1. Combustion Engine Power Plants

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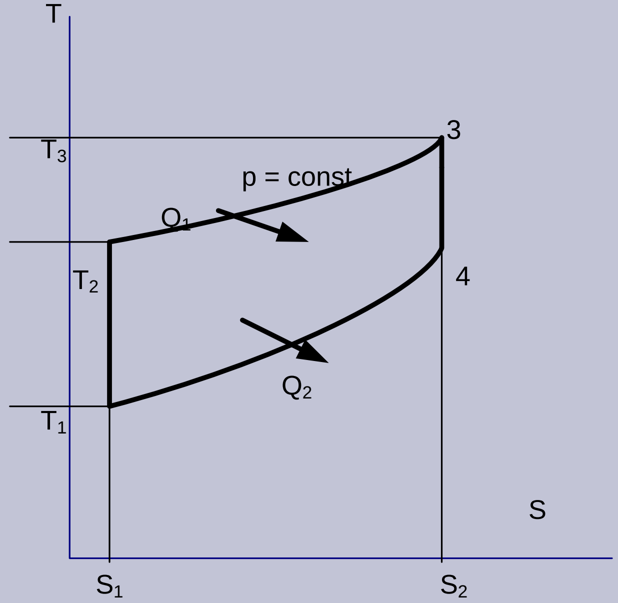
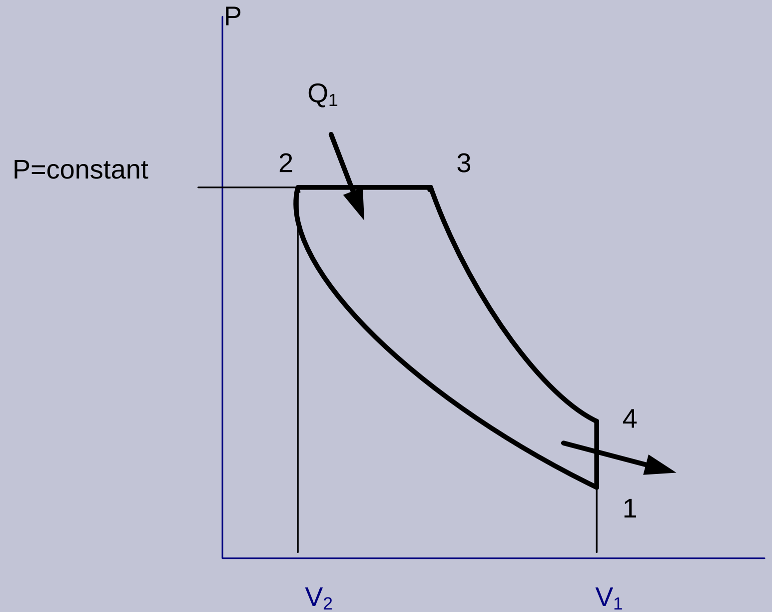
Engine cycles

- Diesel Cycle
- Otto Cycle
- Combined Cycles

Diesel Cycle



T-S Diagram

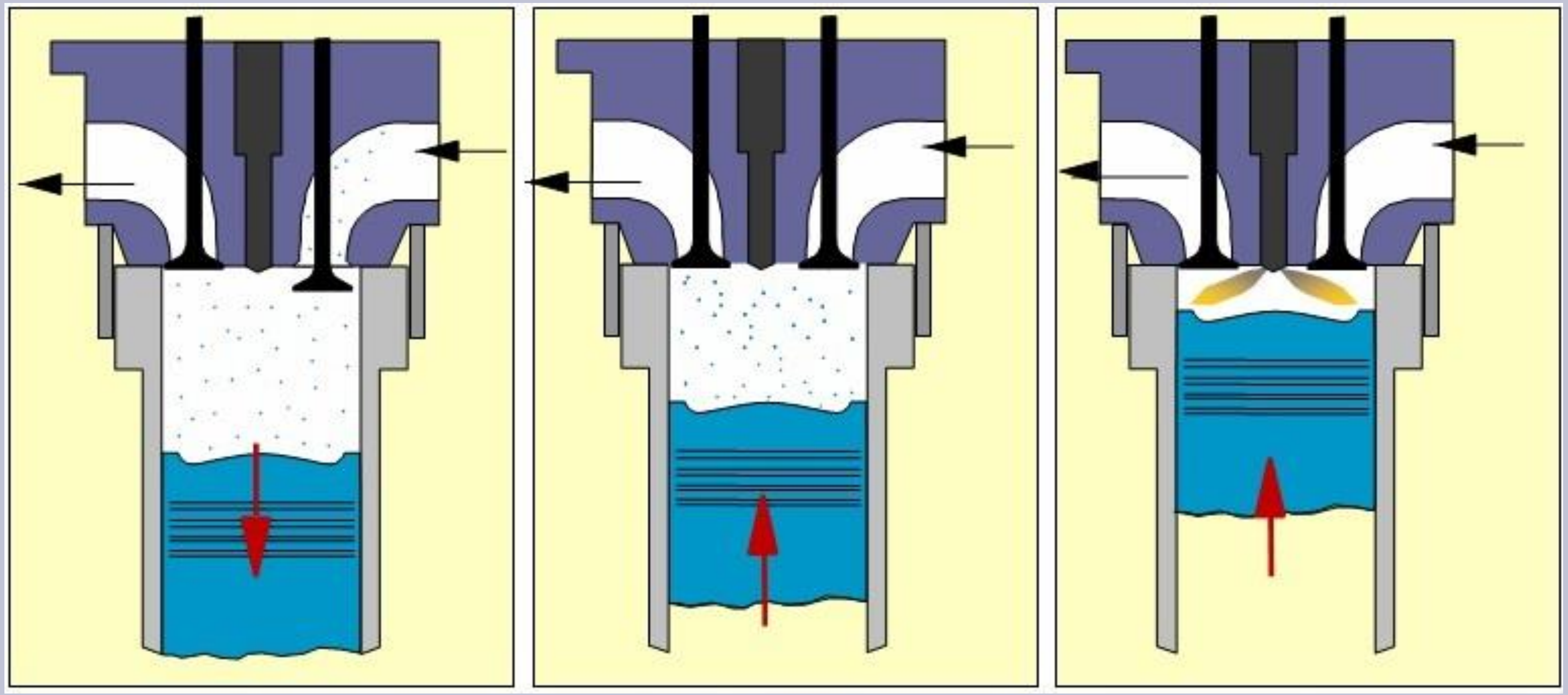


P-V Diagram

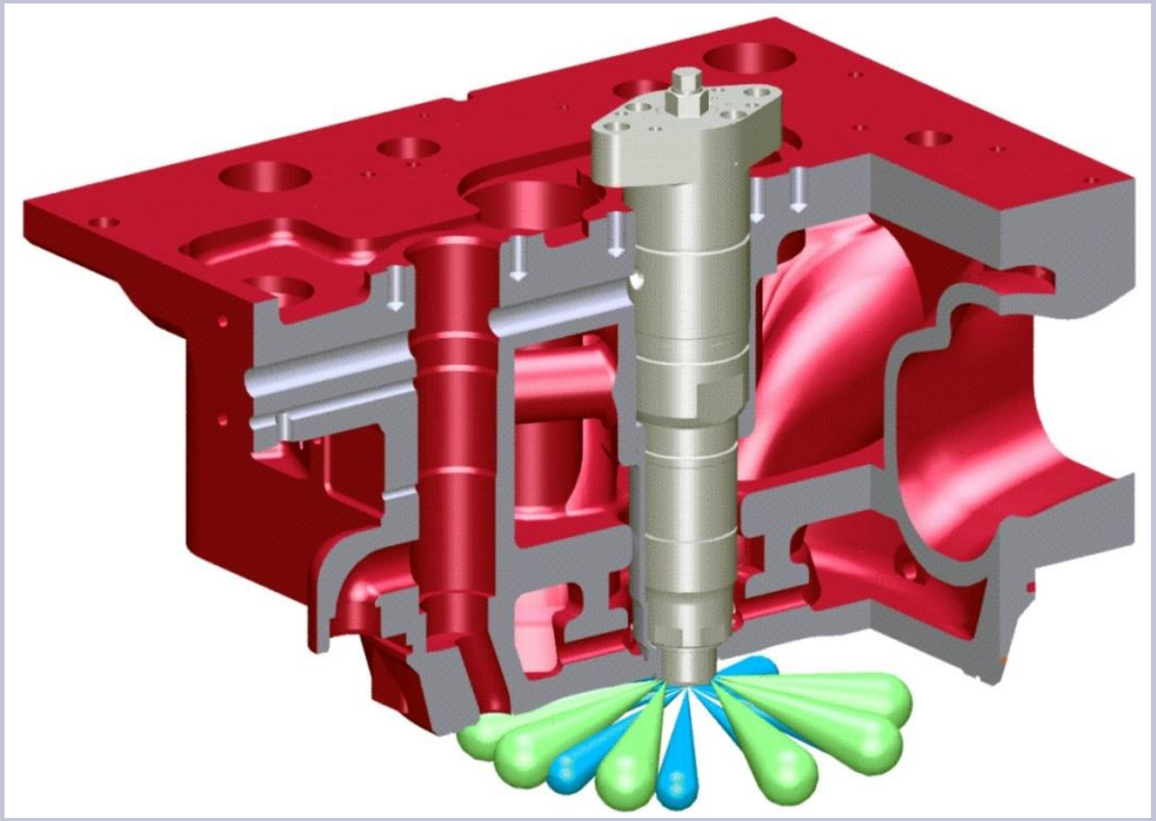
Diesel Cycle, continued

- Rudolf Diesel outlined Diesel engine in 1892 in his patent
- Heat is added at constant pressure and discharged at constant volume
- Ignition happens by self ignition by injecting fuel at top dead center
- Some call Diesel engines as compression ignion (CI) engines

