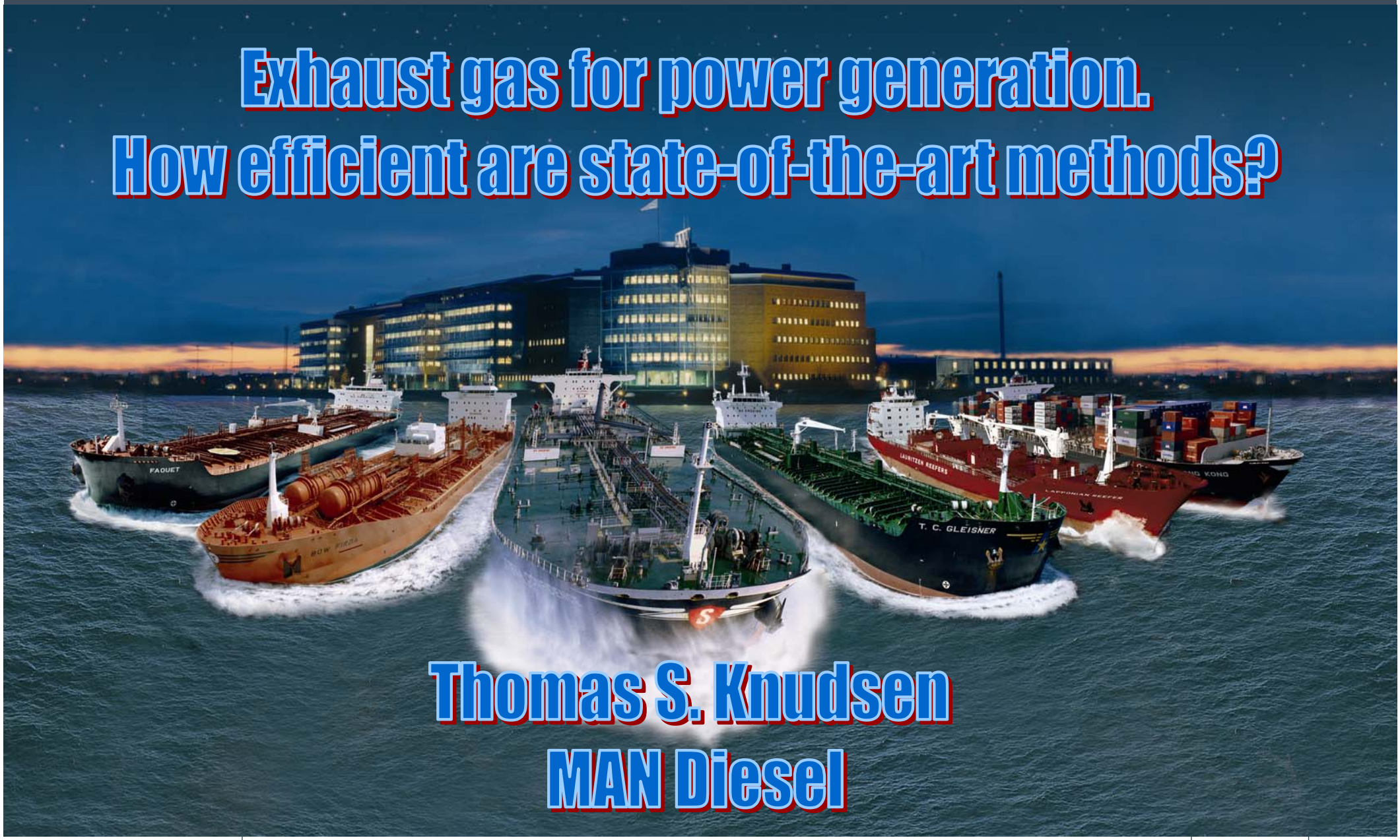
Exhaust gas for power generation.
How efficient are state-of-the-art methods?

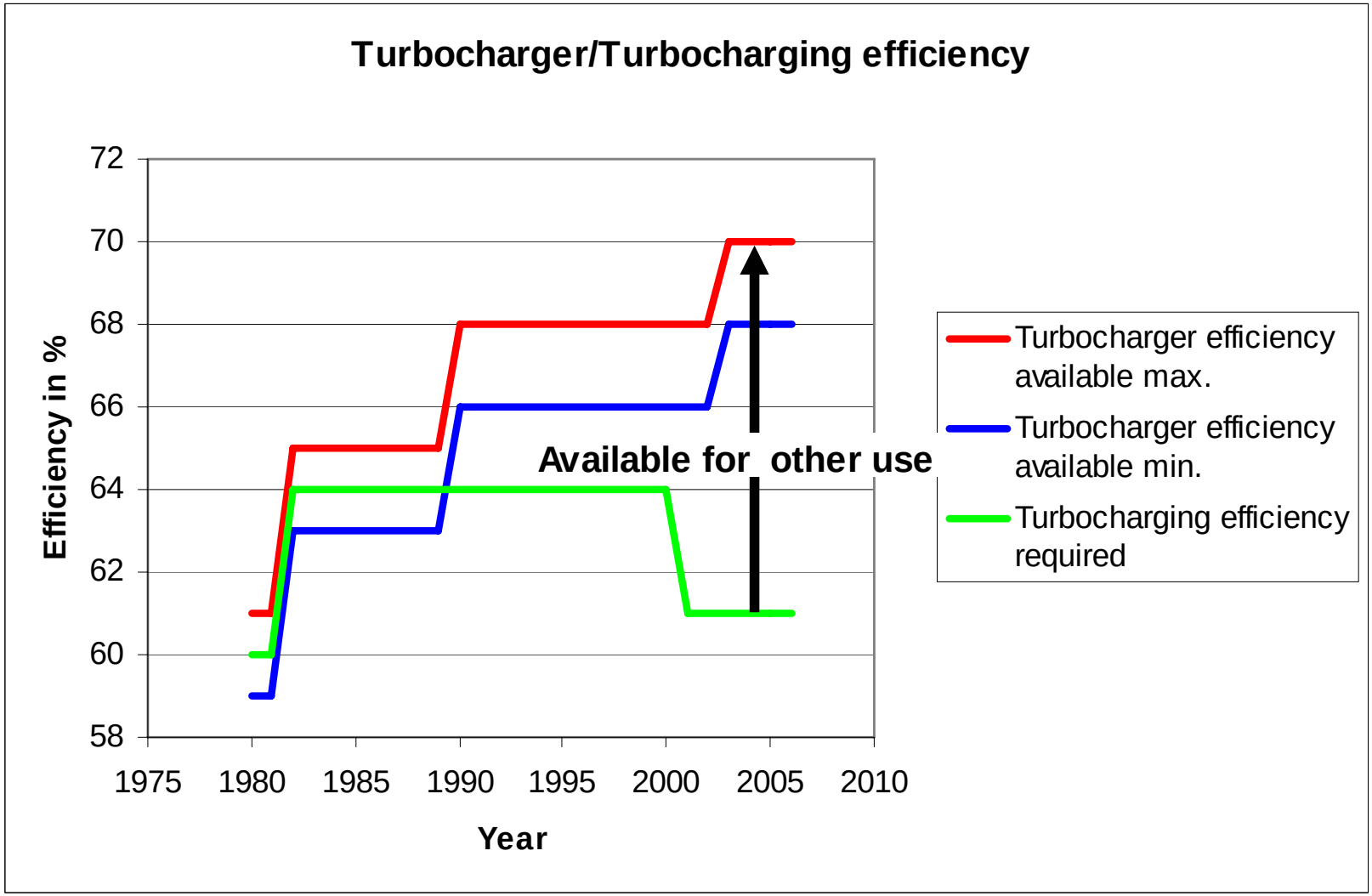


Thomas S. Knudsen
MAN Diesel

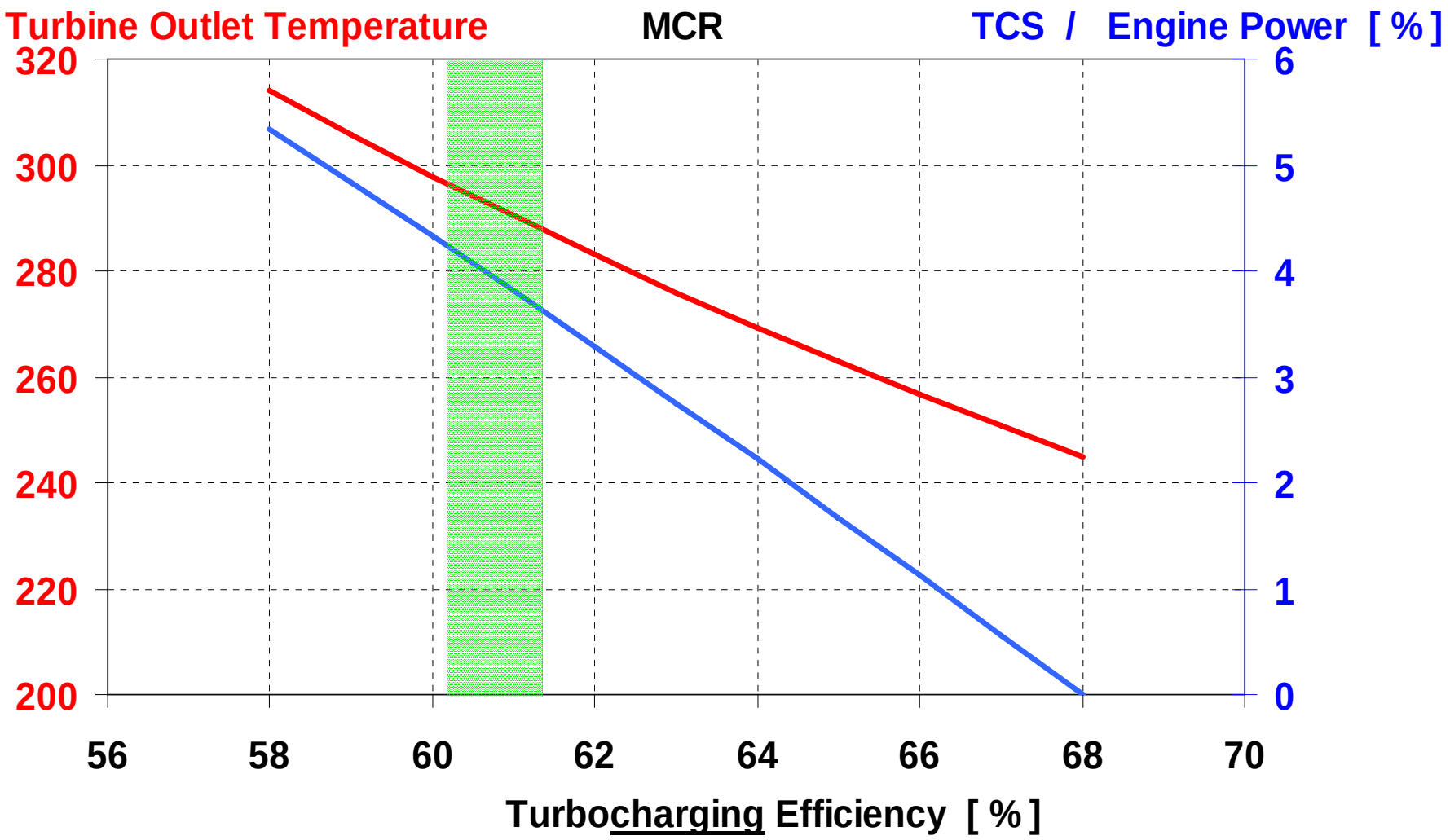
TES (Thermo Efficiency System)

