Snøhvit LNG

Rotating equipment

Main power supply

StatoilHydro

Outline

- ***Snøhvit gas turbines 81-DTn01 (n = 1 to 5):***
  - ***General data***
  - ***Air intake system***
  - ***Water wash system***
  - ***Gas turbine detailed design***
  - ***Low NOx combustor design (DLE)***
  - ***Typical performance data***
- ***Expanders - short***
  - ***LNG expansion turbine 25-CT201***

Gas turbines

Power production based on utilising the chemical energy in a fuel by combustion can be obtained in several different machine designs. Of these, the gas turbines is often selected based on:

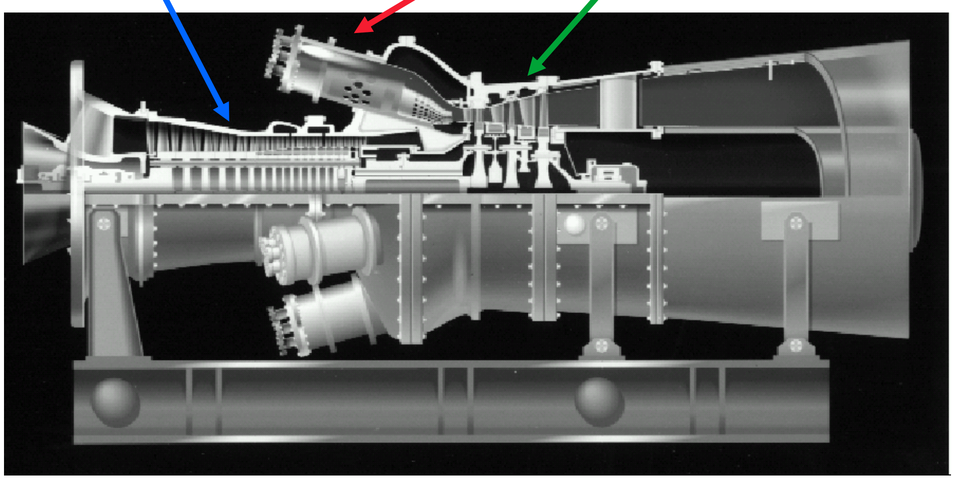
- **Size and weight (relative to the power produced) – airplanes, offshore**
- **The possibility to use either gas or liquid fuel**
- **Minimum requirements for utilities and cooling**
- **Good reliability and low maintenance requirements**
- **The exhaust heat can be utilised for heating or process purposes**

Gas turbines can be used for:

- **Electric power production (Snøhvit)**
- **Drive for compressors or pumps**

The gas turbine cycle consists of:

Compressor **Combustor** **Turbine**

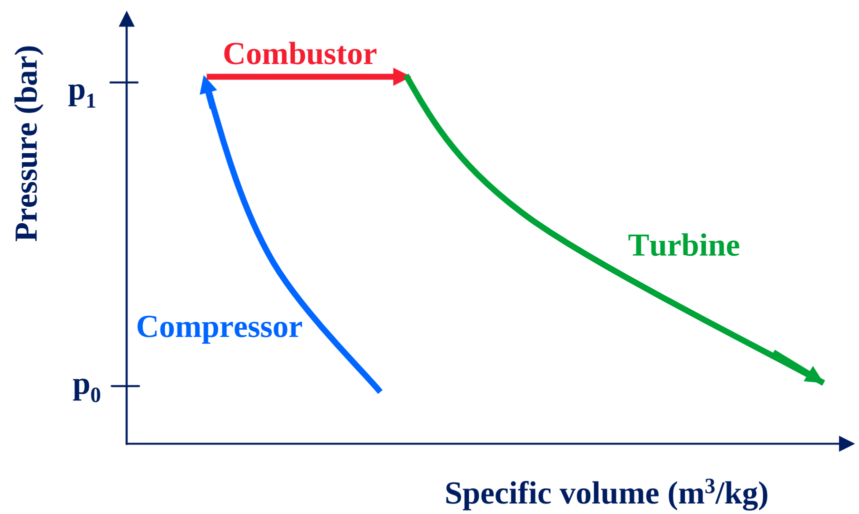


The efficiency of a gas turbine is given by (<u>thermal efficiency</u>):

$$\eta_{th} = \frac{P_{net}}{\dot{m}_{fuel} \cdot \Delta H_{fuel}}$$

It is the ratio between net power produced (turbine power – compressor power) and the energy supplied by the fuel