Diesel Cycle



Gas Diesel (GD) Engine



Gas and diesel oil injected at compression stage

Demonstarion Gas Diesel plant in Järvenpää 1991

Wärtsilä 32 GD, 6/7 MW, Järvenpää 1991

Diesel Cycle, continued

Efficiency

$\eta = 1 – 1 /r^{k-1} (r_c^k – 1)/(k(r_c-1)$

where

r = comperssion ratio = V_2/V_1

rc = cut off ratio = V_3/V_2

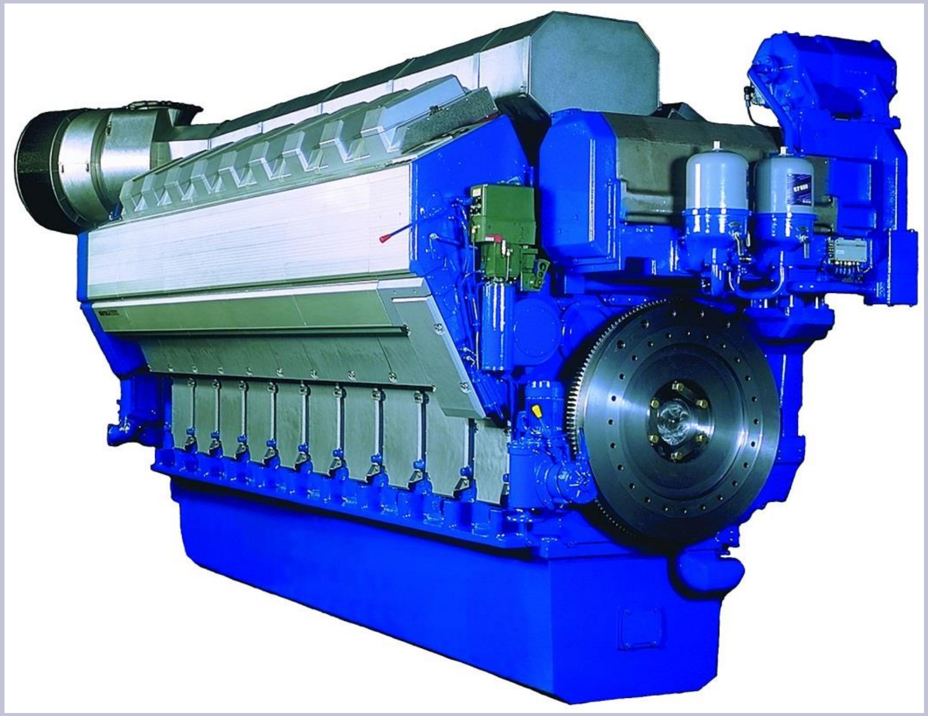
note

If r is the same, Diesel cycle has lower efficiency than Otto cycle

Diesel Cycle, continued

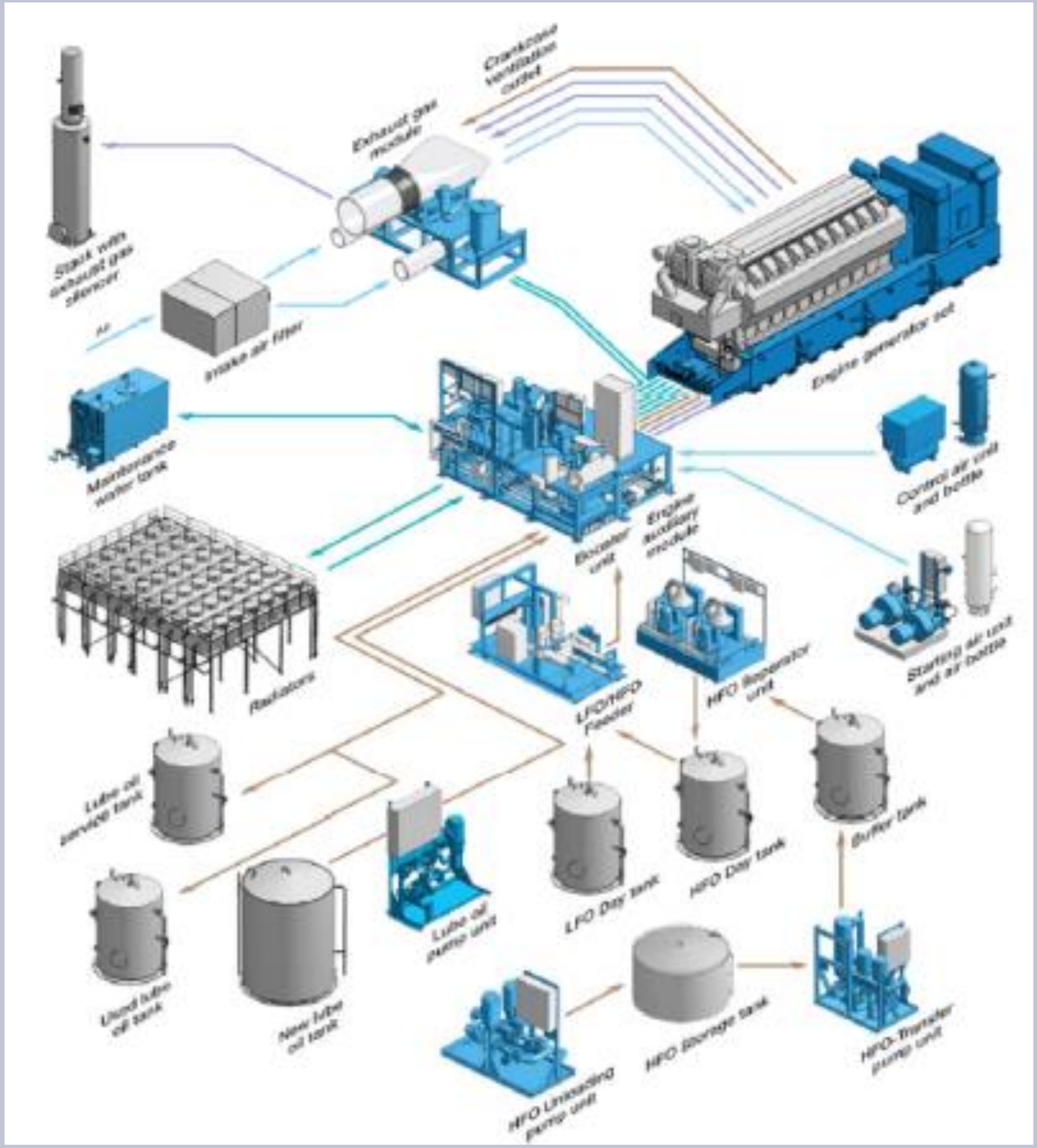
- Diesel engines are most built energy conversion machines after SI-engines
- Car industry builds about 20 million/a diesel cars and trucks (1400 GW/a)
- Ship industry about 30 GW/a (>0,5 MW unit size)
- Power plant orders are 40 GW/a (>0,5 MWe unit size, 20 % market share)

Wärtsilä Diesel Engines 32/34

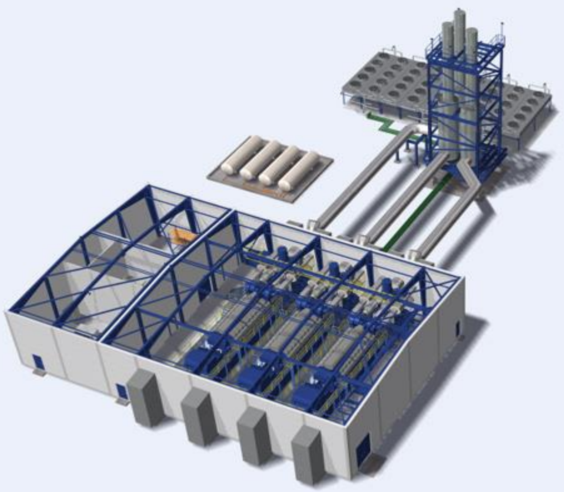


Output	2,6 -9.7 MW
Cylinders	6 – 20
Factory	Vaasa
Weight	58 – 130 t
Sold	6000 pcs
Capacity	30 GW