- **Theoretical background**
- **Confirmation of potential**
- **Application possibilities**
- **Future application possibilities**

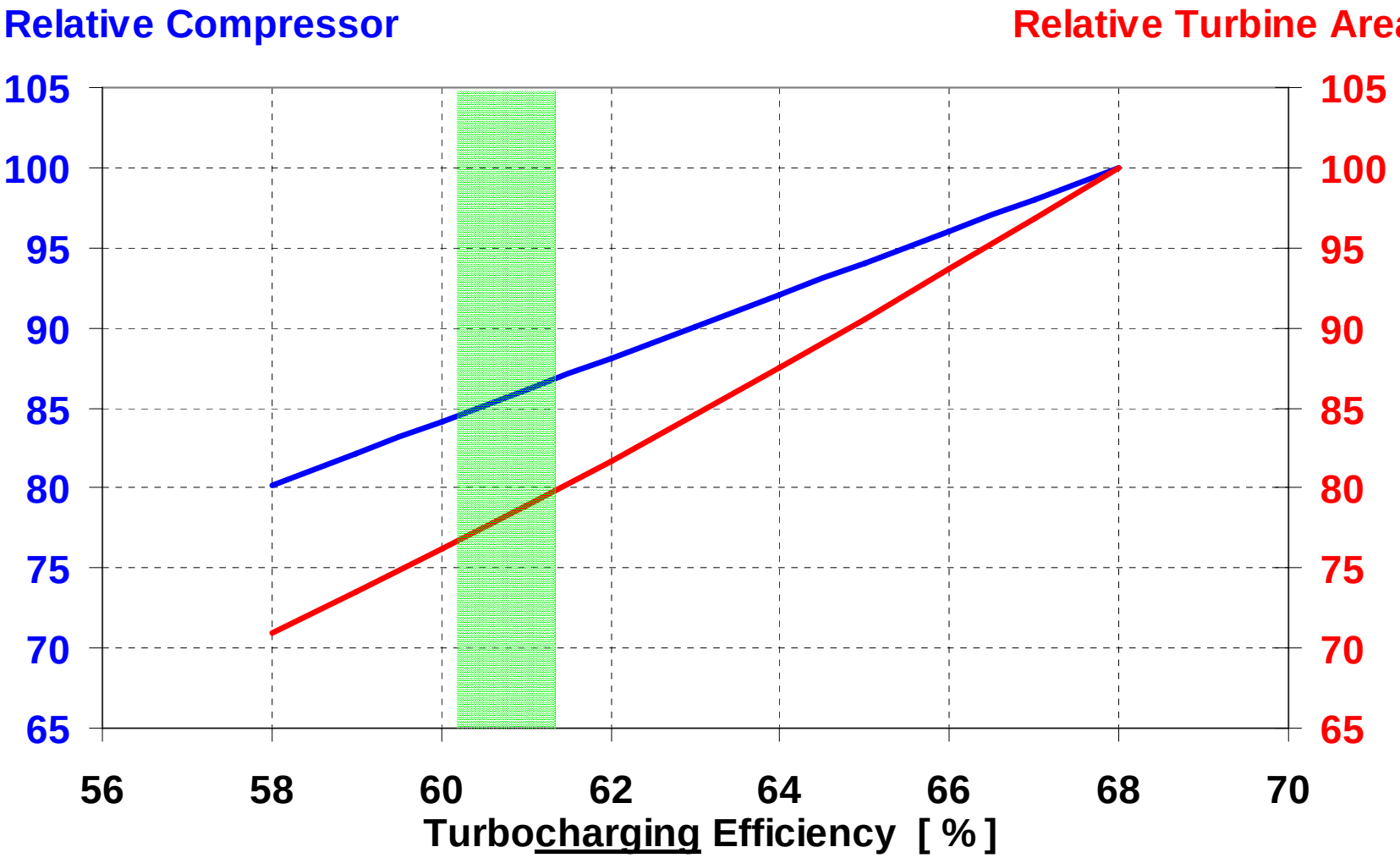
Turbocharging Efficiency



TES Applications



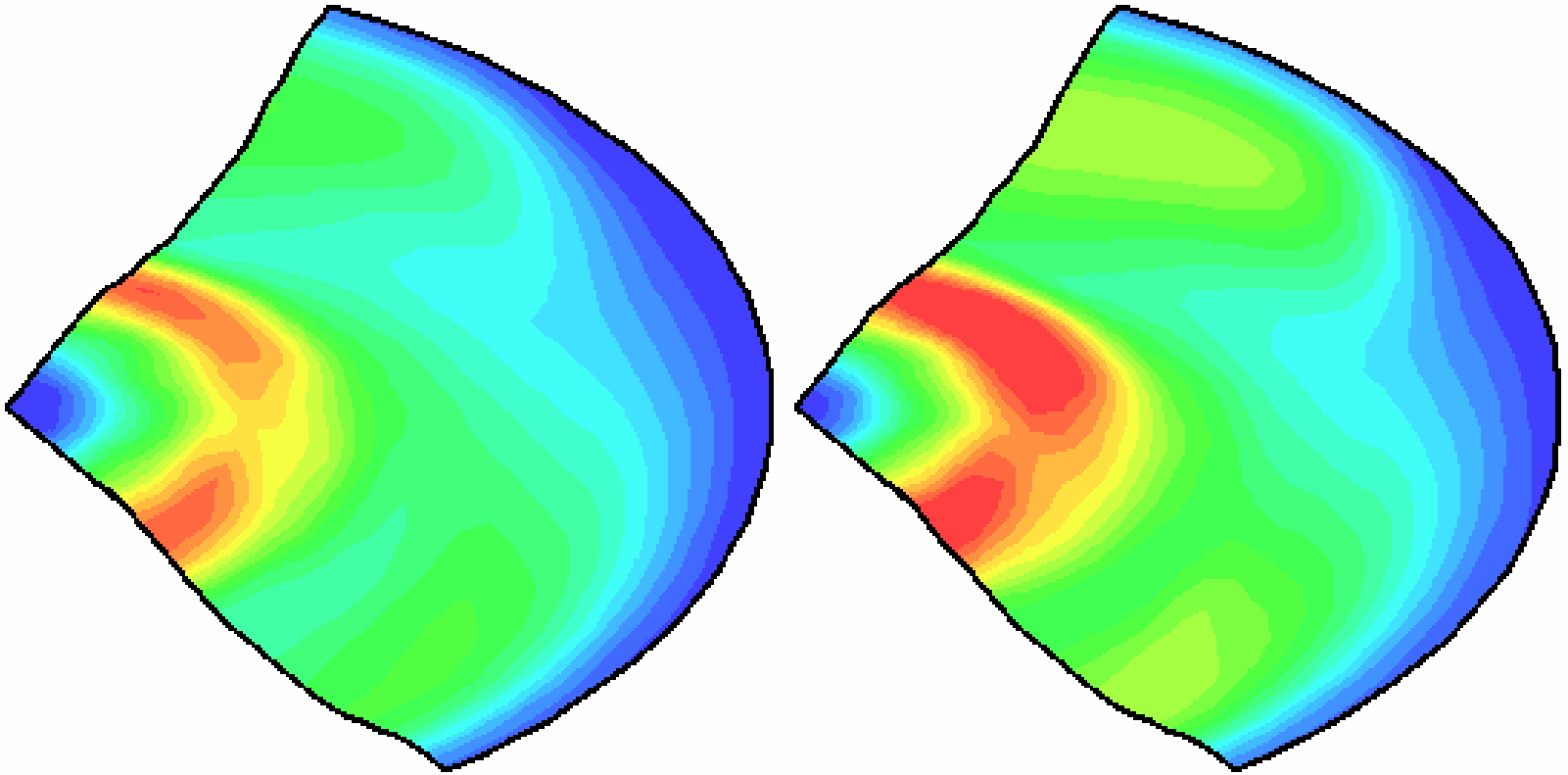
TES Applications



TES Calculations (CFD Heat Load)

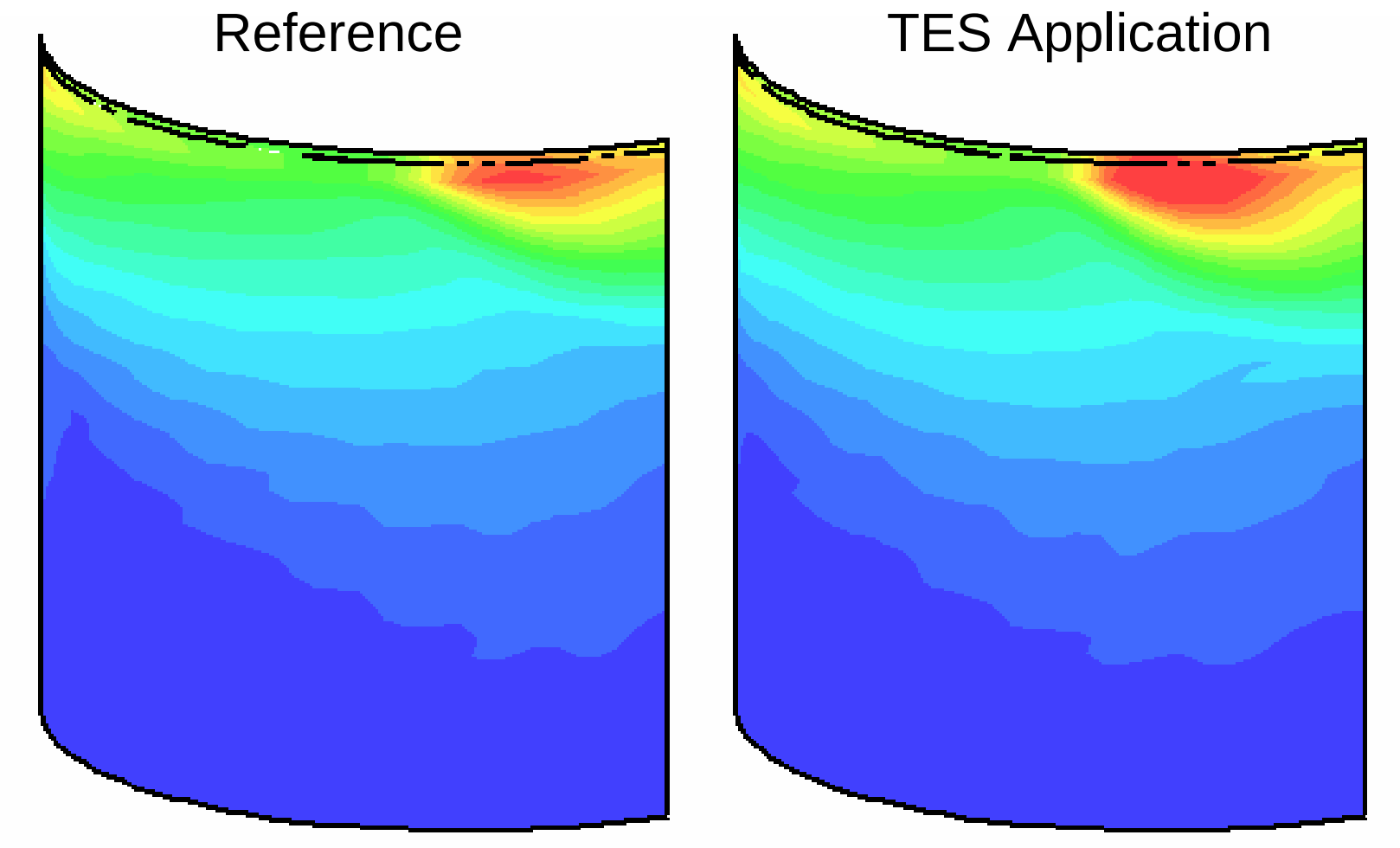
Reference

TES Application



Piston top surface at 100% engine load

TES Calculations (CFD Heat Load)



