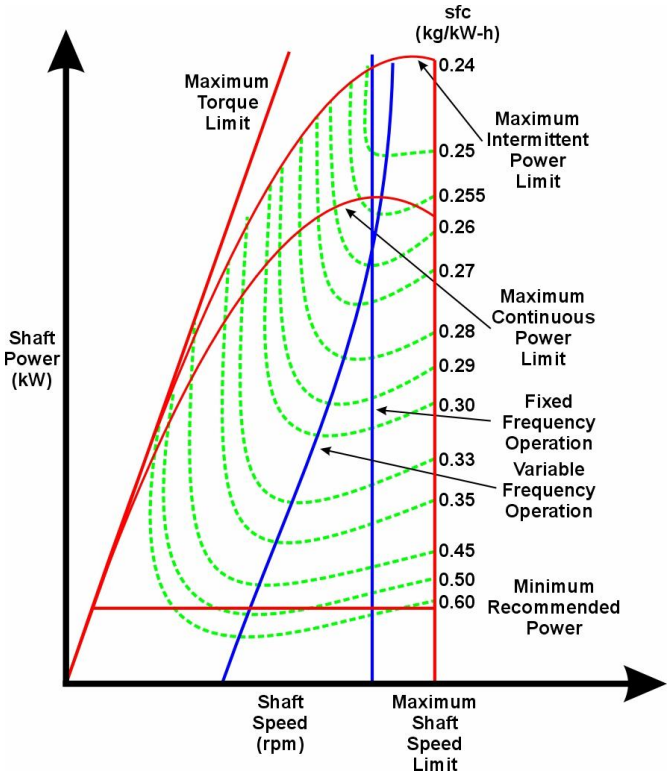
- Liquid Natural Gas (LNG)
  - Reduces emission of SO_X and CO_2
  - Requires engines designed to run on LNG
  - Requires special storage tanks
- Methanol (CH_3OH)
  - Reduces emission of SO_X and CO_2
  - Less impact to ship than LNG
  - Requires engines designed to run on methanol
  - Must address high toxicity and high flammability
- Ammonia (NH_3)
  - Eliminates emission of SO_X and CO_2
  - Requires engines designed to run on ammonia
  - Must address high toxicity and high corrosiveness

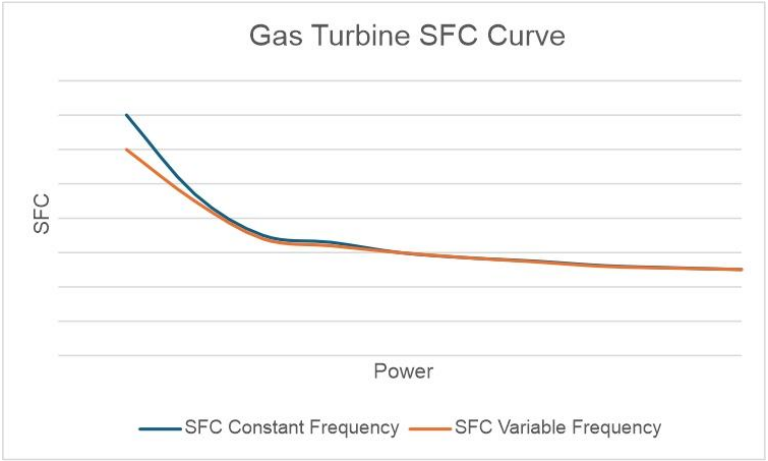
Specific Fuel Consumption (SFC) vs Fuel Rate

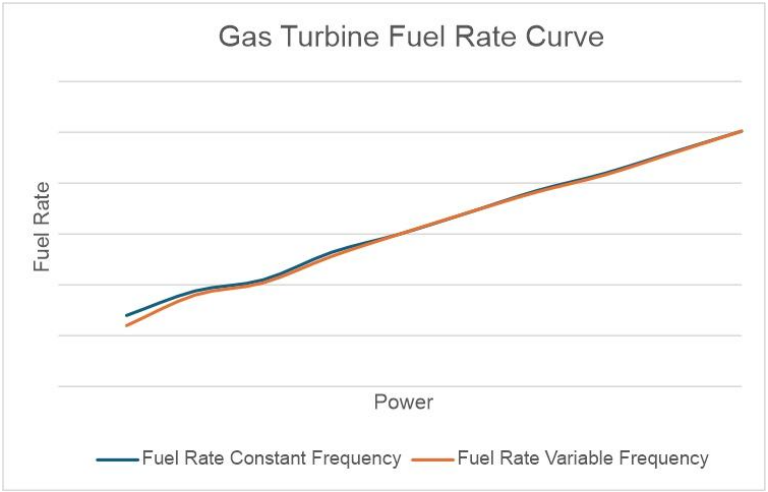
- Specific Fuel Consumption
  - Fuel Rate (kg/hr) divided by power delivered (kW)
  - Units kg/kW-hr (or lbs/HP-hr , g/kW-s, etc.)
  - Depends on fuel used and the operating point of the engine (power and shaft speed)
  - Inversely proportional to the prime mover efficiency
  - Relatively constant above about 50% Power
  - SFC often provided for engines at a few data points
  - Tends to infinity as one approaches idle power
    - Idle fuel rate divided by 0 output power.
    - SFC generally not good for directly modeling fuel rates at low power levels.
- Fuel Rates
  - For many engines, the fuel rate as a function of power delivered is nearly linear (with a y-intercept equal to the idle fuel rate)
  - For given data points, better to interpolate based on fuel rate rather than SFC
    - Usually have to convert SFC to a Fuel Rate, then perform linear interpolation

Gas turbine engine map - sfc curve – fuel rate curve

- If an engine map is available, plot the load line (shaft power vs shaft speed) on the engine map and interpolate sfc from iso-sfc line to produce sfc vs power curve.
- Convert the sfc vs power curve to a fuel rate vs power curve.







Diesel engine map – sfc curve – fuel rate curve