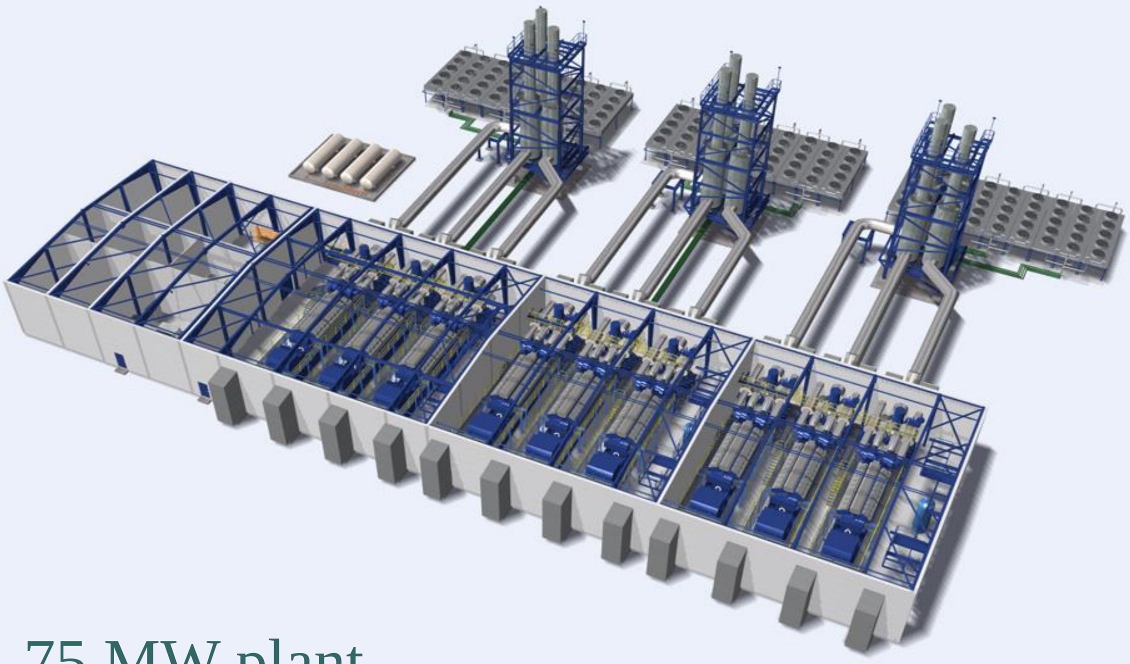
Engine Power Plant



Modular 4 x 8 MW and 12 x 8 MW Power Plants



25 MW plant

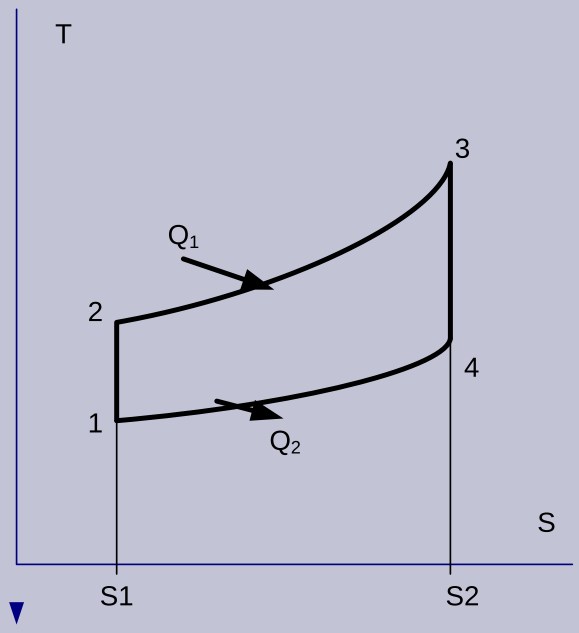


75 MW plant

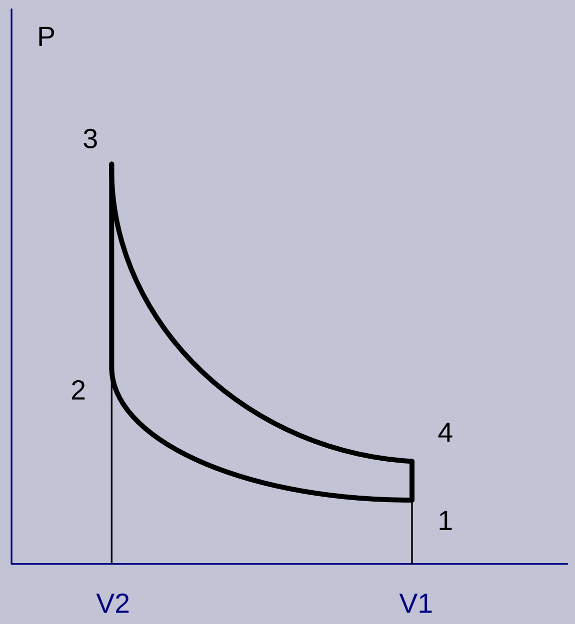
Loviisa 10 MW reserve diesel plant (Wärtsilä 2010)