Liner surface at 100% engine load

TES Calculations

Summarising calculation results for TES engine

- Increased heat load on exhaust valve and piston
- Slightly increased heat load on liner and cover
- Approx. 2 g/kWh increased SFOC due to reduced purity at compression start
- Nearly unchanged NO_x emission

TES (Thermo Efficiency System)

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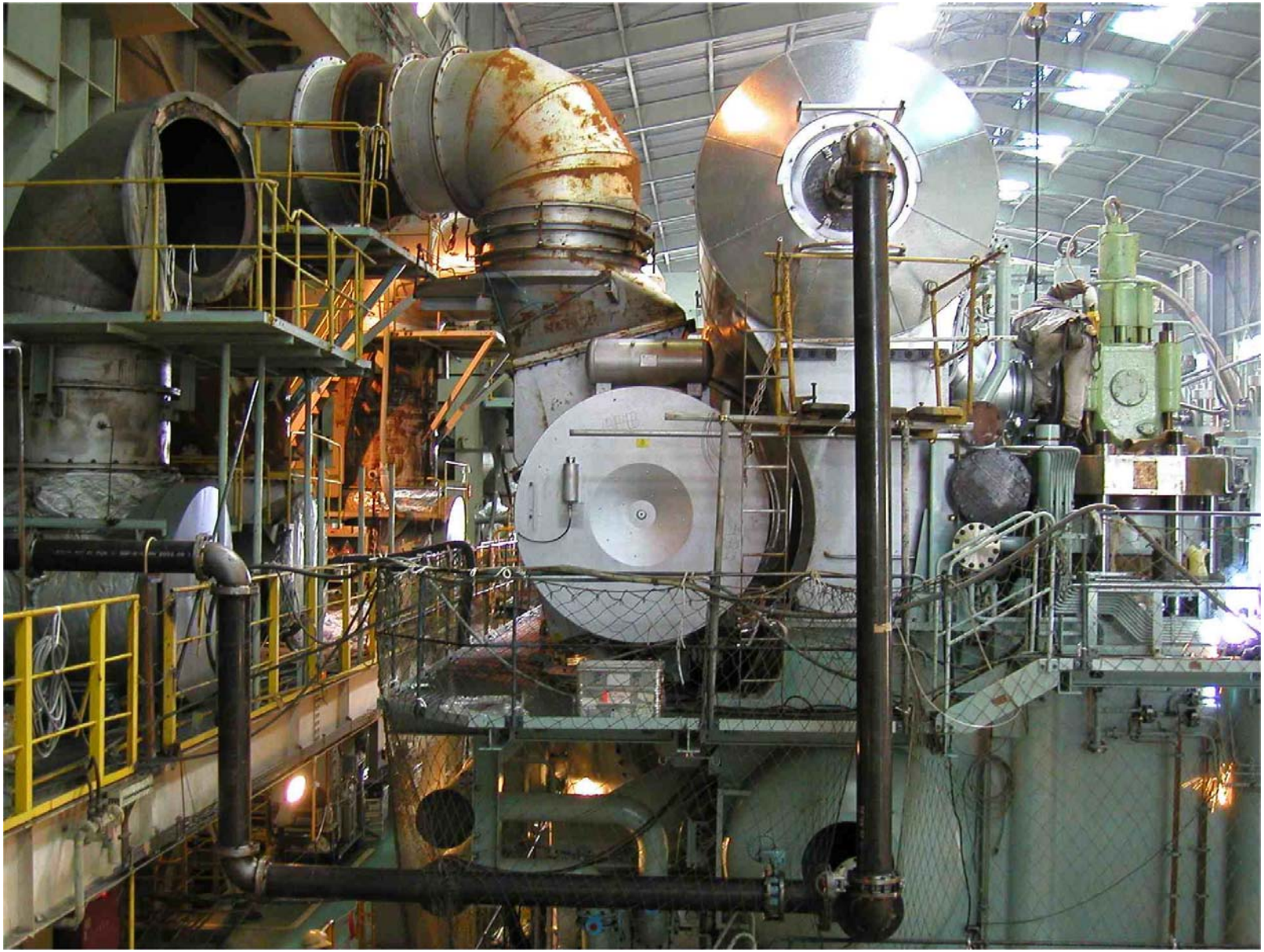
Fore End Bypass From the Exhaust Receiver to the Scavenge Air Receiver



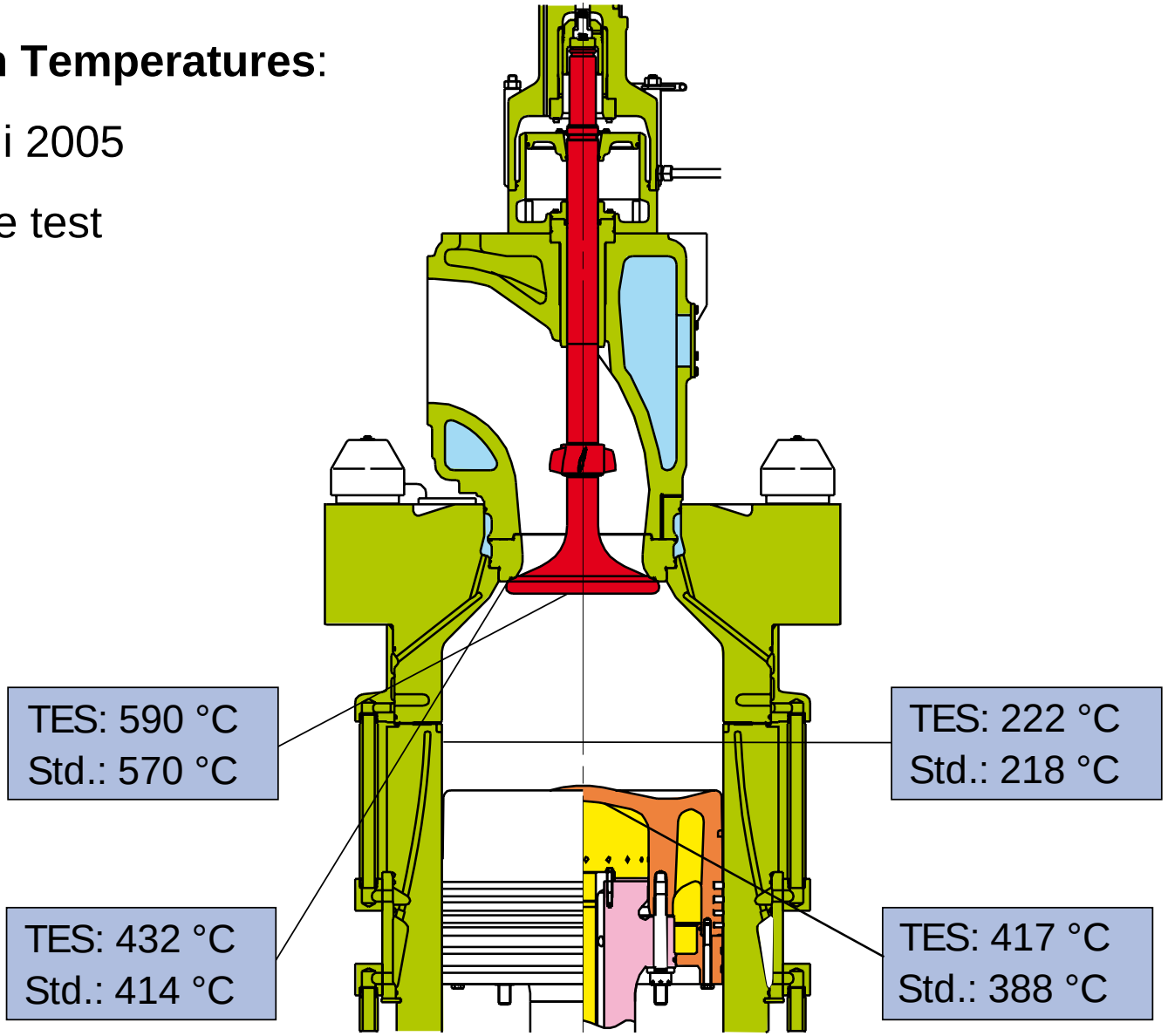
TES: Combustion Chamber Temperature

Measured Mean Temperatures:

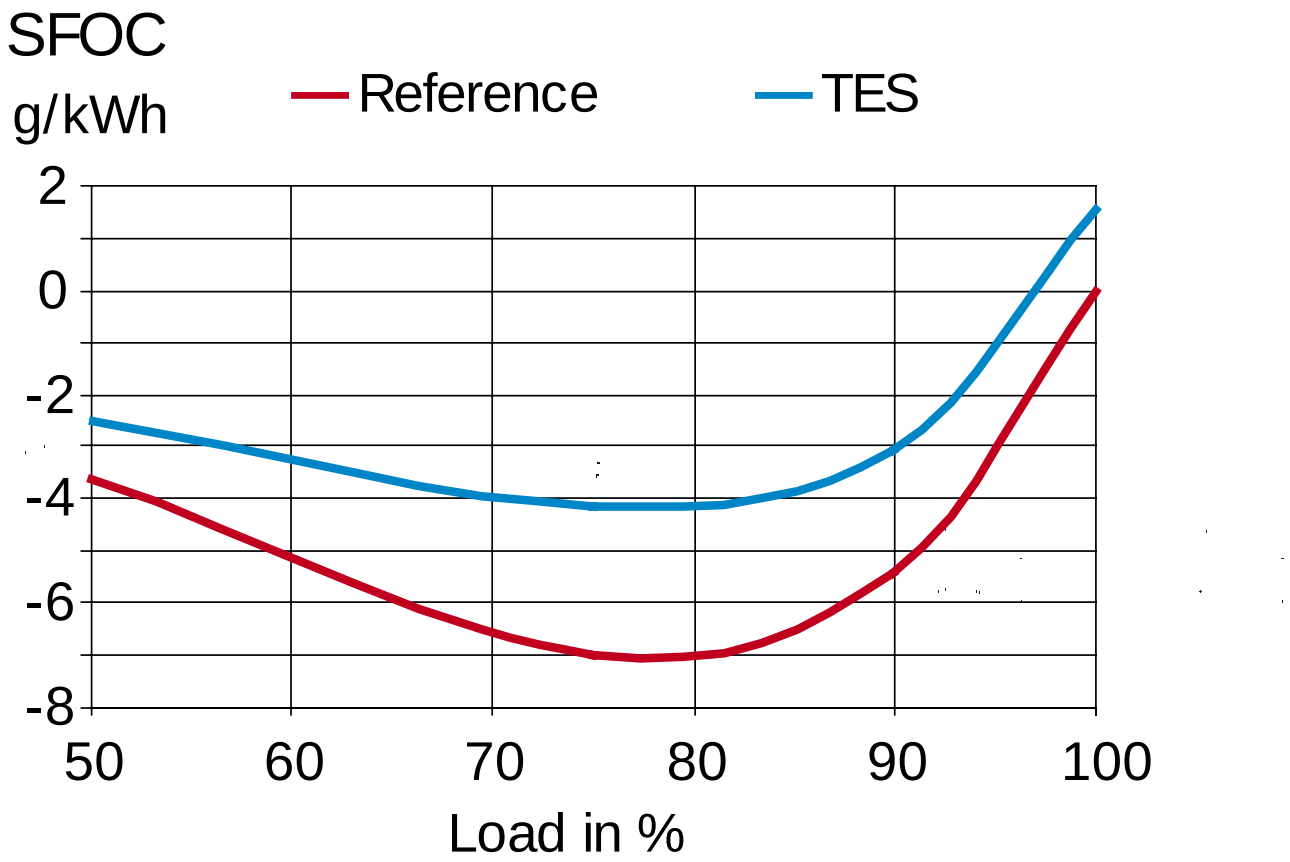
10K98MC Mitsui 2005

100% Reference test

100% TES

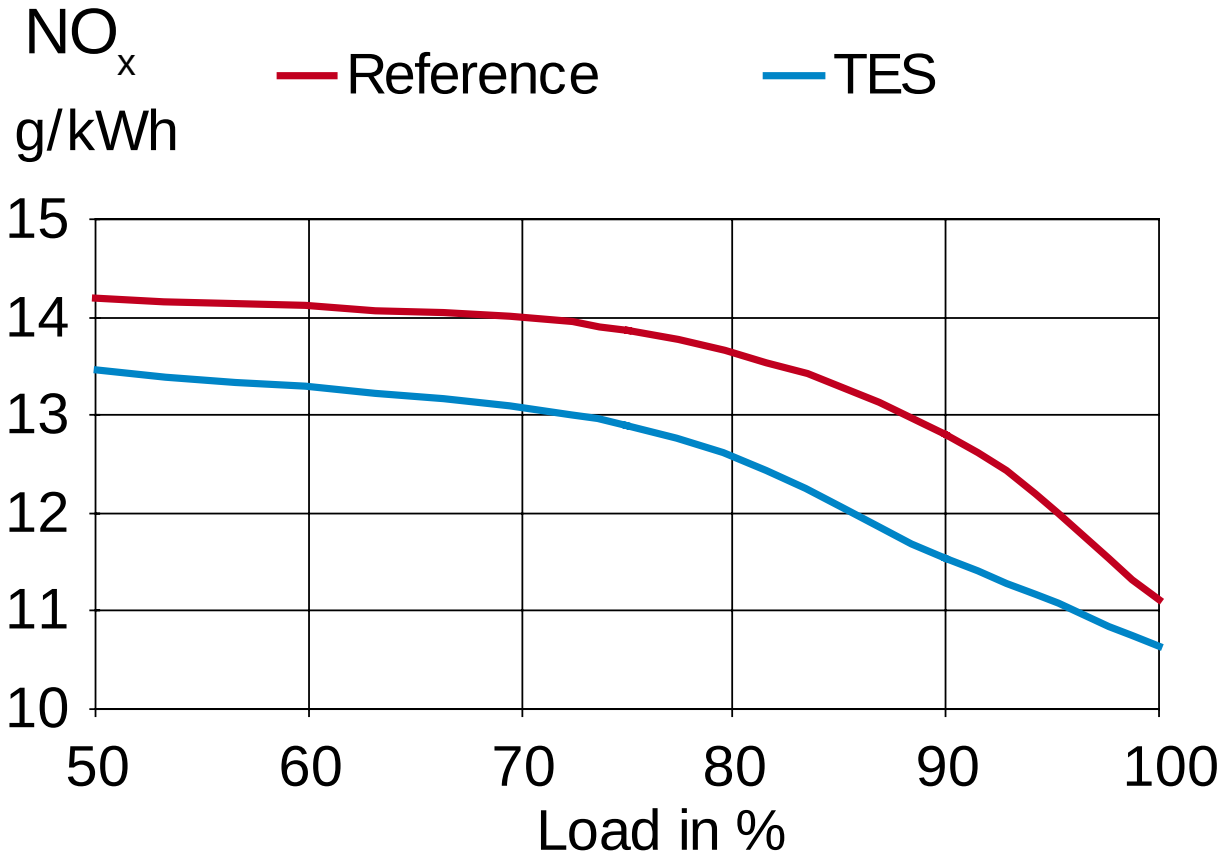


Measured Influence on SFOC



All data are corrected to ISO and reference p_{max}

Measured Influence on Specific NO_X Emissions



All data are corrected to ISO and reference p_{max}

TES (Thermo Efficiency System)