Full speed in 13 s, full power in 60 s

Otto Cycle



T-S Diagram

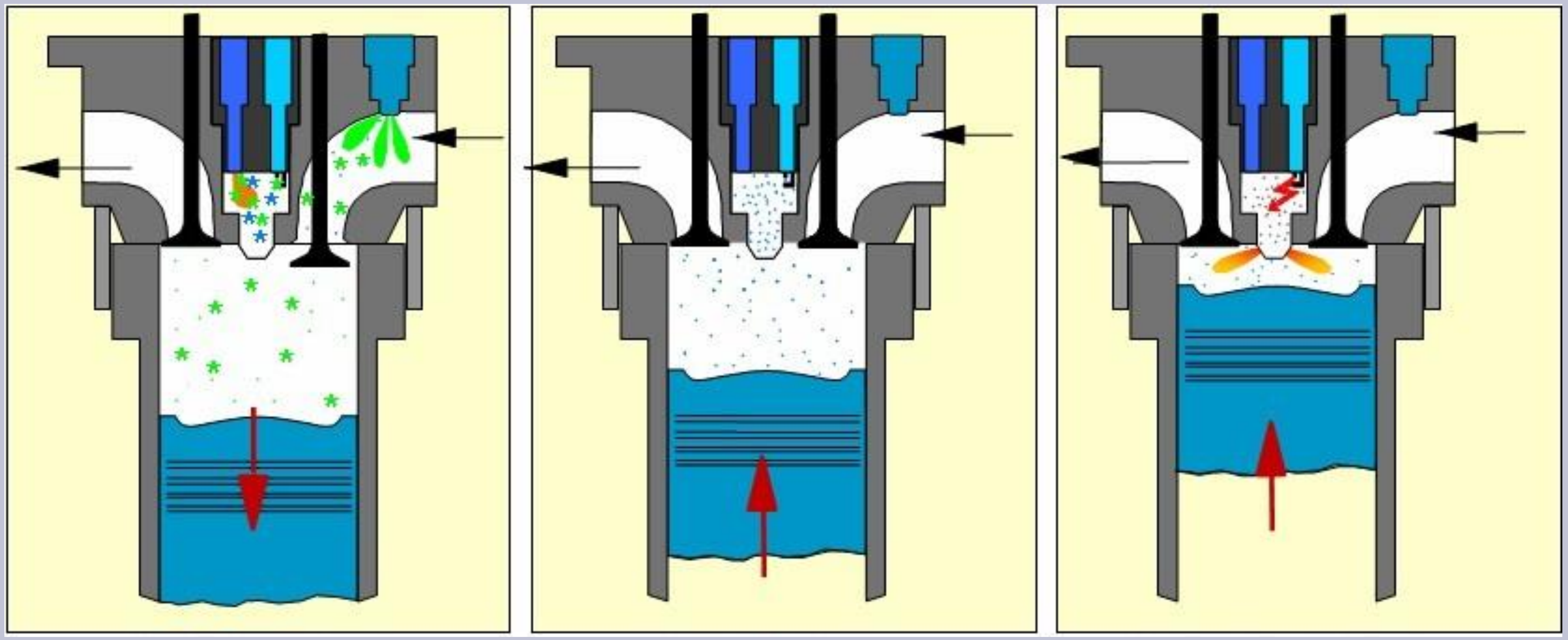


P-V Diagram

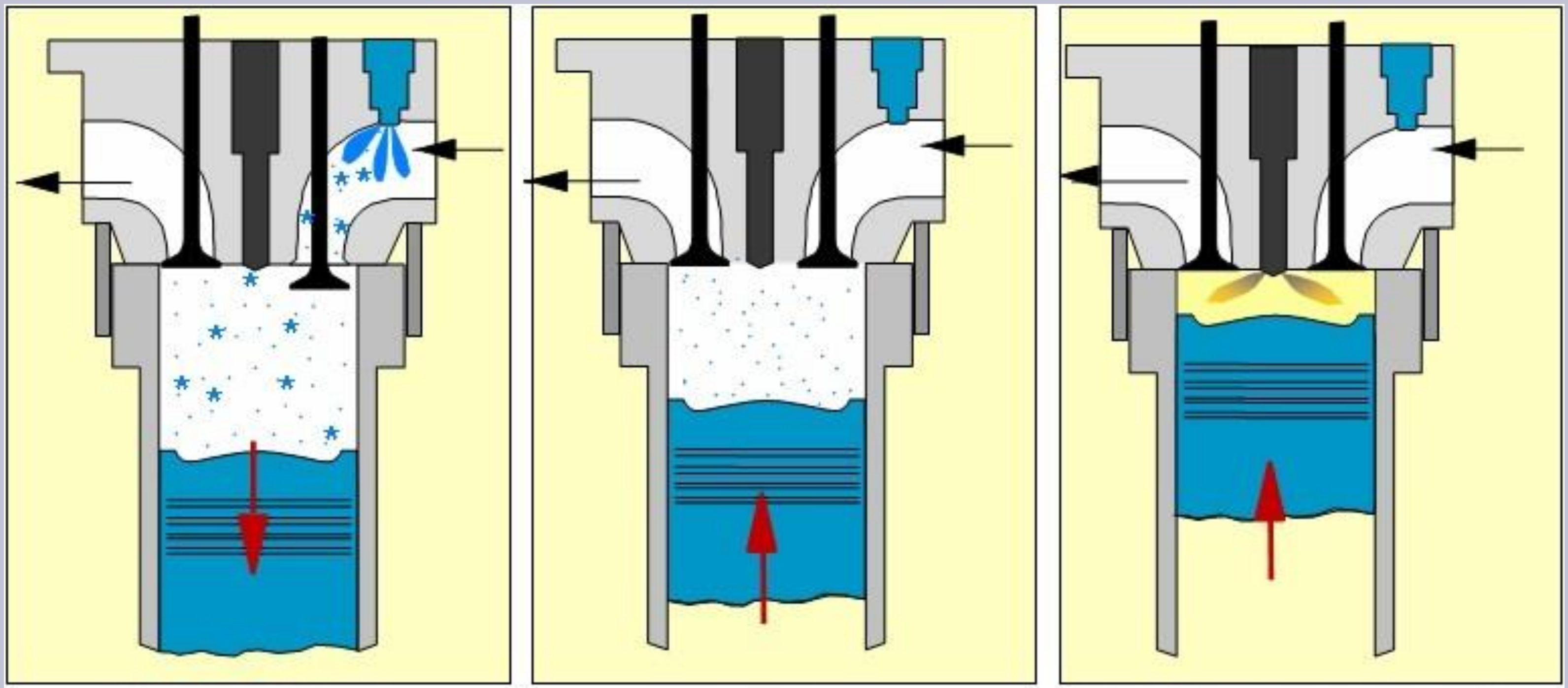
Otto Cycle, continued

- Nicolaus Otto discoverd spark ignition (SI) four stroke gas engine 1876
- Heat is added in constant volume V_1 at top dead center (TDC) by igniting gas air mixture by spark
- Heat is discharged at constant volume V_2 at botton dead center (BDC)

Otto Cycle, Spark ignition



Otto Cycle, Dual Fuel



Dual Fuel (DF) Engine

Pilot oil nozzle for gas operation
and
Diesel nozzle for oil operation

Otto Cycle, continued

Efficiency of Otto Engine

$$\eta = 1 - 1/\, r^{\,k-1}$$

where

r = compression ratio= V_2/V_1

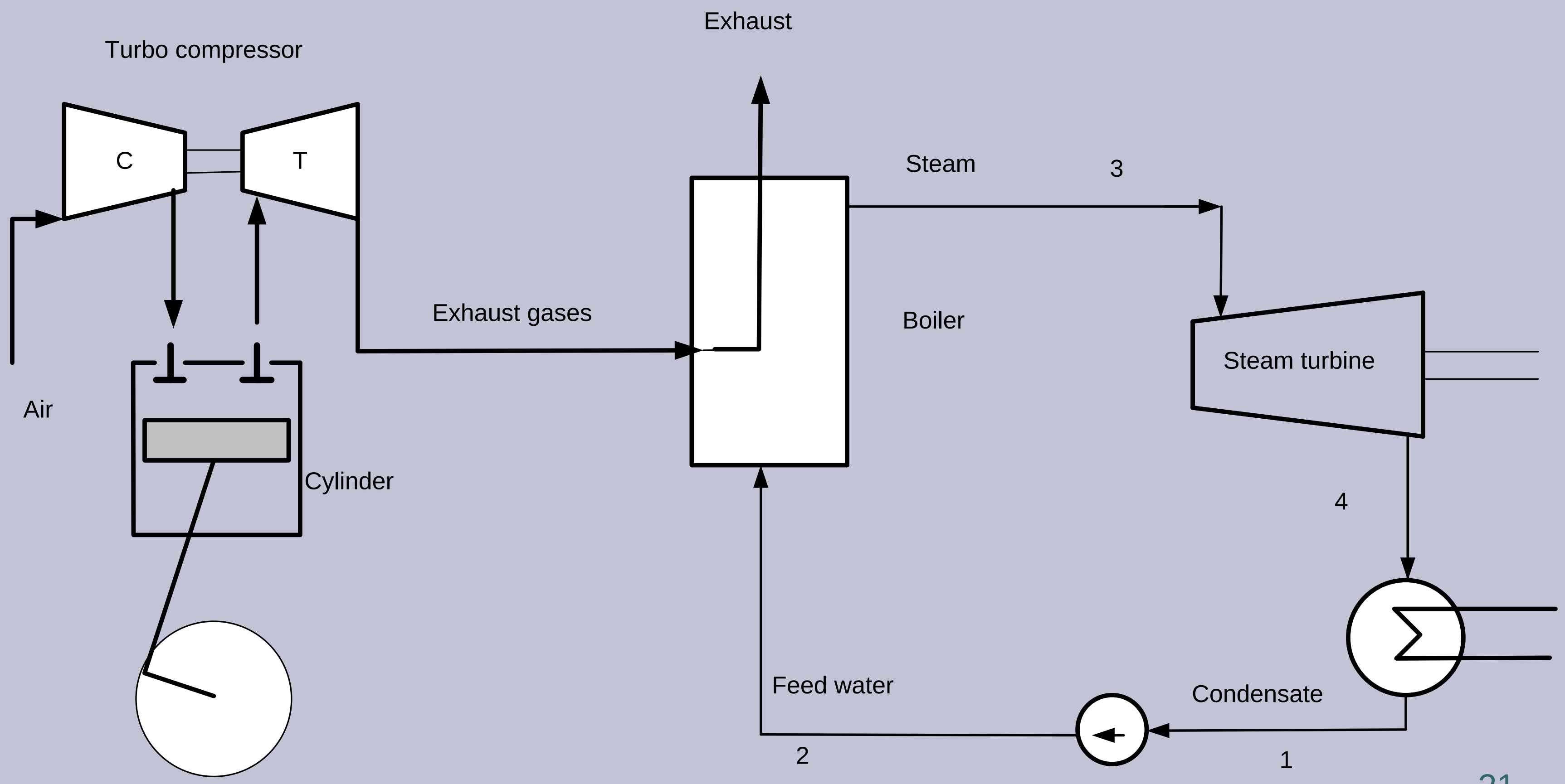
k= gas constant

Otto Cycle, continued

- Spark ignition (SI) engines are most built engines in the world
- About 50 million engines/a for cars (2000 GW/a)
- About 4000 engines/a for power plants (6 GW/a)

IC Engine Combined Cycle

IC- ENGINE COMBINED CYCLE



IC Engine Combined Cycle (ECC)

- Combines a Internal Combustion Engine (Diesel or Otto cycle) and steam turbine (Rankine Cycle)
- About 90 % of power is generated in the engine and 10 % in steam turbine
- Efficiency of ECC plant is typically 1.1 times the efficiency of the single cycle IC engine plant