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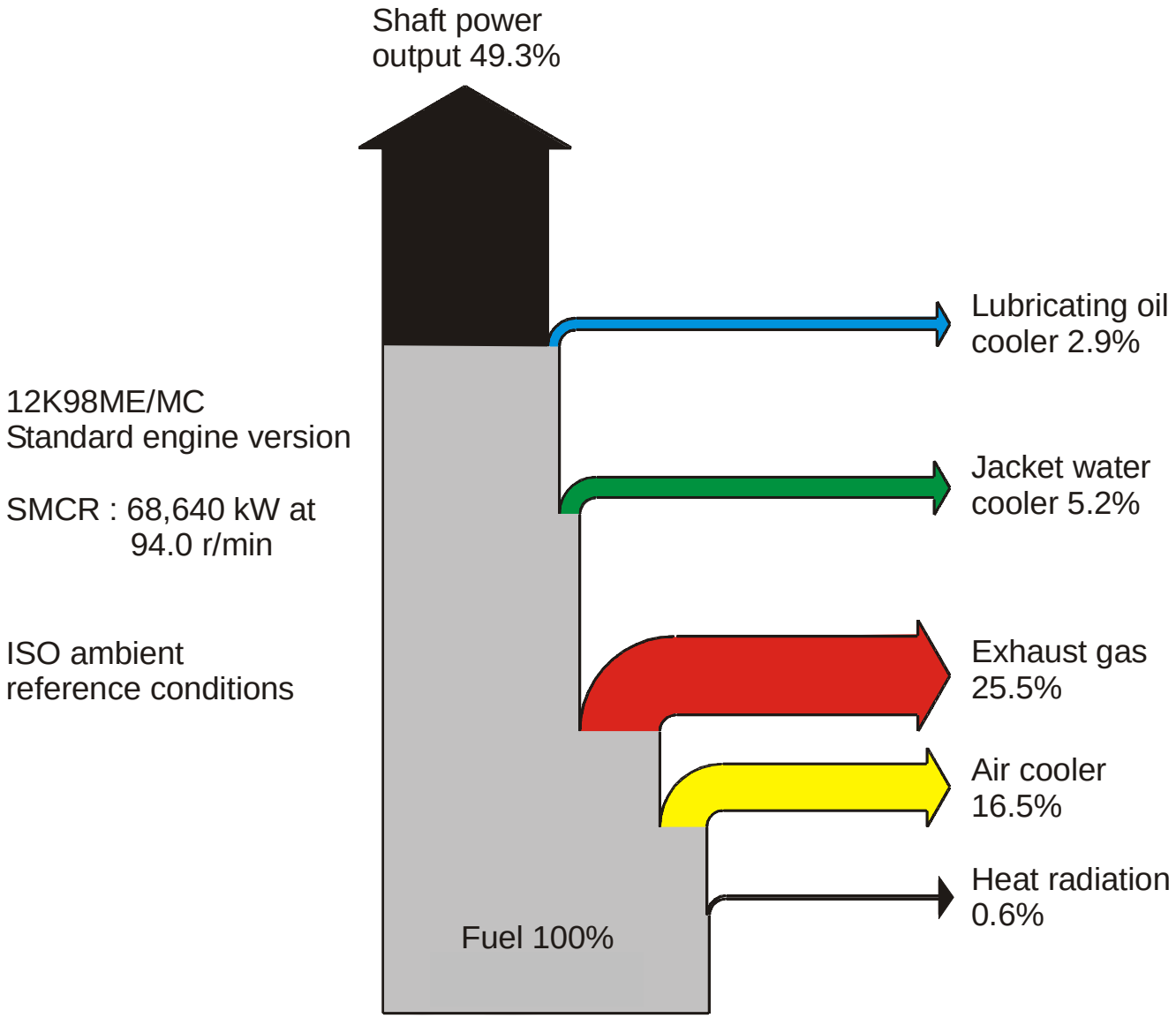
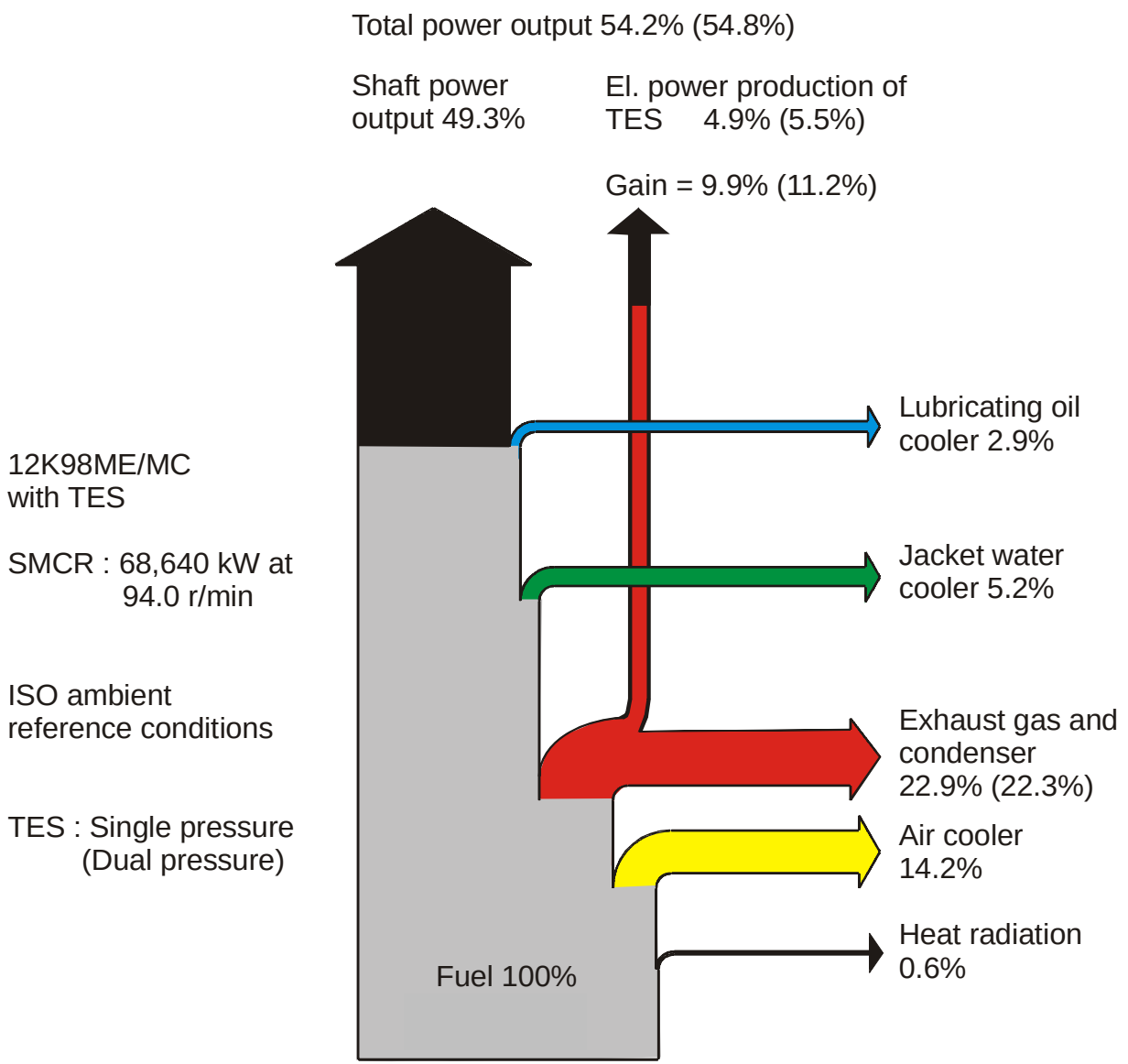
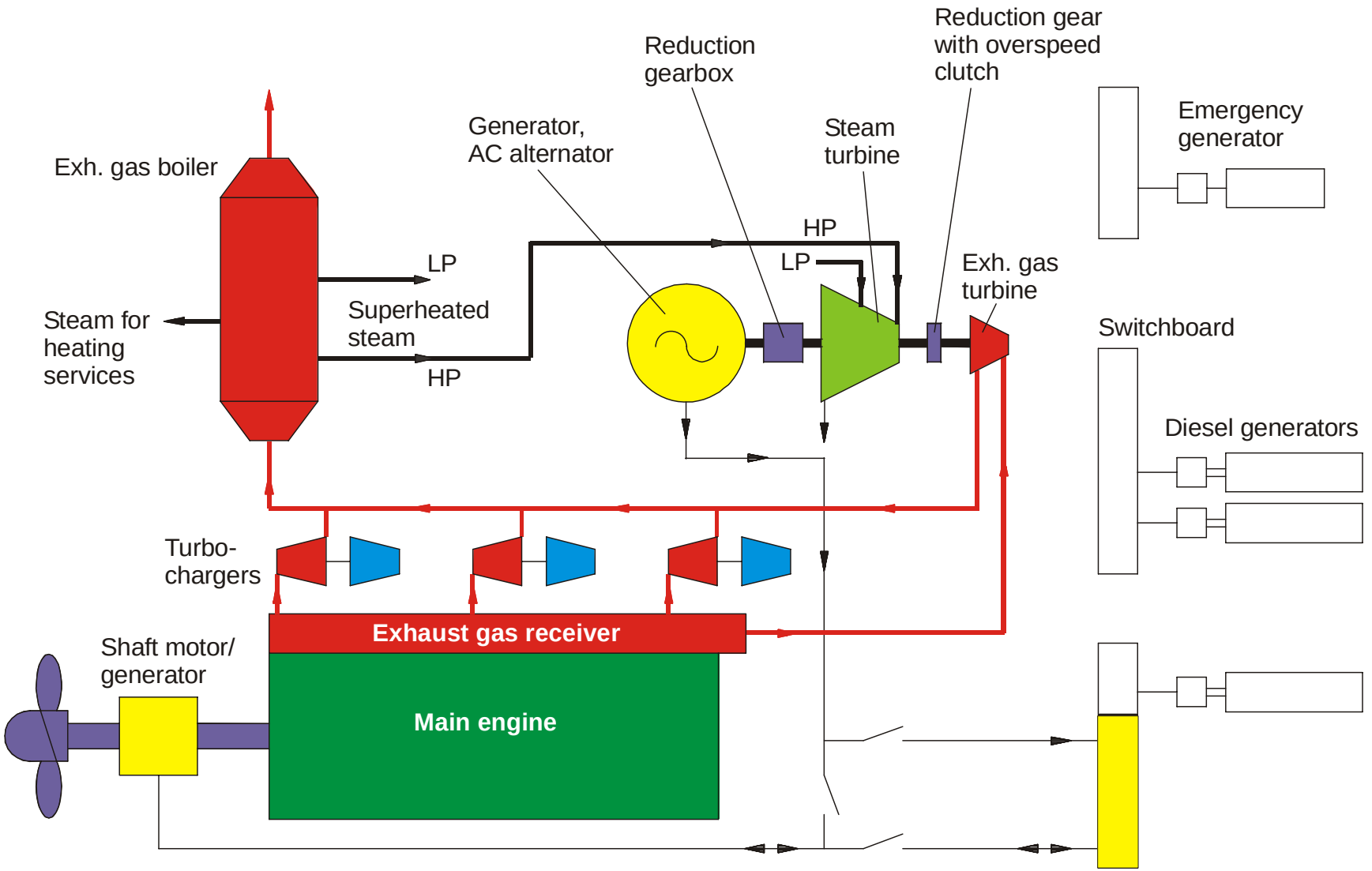
Heat Balance at 100% SMCR for Main Engine 12K98ME/MC without TES



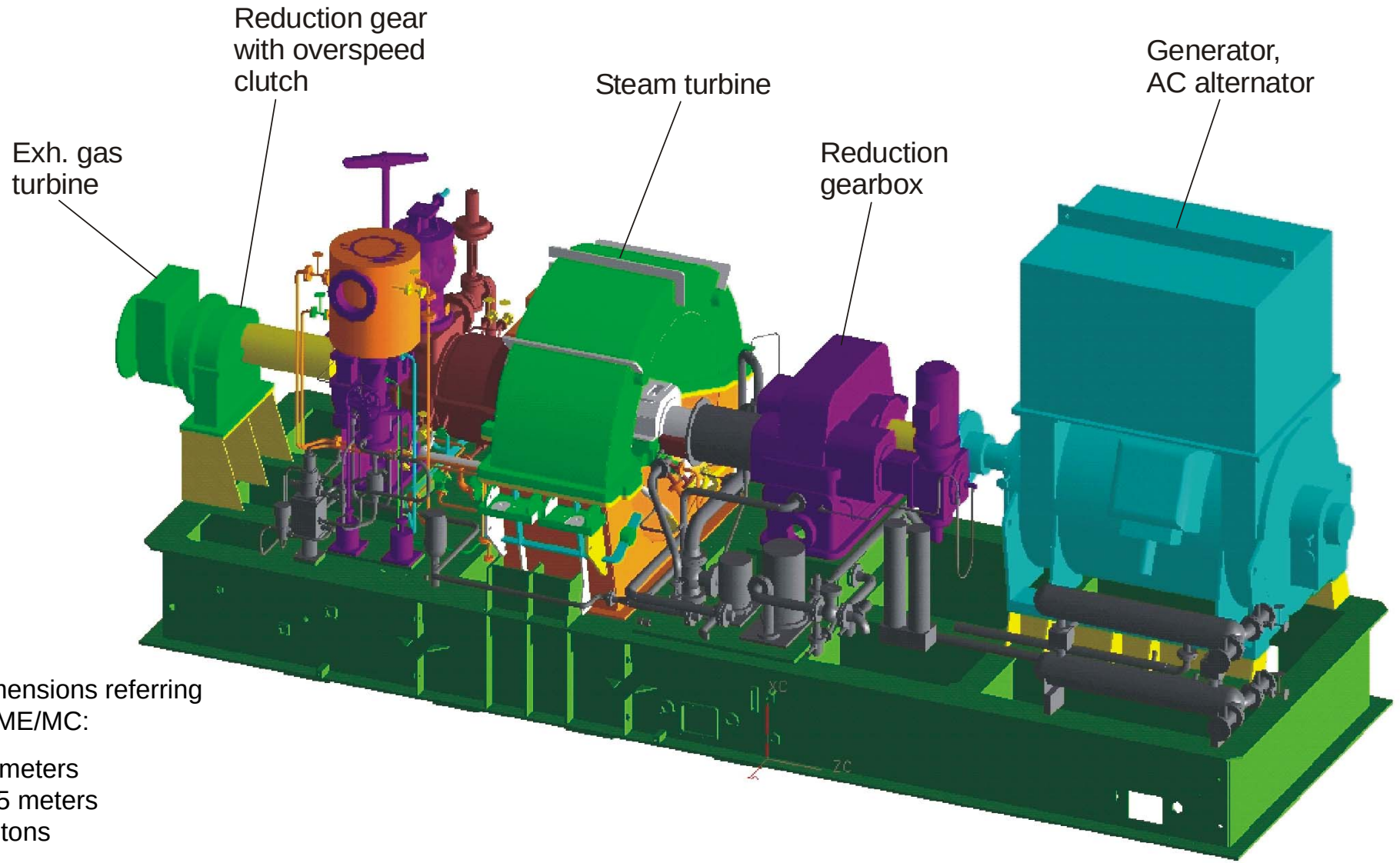
Heat Balance at 100% SMCR for Main Engine 12K98ME/MC with TES



Power Concept for Thermo Efficiency System



Thermo Efficiency System (TES)



Approx. dimensions referring to a 12K98ME/MC:

Length: 10 meters
Breadth: 3.5 meters
Weight: 58 tons

Arrangement as proposed by Peter Brotherhood Ltd.

PTG/PT Series with Expected Max. Shaft Power Output

PTG based on NR

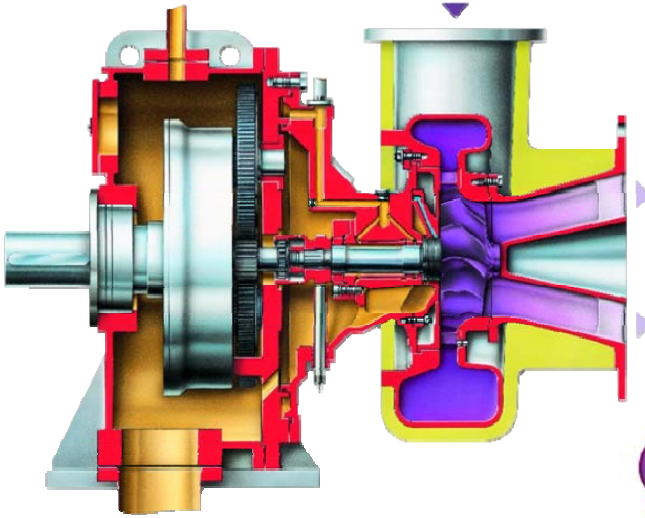
PTG18	-	355 kW
PTG23	-	590 kW
PTG26	-	1,120 kW

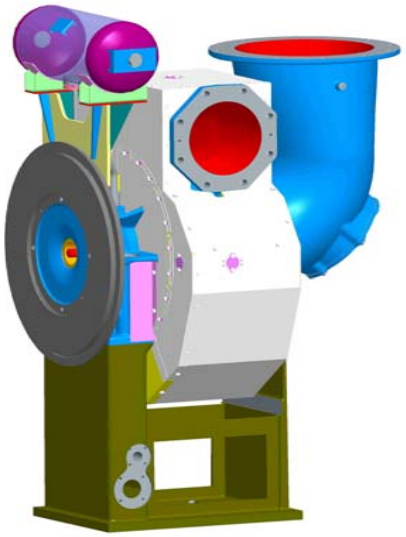
PT based on TCR

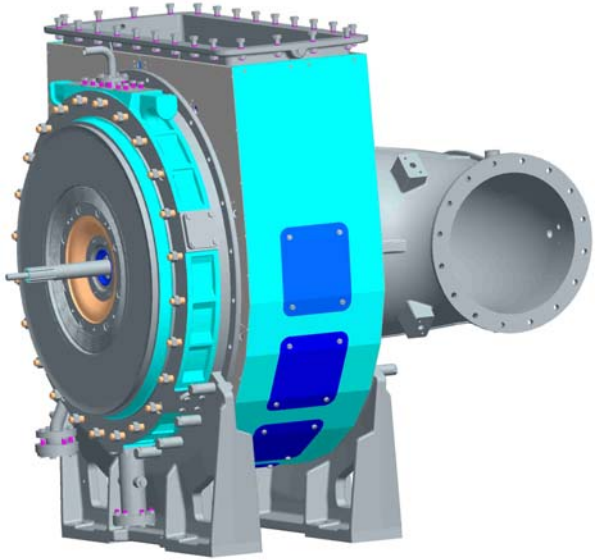
PT12	-	250 kW
PT14	-	350 kW
PT16	-	500 kW
PT18	-	700 kW
PT20	-	1,000 kW
PT22	-	1,800 kW

PT based on TCA

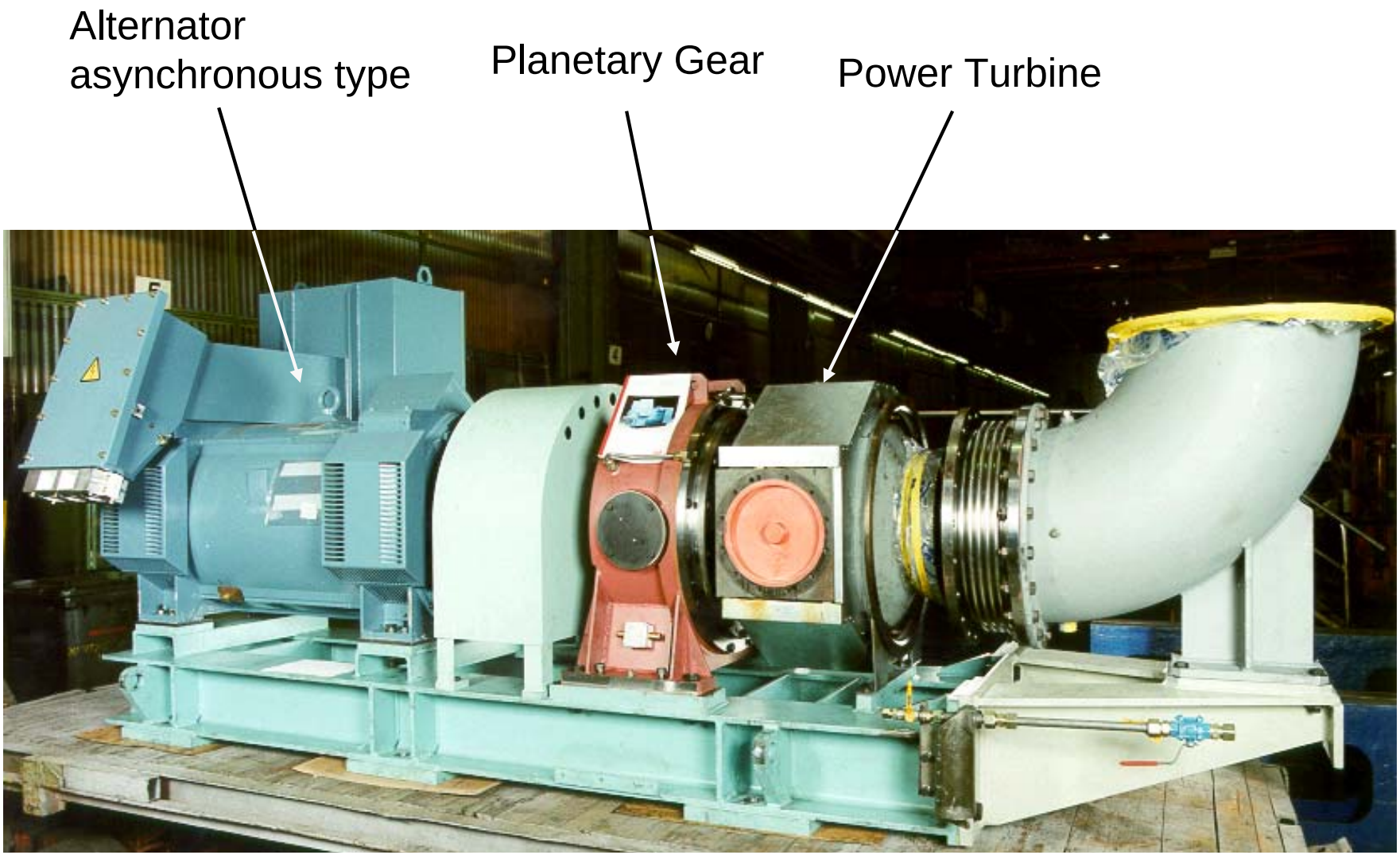
PT44	-	2,300 kW
PT55	-	3,200 kW
PT66	-	4,500 kW