160 MW Diesel Combined Cycle Plant in Pakistan

Diesel Eng. 9 x 17 MW
Steam Turbine 12 MW
Total 160 MW
Efficiency 46 %

Electrical efficiency

Efficiency $\eta = (P - P_{aux})/Q \times K_t \times K_l$

where

P = electrical output

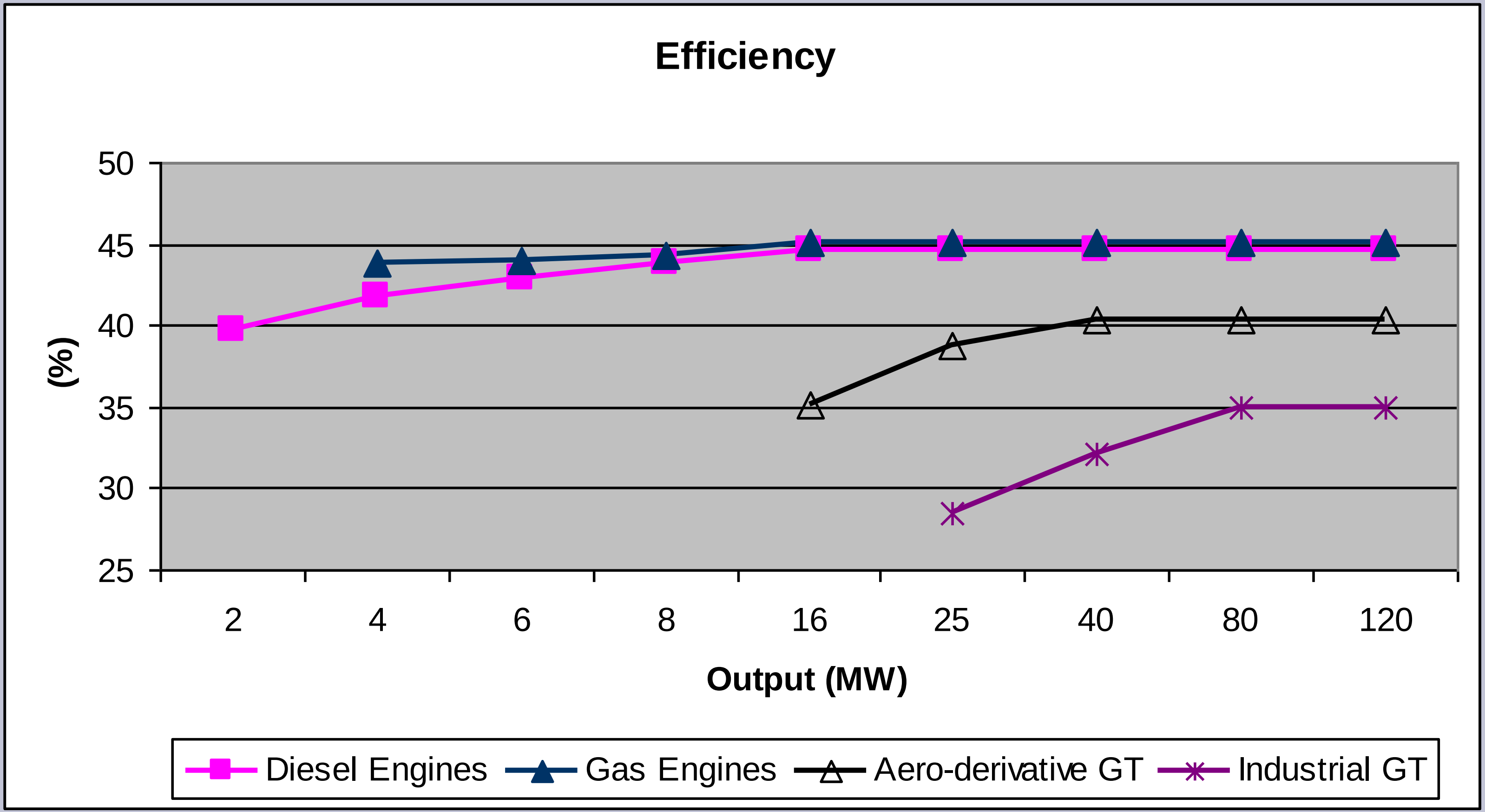
P_{aux} = auxiliary power consumption

Q = heat output

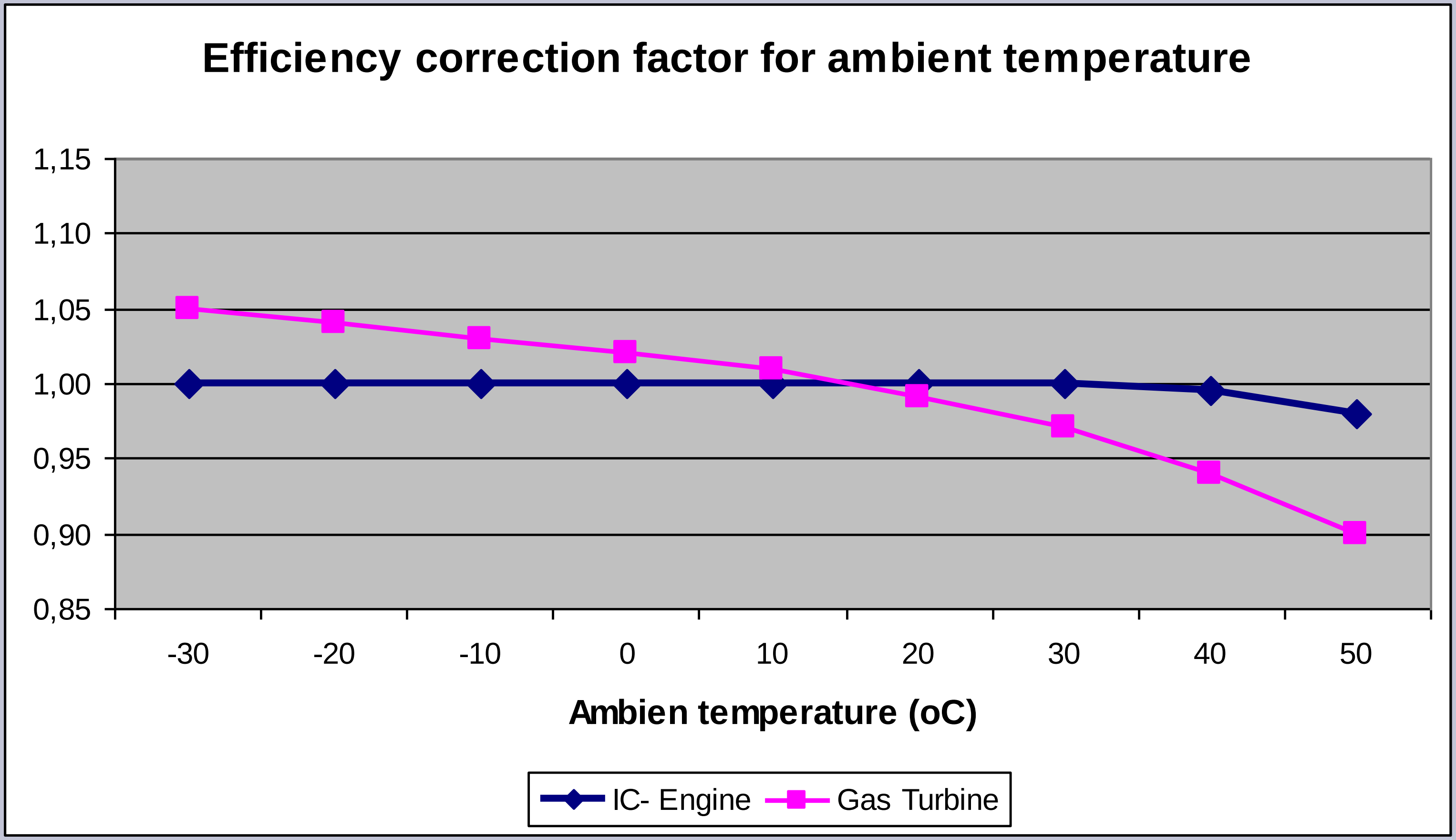
K_t = temperature correction factor

K_l = part load correction factor

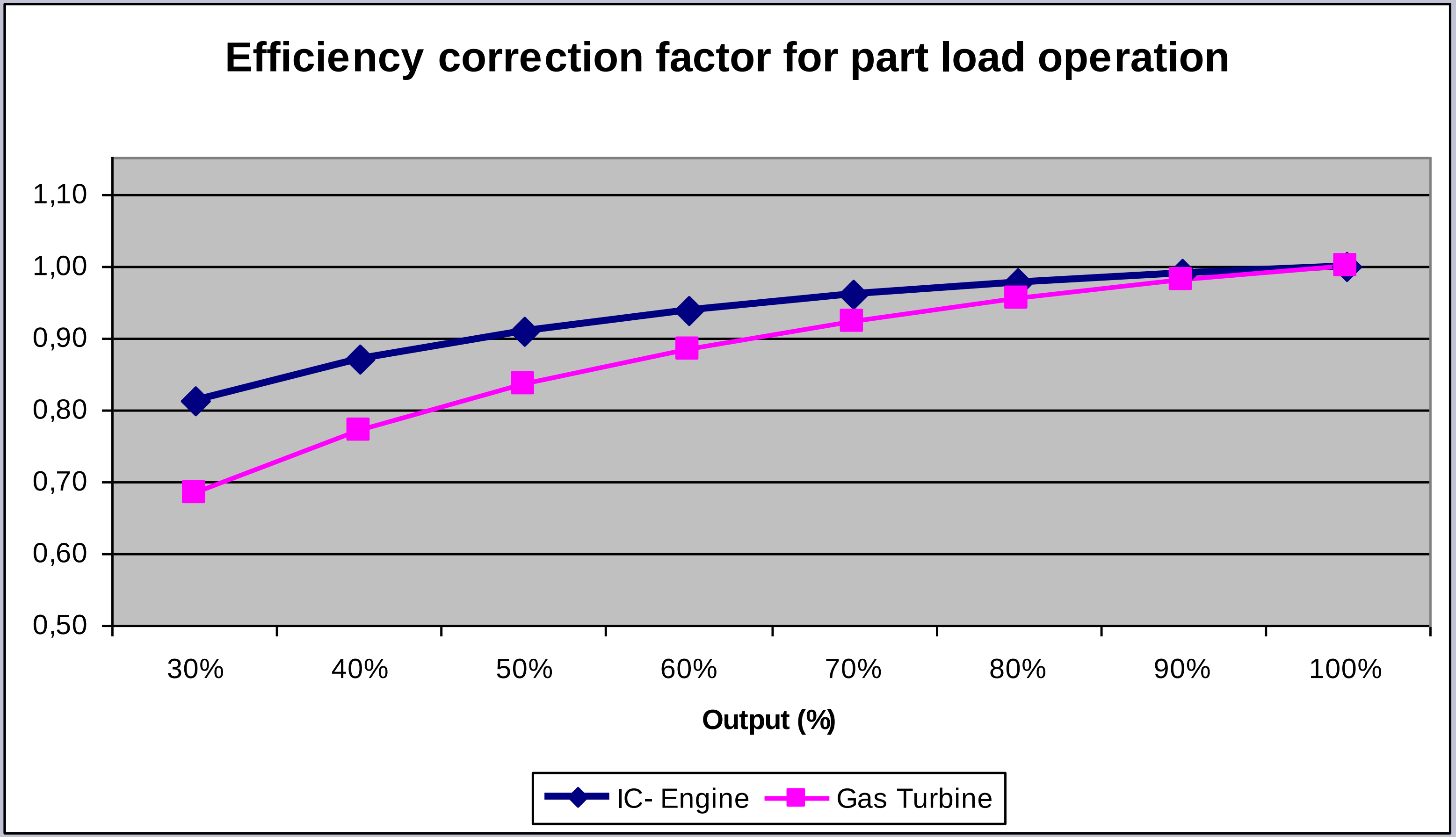
Electrical efficiency



Efficiency correction factor for ambient temperature



Efficiency correction factor for part load operation



Classification of power plants by place of combustion

- Internal combustion engines
  - Diesel engines
  - Gas engines
  - Dual fuel engines
- External combustion engines