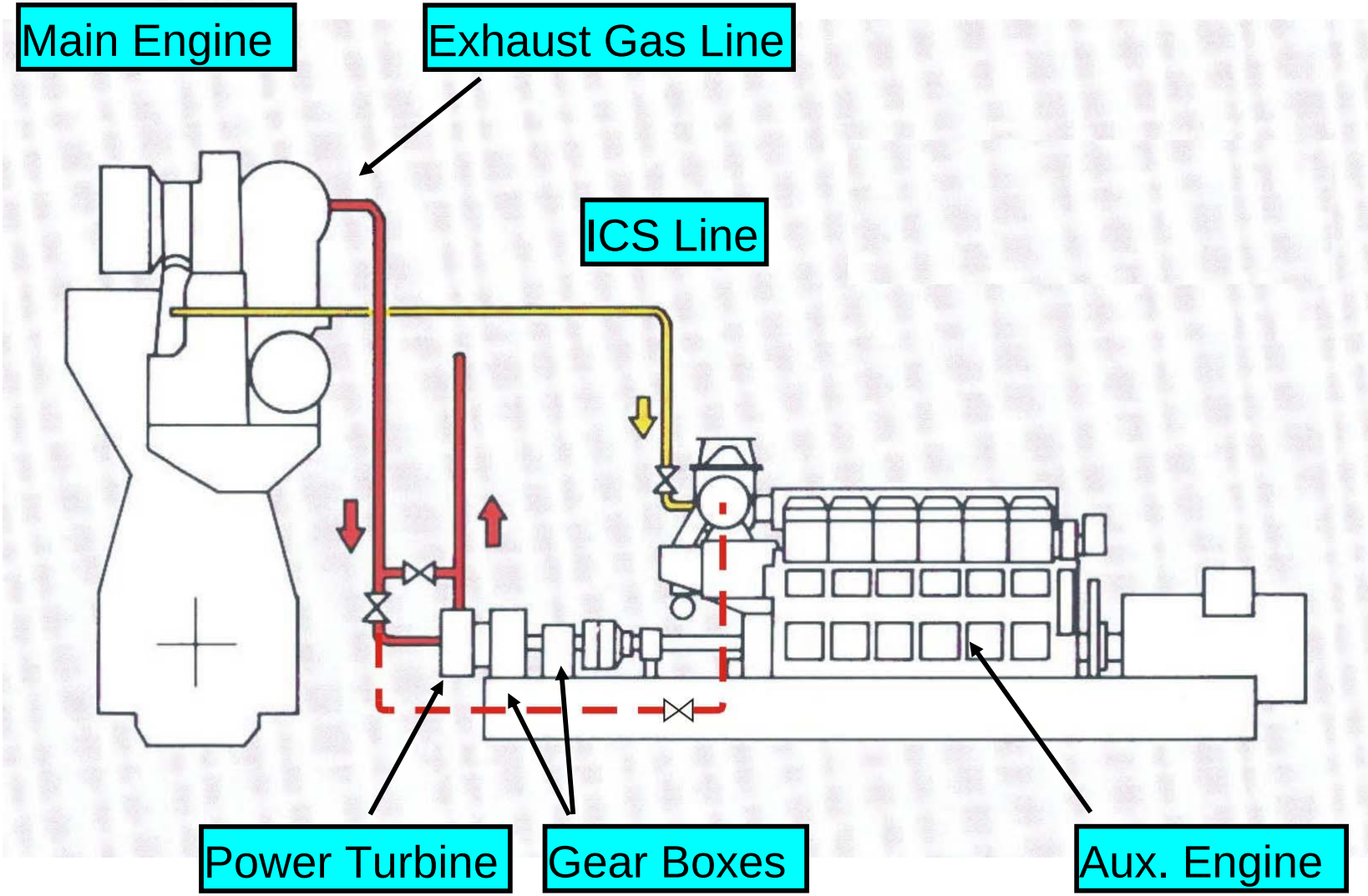




Power Turbine Generator



CODAG
Combination of Diesel and Gas-turbine



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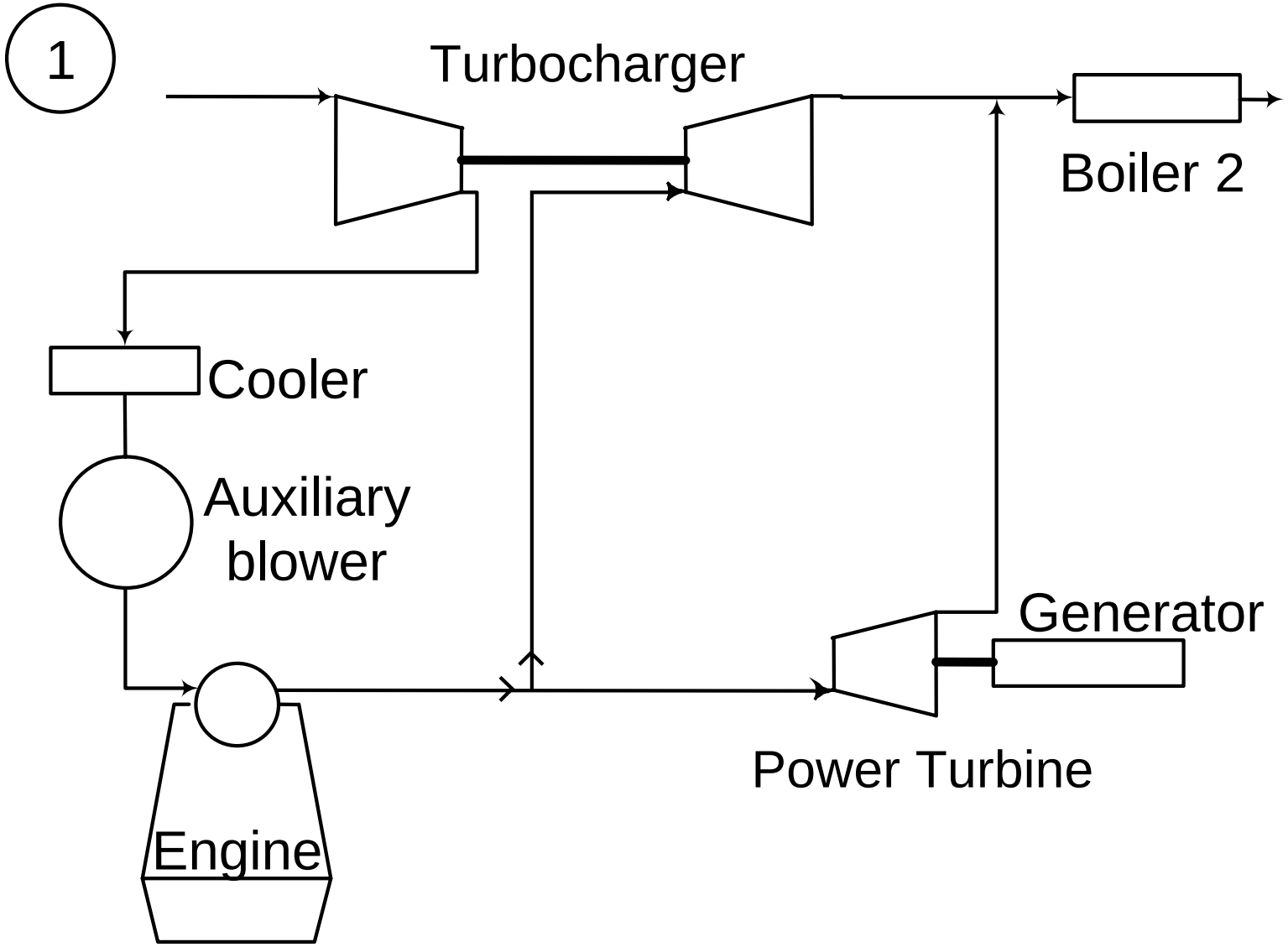
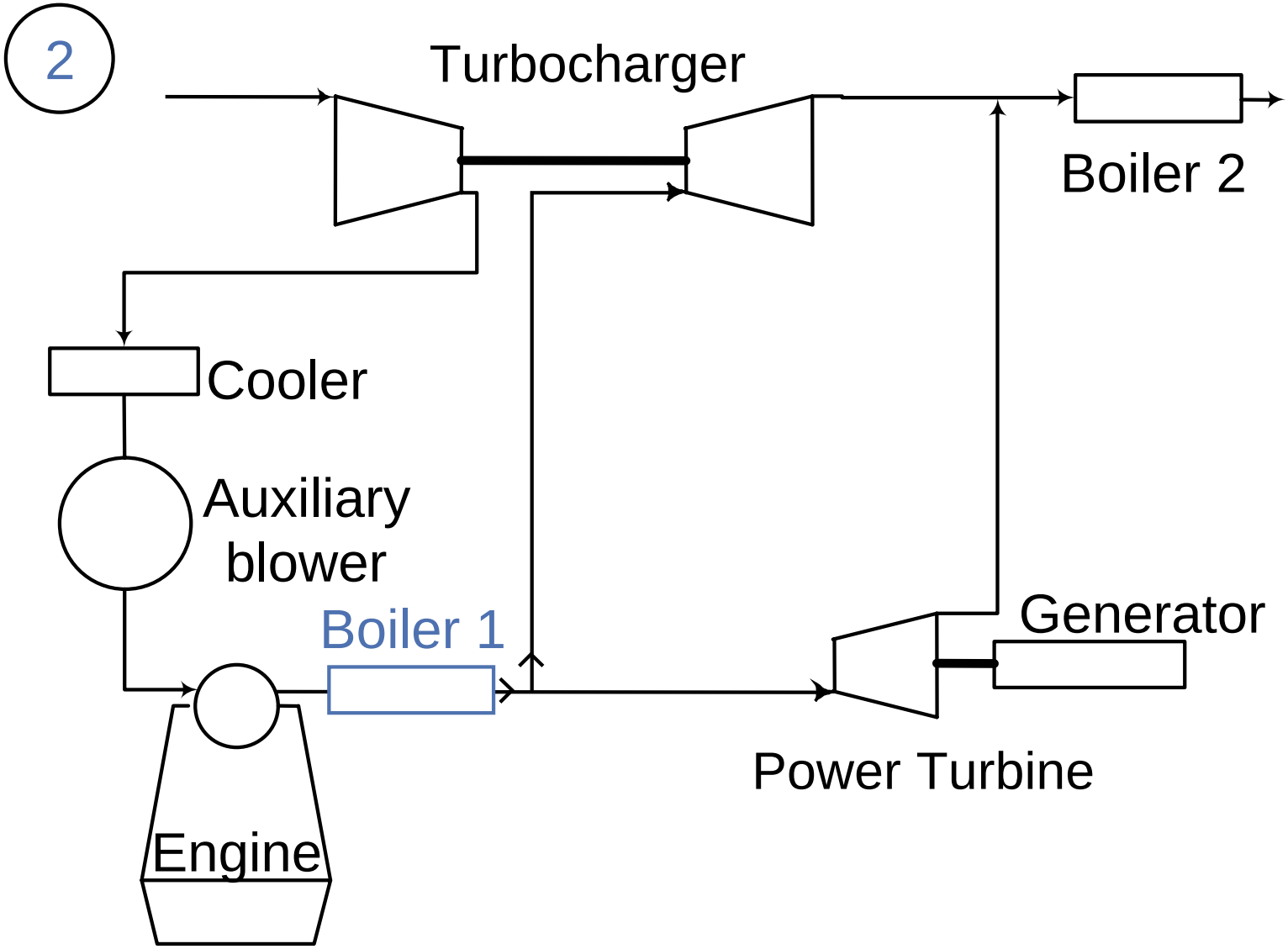
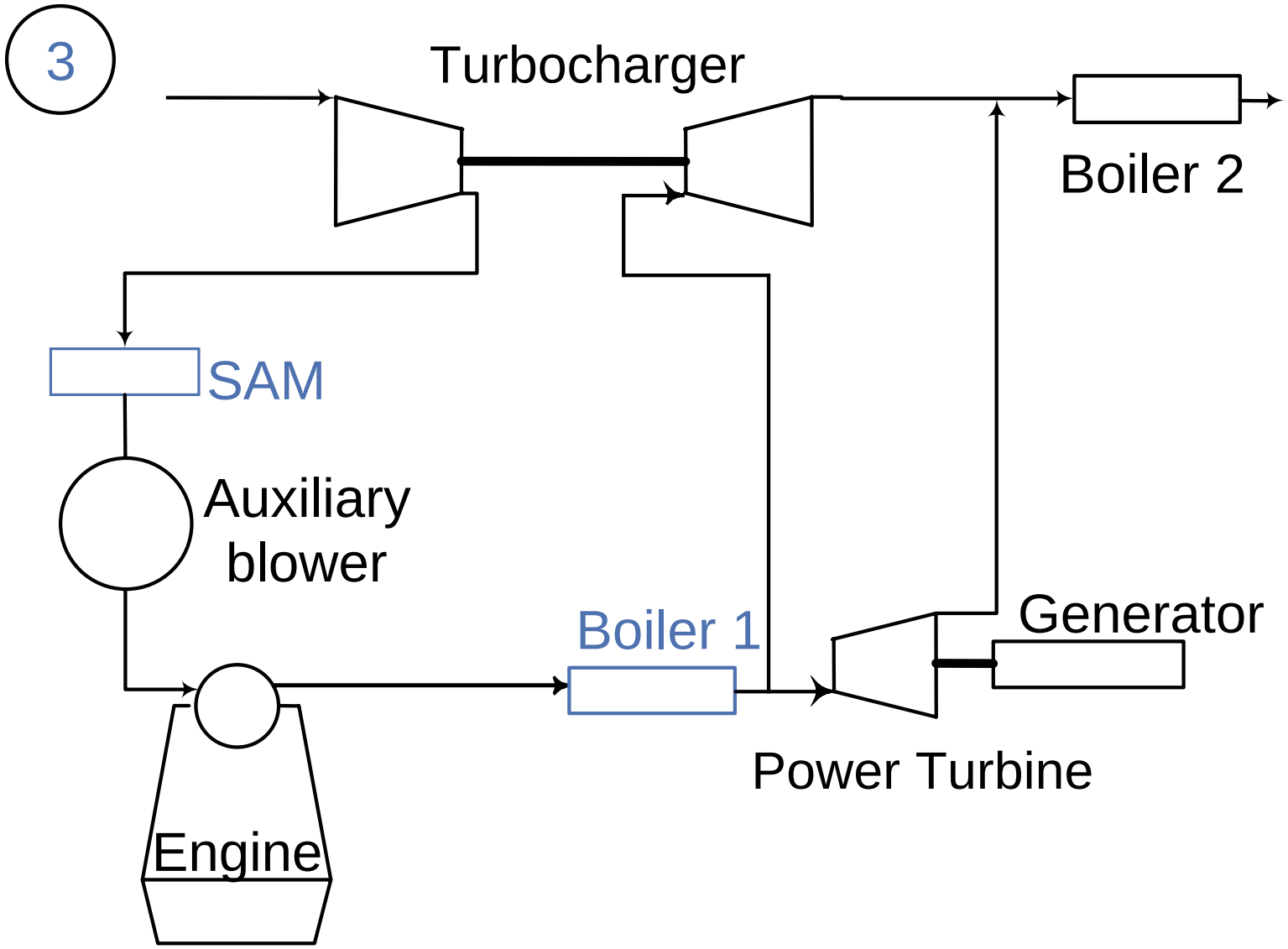

1
Turbocharger
Boiler 2
Cooler
Auxiliary
blower
Generator
Power Turbine
Engine

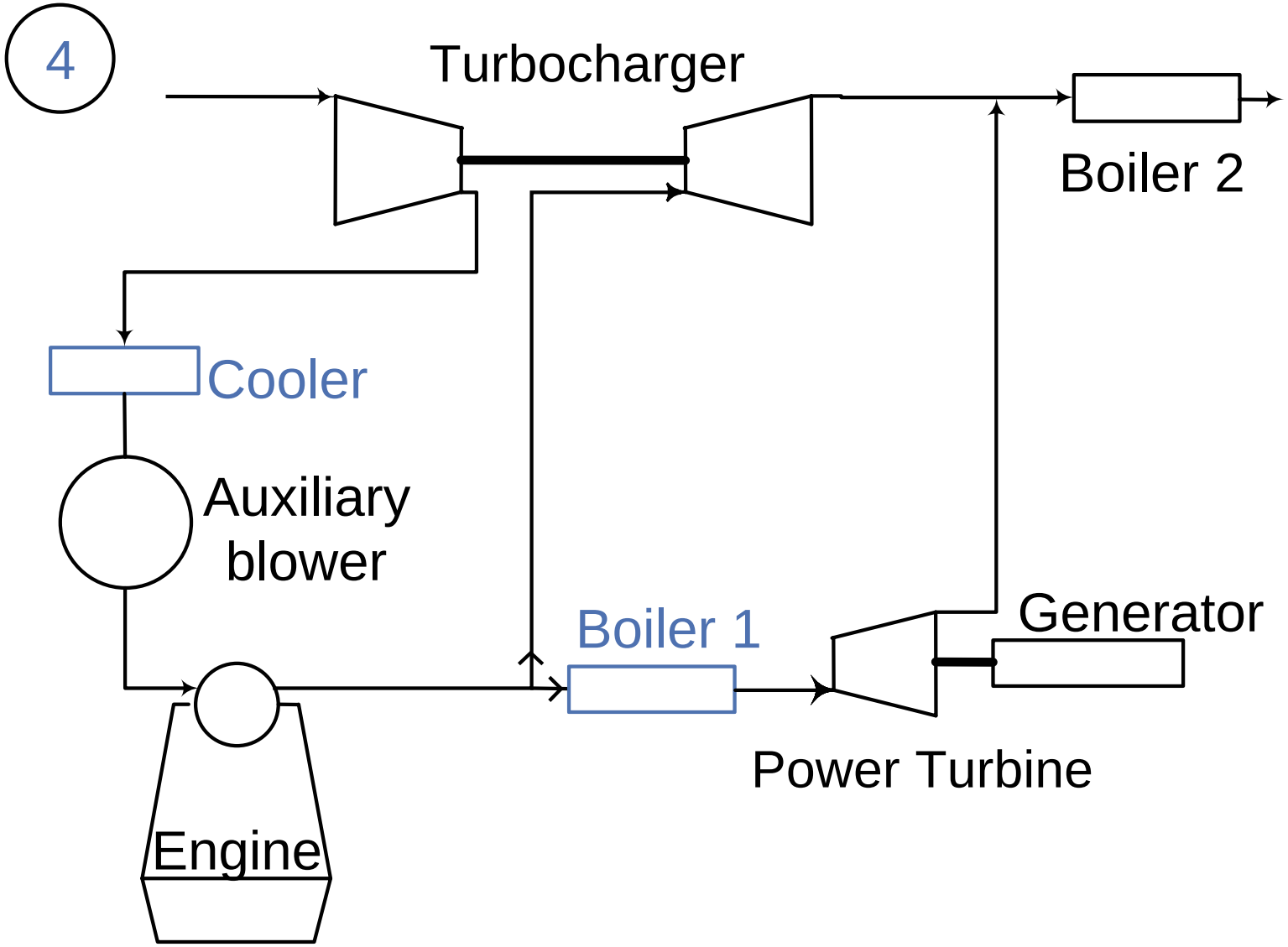
	Case 1
LP pressure [bar a]	**7**
LP super heat temperature [°C]	**270**
HP pressure [bar a]	**-**
HP super heat temperature [°C]	**-**
Heat extraction in Boiler 1 [kW]	**0**
Heat extraction in Boiler 2 [kW]	**20900**
Power turbine [kW]	**3017**
Steam turbine [kW]	**3798**
Total electrical power [kW]	**6815**
Power rel. to main engine [%]	**10**


2
Turbocharger
Boiler 2
Cooler
Auxiliary
blower
Boiler 1
Generator
Power Turbine
Engine

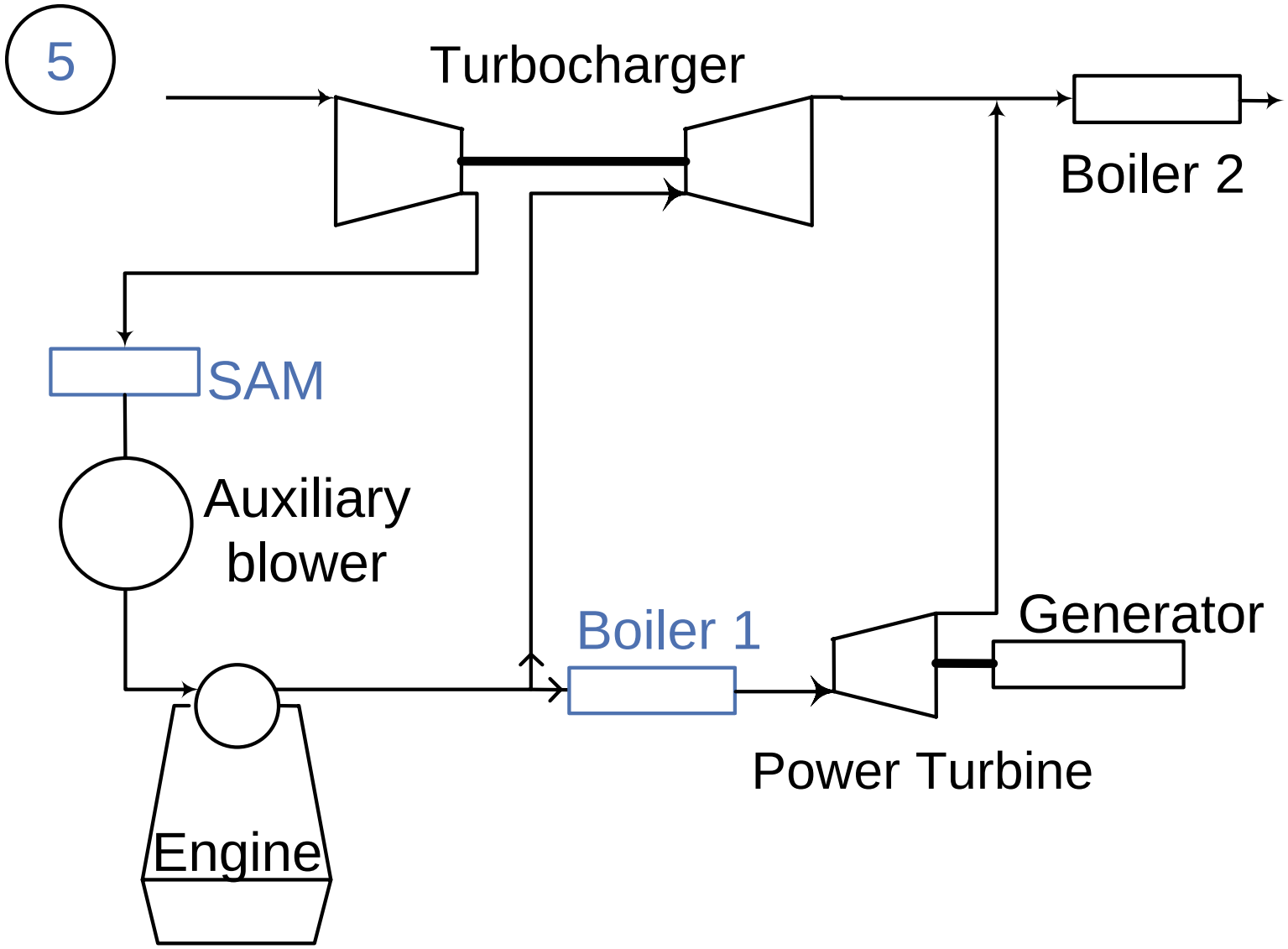
	Case 1	**Case 2**
LP pressure [bar a]	7	**7**
LP super heat temperature [°C]	270	**440**
HP pressure [bar a]	-	**-**
HP super heat temperature [°C]	-	**-**
Heat extraction in Boiler 1 [kW]	0	**4135**
Heat extraction in Boiler 2 [kW]	20900	**16460**
Power turbine [kW]	3017	**2080**
Steam turbine [kW]	3798	**5590**
Total electrical power [kW]	6815	**7670**
Power rel. to main engine [%]	10	**11.2**


3
Turbocharger
Boiler 2
SAM
Auxiliary
blower
Boiler 1
Generator
Power Turbine
Engine

	Case 1	Case 2	**Case 3**
LP pressure [bar a]	7	7	**7**
LP super heat temperature [°C]	270	440	**446**
HP pressure [bar a]	-	-	**-**
HP super heat temperature [°C]	-	-	**-**
Heat extraction in Boiler 1 [kW]	0	4135	**4840**
Heat extraction in Boiler 2 [kW]	20900	16460	**18880**
Power turbine [kW]	3017	2080	**2262**
Steam turbine [kW]	3798	5590	**6451**
Total electrical power [kW]	6815	7670	**8713**
Power rel. to main engine [%]	10	11.2	**12.7**


4
Turbocharger
Boiler 2
Cooler
Auxiliary
blower
Boiler 1
Generator
Power Turbine
Engine

	Case 1	Case 2	Case 3	**Case 4**
LP pressure [bar a]	7	7	7	**7**
LP super heat temperature [°C]	270	440	446	**281**
HP pressure [bar a]	-	-	-	**19.5**
HP super heat temperature [°C]	-	-	-	**440**
Heat extraction in Boiler 1 [kW]	0	4135	4840	**2902**
Heat extraction in Boiler 2 [kW]	20900	16460	18880	**17840**
Power turbine [kW]	3017	2080	2262	**2436**
Steam turbine [kW]	3798	5590	6451	**6350**
Total electrical power [kW]	6815	7670	8713	**8786**
Power rel. to main engine [%]	10	11.2	12.7	**12.8**


5
Turbocharger
Boiler 2
SAM
Auxiliary
blower
Boiler 1
Generator
Power Turbine
Engine

	Case 1	Case 2	Case 3	Case 4	**Case 5**
LP pressure [bar a]	7	7	7	7	**7**
LP super heat temperature [°C]	270	440	446	281	**266**
HP pressure [bar a]	-	-	-	19.5	**10**
HP super heat temperature [°C]	-	-	-	440	**446**
Heat extraction in Boiler 1 [kW]	0	4135	4840	2902	**4781**
Heat extraction in Boiler 2 [kW]	20900	16460	18880	17840	**19420**
Power turbine [kW]	3017	2080	2262	2436	**4418**
Steam turbine [kW]	3798	5590	6451	6350	**7922**
Total electrical power [kW]	6815	7670	8713	8786	**12340**
Power rel. to main engine [%]	10	11.2	12.7	12.8	**18.0**

Conclusion

- **Significant increase in efficiency is possible.**
- **Reliability of the engine itself is unchanged.**
- **Shipyards are reluctant to introduce due to high order volume.**
- **Payback time is typical 5-6 years with current oil prices.**
- **TES must be considered at an early stage of a project.**


Thomas S. Knudsen