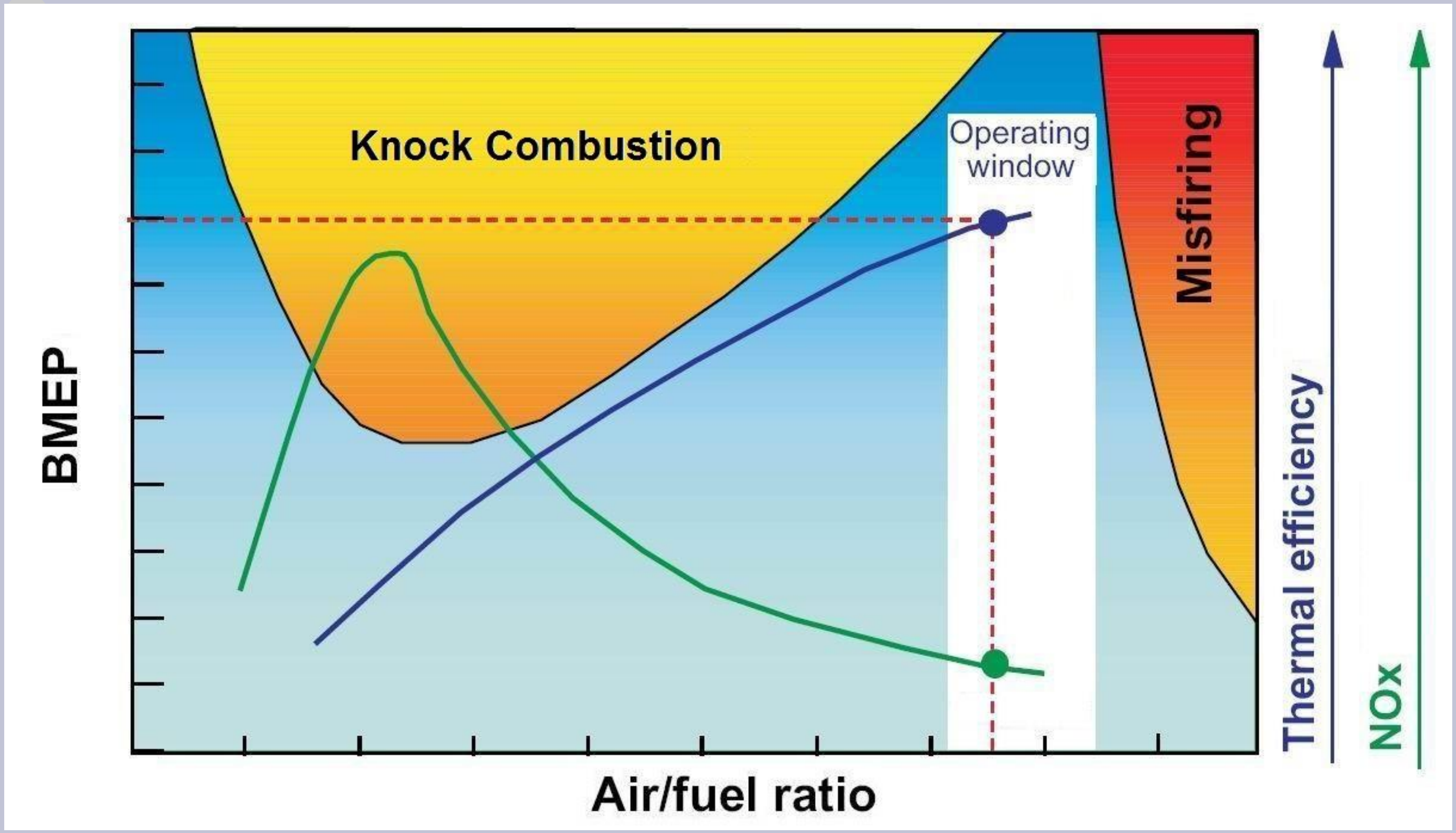
Classification of internal combustion engines

- By speed or rotation
  - Low speed < 300 r/min (ship engines)
  - Medium speed 300 - 1000 r/min (power plants)
  - High speed > 1000 r/min (Standby power plants and cars)
- By number of strokes
  - 2 - stroke (large ships)
  - 4 - stroke (power plants and cars)

Classification of internal combustion engines, continued

- By type of combustion
  - Lean burn (lambda > 1.2 -2.2)
  - Stoichiometric (lambda = 1)
- By combustion chamber
  - Open chamber
  - Pre-chamber

Lean-burn engines



Classification of internal combustion engines, continued

By fuel

- Heavy fuel oil (HFO)
- Light fuel oil (LFO)
- Liquid bio fuel (LBF)
- Natural gas (NG)
- Biogas (BG)
- Dual-fuel (NG/LFO)
- Tri-fuel (NG/LFO/HFO)
- Multi-fuel (NG/LFO/HFO/LBF)

Operating parameters

- Start-up time (minute)
- Maximum step change (%/5-30 s)
- Ramp rate (change in minute)
- Emissions

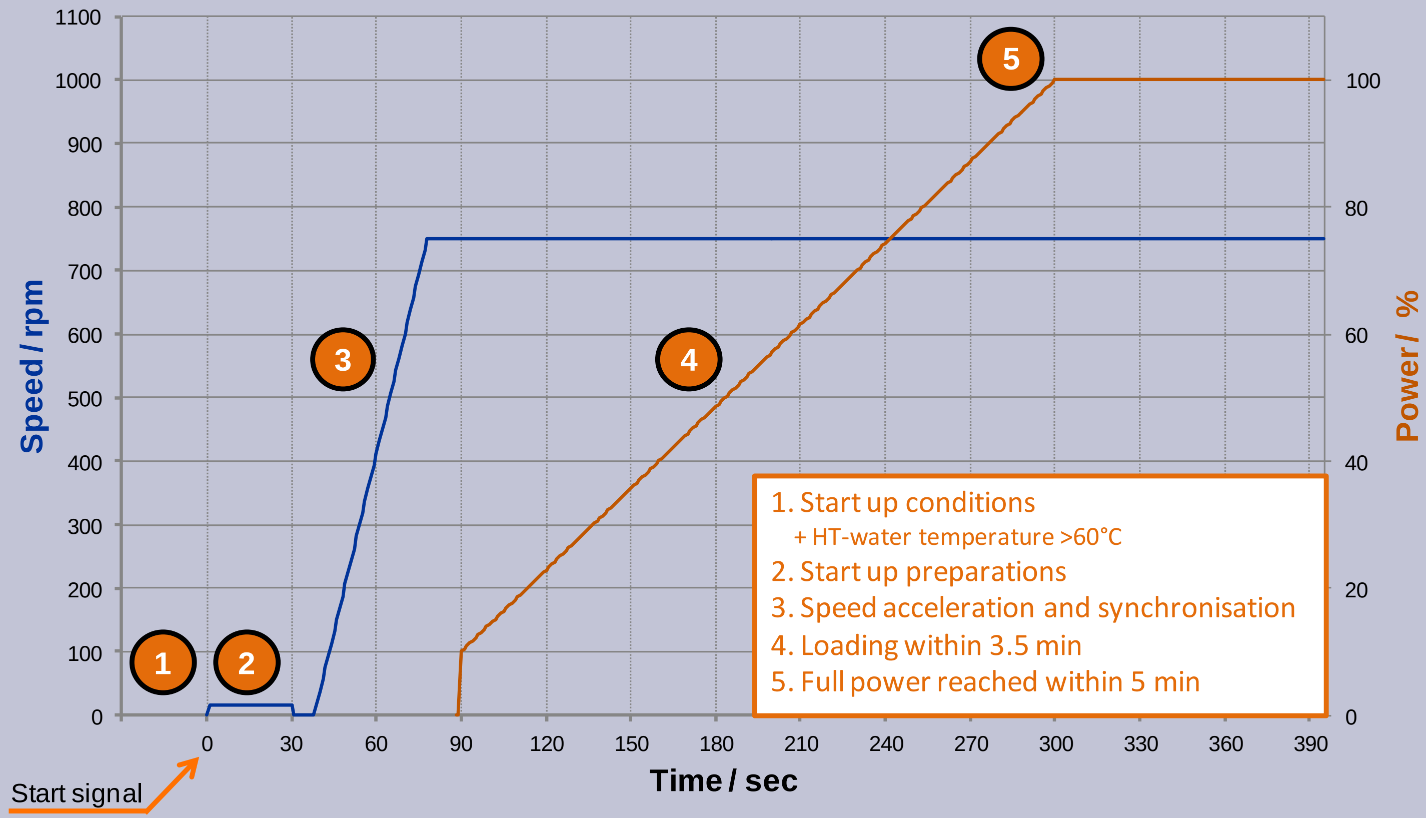
Start-up time (Full Power)

Diesel engines	1 - 5 min
Gas engines	3 - 10 min
Aeroderivative GT	5 - 10 min
Industrial GT	10 - 20 min
GT Combined Cycle	30 – 60 min
Steam turbine plants	60 – 600 min

Large plants need longer start-up time

Gas Engines
Full power in 5 minutes

W34SG-C2 - 5 min start up and loading



Maximum change in 30 s

Diesel engines	60 - 100%
Gas engines 34SG	35 - 85 %
Aeroderivative GT	20 - 30 %
Gas engine 50SG	10 - 30 %
Industrial GT	10 - 30 %
GT Combined Cycle	10 - 20 %
Steam turbine plants	5 - 10 %
Nuclear plant	5 - 10 %

Maximum ramp rate

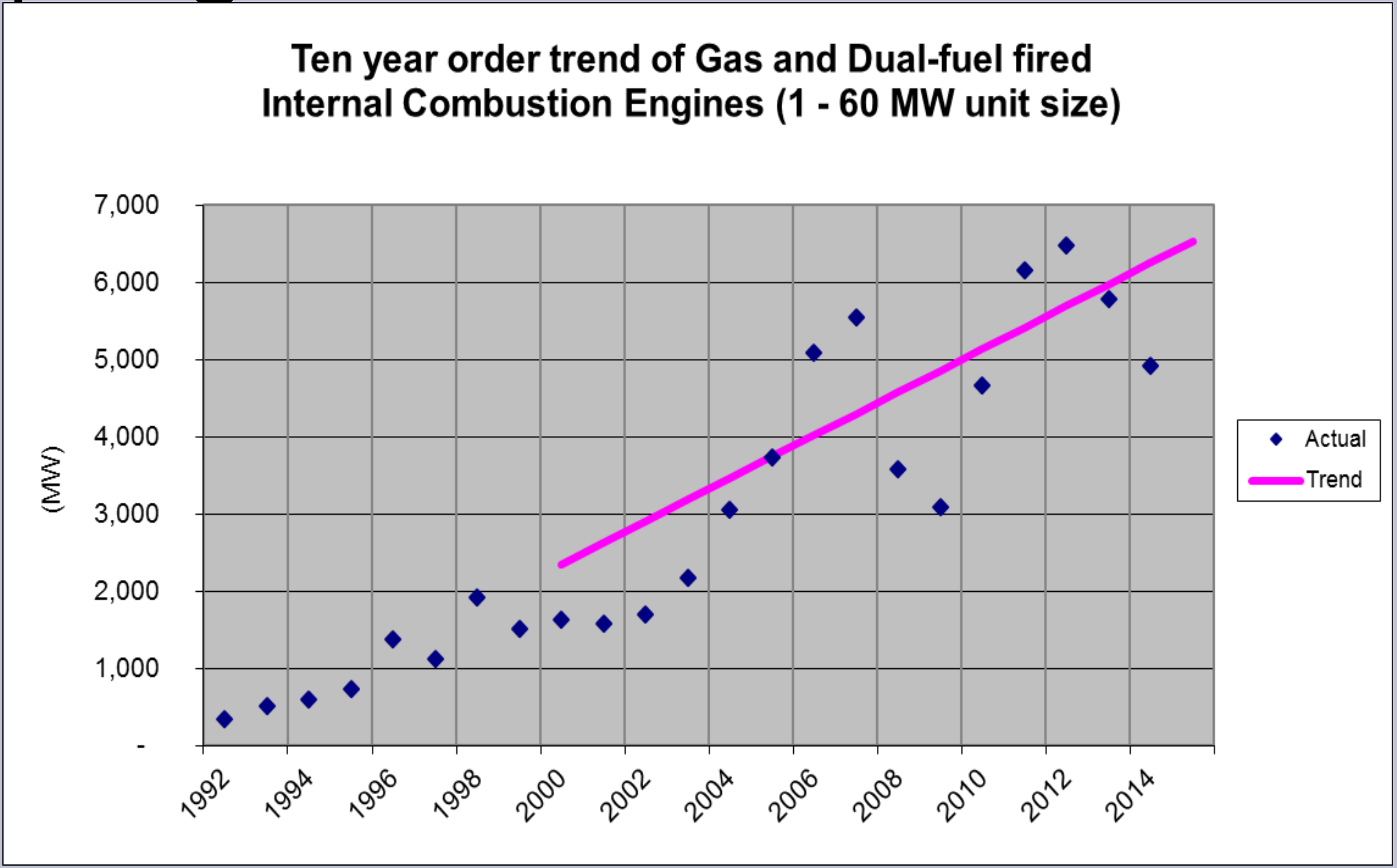
Diesel engines	40 %/min
Gas engines	10-85 %/min
Aeroderivative GT	20 %/min
Industrial GT	20 %/min
GT Combined Cycle	5 -10 %/min
Steam turbine plants	1- 5 %/min
Nuclear plants	1- 5 %/min

CO2-emissions

- Gas fired plants g/kWh
  - CHP 90 % efficiency 224
  - GTCC 55 % efficiency 367
  - Gas Engine 45 % efficiency 449
  - Gas Turbine 33 % efficiency 612
- Coal fired plants
  - Supercritical 45 % efficiency 757
  - Subcritical 38 % efficiency 896

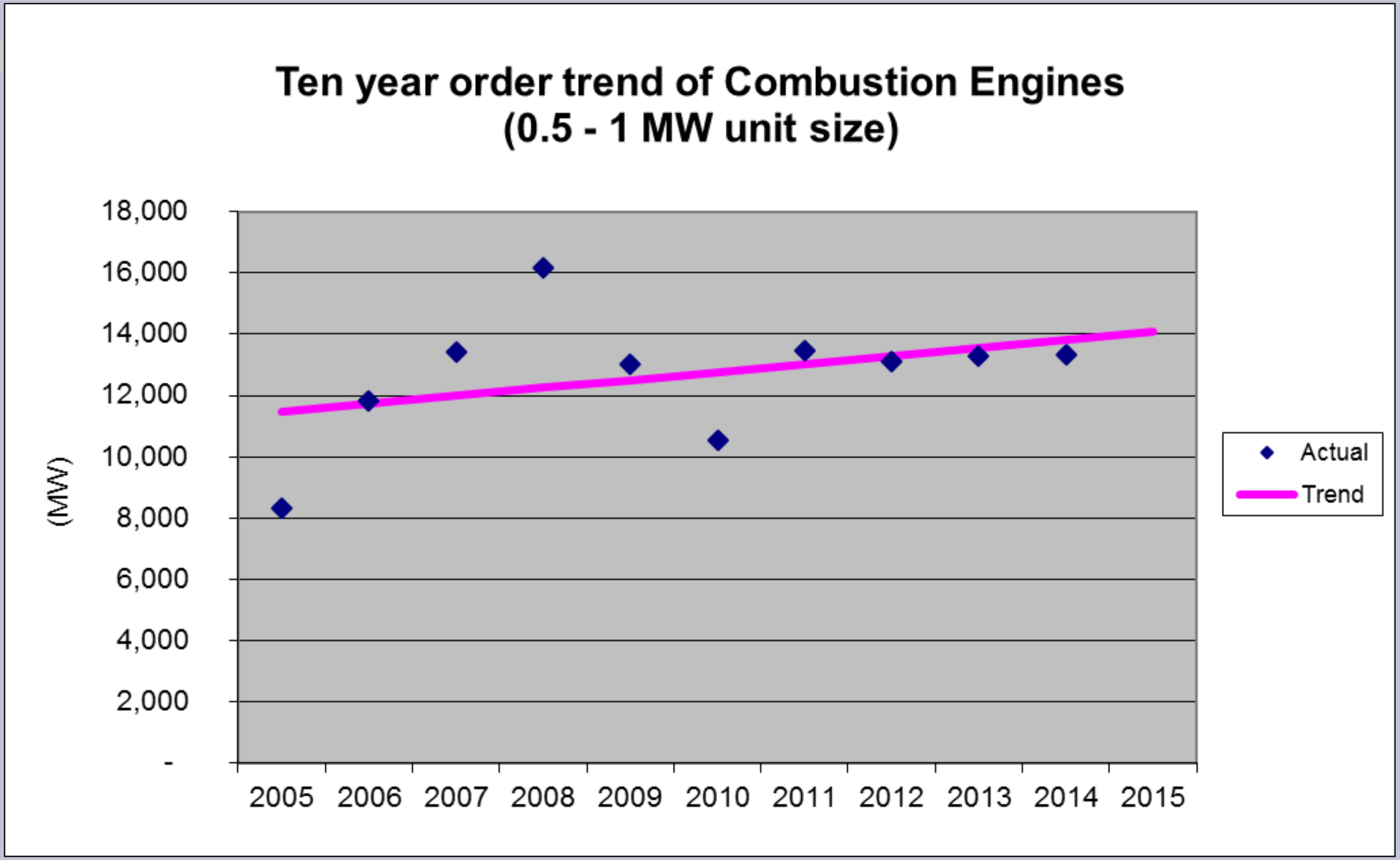
Orders of gas and dual fuel engines

Wärtsilä's market share 20 – 30 %



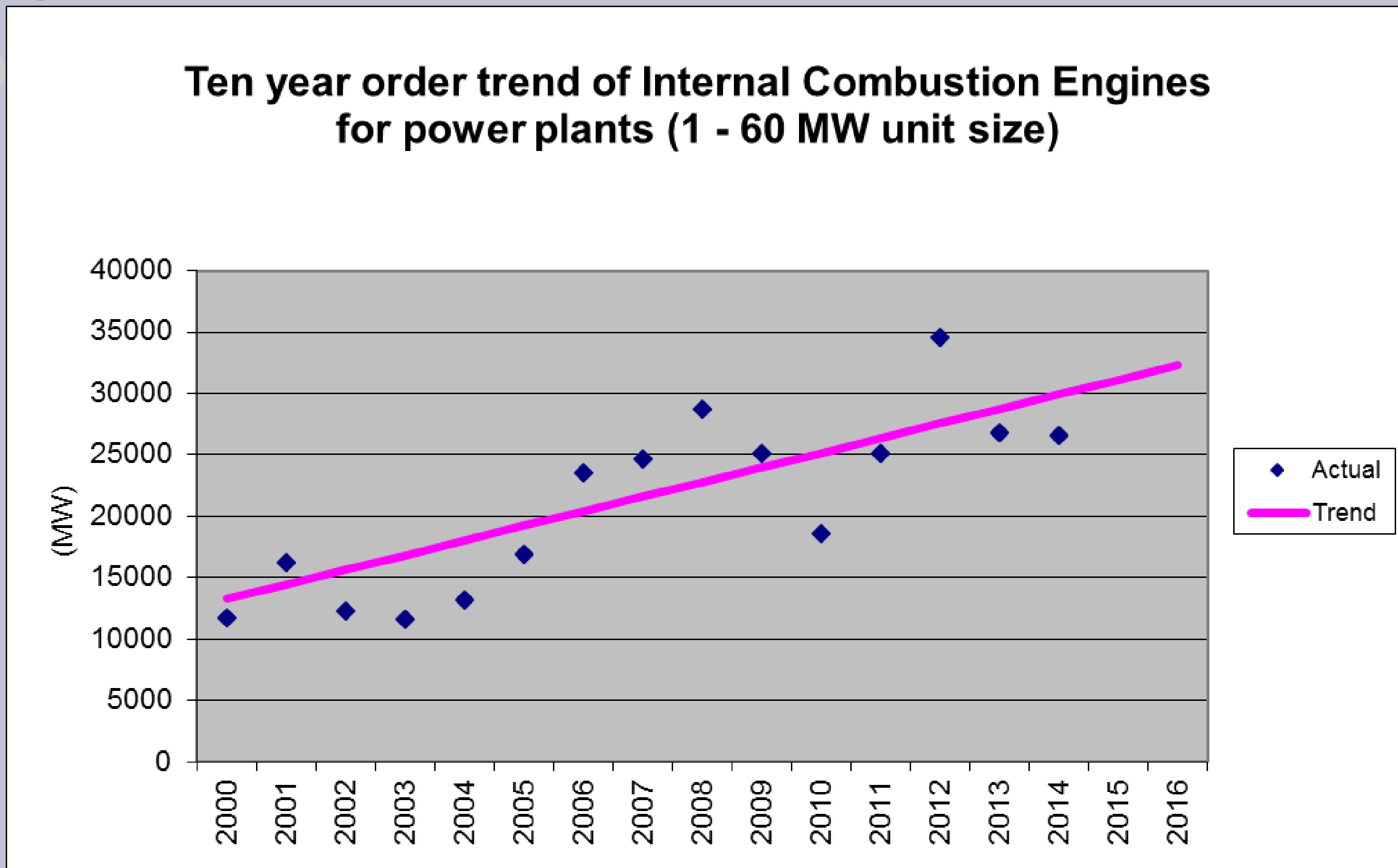
Source: Diesel Engine and Gas Turbine World Wide

Orders of Combustion Engines for power plants (0.5 – 1 MW)



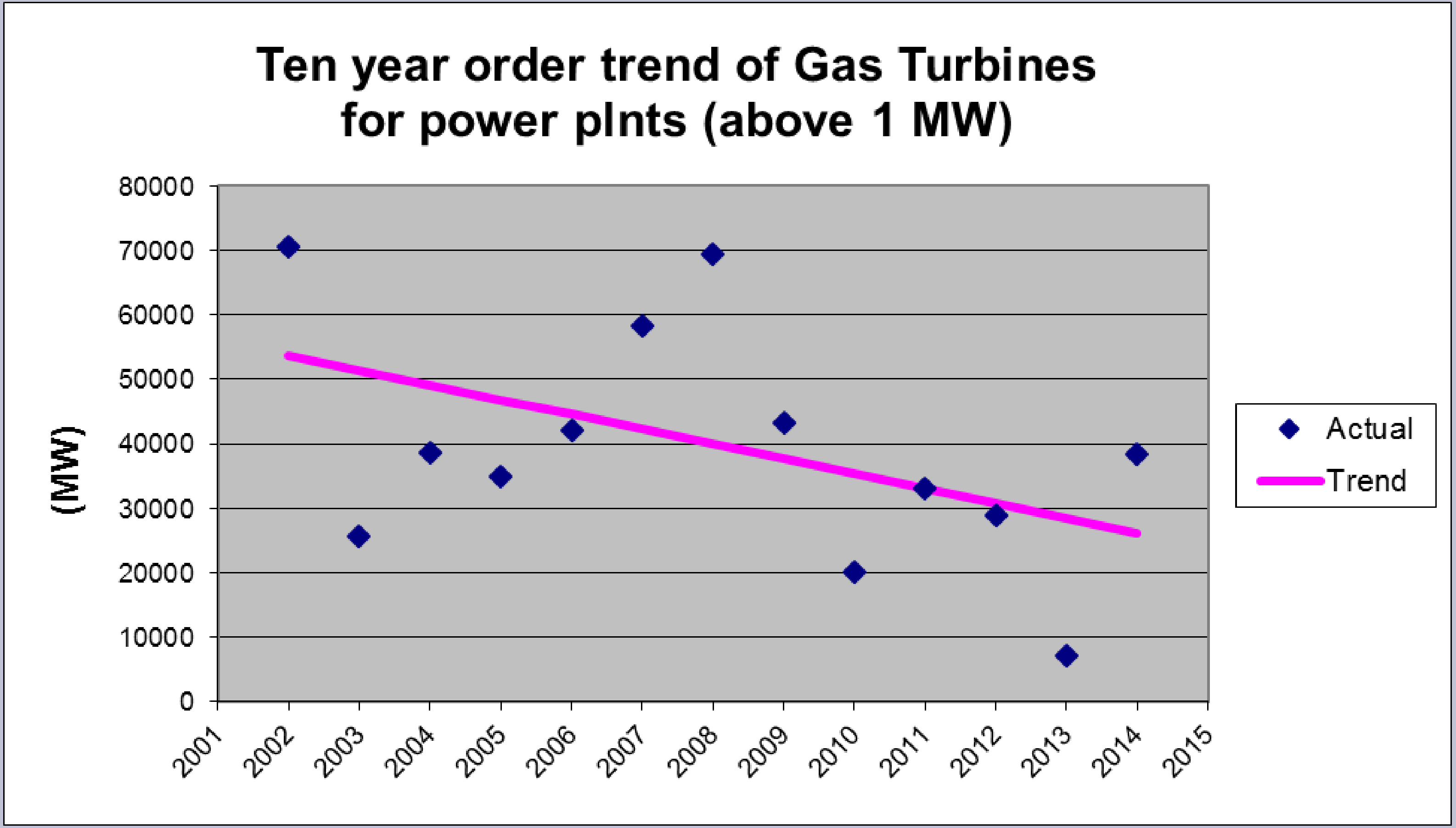
Source: Diesel Engine and Gas Turbine World Wide

Orders of Combustion Engines for power plants (1 – 60 MW)



Source: Diesel Engine and Gas Turbine World Wide

Orders of Gas turbines for power plants



Source: Diesel Engine and Gas Turbine World Wide

Annual orders

Transportation	**3500 GW/a**	
1 Otto cycle	2000 GW	
2 Diesel cycle	1500 GW	
3 Brayton cycle	20 GW	
Power plants	**250 GW/a**	
1 Rankine Cycle	70 GW?	28 %
2 Wind turbines	50 GW	20 %
3 Solar	40 GW	16 %
4 Diesel/Otto Cycle	40 GW	16 %
5 Brayton Cycle	40 GW	16 %
6 Hydro turbines	10 GW	4 %

Why combustion engines?

1. High efficiency at any load (40 %+ from 5 to 300 MW)
2. High reliability (90 % output all the time)
3. Multi-fuel (natural gas, LFO, HFO, LBF, Biogas)
4. Fast start-up time (2 - 5 min in regulation and non-spinning)
5. Short construction time (300 MW in two years)
6. All sizes available (from 1 kW to 300 MW)
7. 20 % market share in power plants
8. 90 % market share in ships
9. 95 % market share in stand-by applications
10. 99 % market share in cars and trucks

Summary

Combustion engines are leaders in power plant applications

- High efficiency
- Fast start-up time
- Modularity

For details see reference text book **”Planning of Optimal Power Systems”**

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