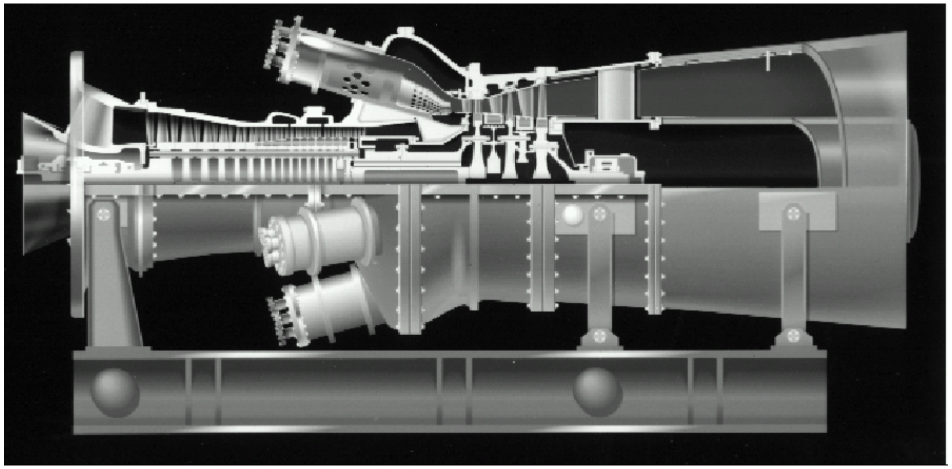
The gas turbine cycle is illustrated in the figure below:



The power delivered by one gas turbine system can range from some kW (micro machines) to more than 250 MW

Gas turbines – Compressor, combustor and turbine

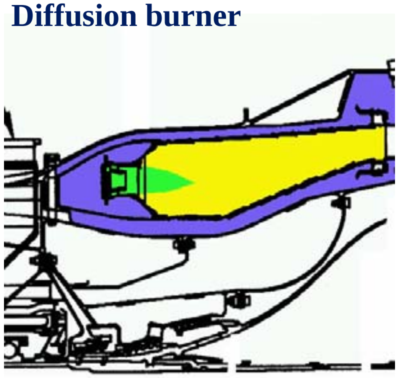
The compressor and turbine in the gas turbine are mostly axial design. The compressor uses in the area of 1/2 to 2/3 of the total power developed by the turbine.



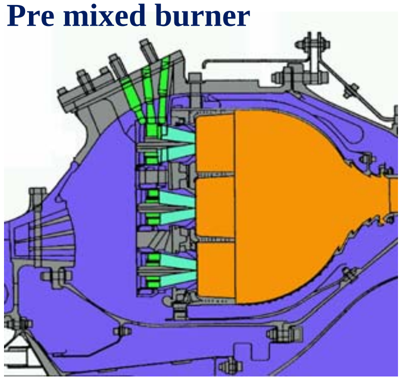
The combustor is the part of the engine where the energy is supplied by combustion of the fuel:

- Diffusion burners do not mix air and fuel before combustion – high NOx emissions
- Premixed burners mix air and fuel as much as possible before combustion – low NOx emissions (DLE combustors)
- Independent of design, the air to fuel ratio is 3 to 4 times the theoretical amount (air is45 to 60 times the mass of fuel)

Diffusion burner



Pre mixed burner



The turbine inlet temperature limits the power production and efficiency:

- The turbine inlet temperature is limited by the material used – Nozzles and blades are cooled by using air from the compressor (5 to 8 %).

Gas turbines – Classification

Gas turbines are classified as follows:

- **Heavy duty turbines or industrial turbines which were based on knowledge from design of steam turbines. They are typically low pressure and temperature of a robust design. Efficiency in the area of 30 to 35%.**
- **Aero derivate turbines which are based on turbines originally developed for airplanes. These are light weight modular gas turbines with higher pressure and temperature and hence higher efficiency – 35 to 40%**

Some advantages of aeroderivatives are:

- **30 to 50 % less footprint**
- **3 – 5 times less weight**
- **20 to 30 % lower specific fuel consumption**
- **Less power required for starting**
- **Faster start up and run down**
- **Substantial less lube oil requirement**
- **Easier inspection and higher availability – modular design i.e. sections of the machine can be replaced**

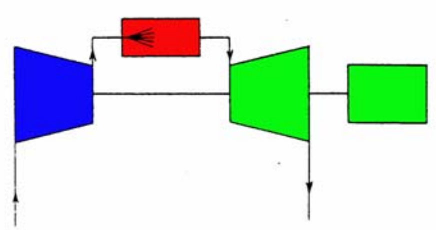
Some disadvantages of aeroderivatives are:

- **Slightly poorer reliability**
- **Up to 30 % higher investment cost**
- **Shorter operating life**
- **More stringent fuel quality requirements**

The gas turbine can consist of one, two or three shafts depending on design:

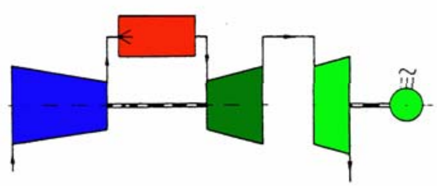
Single shaft (heavy duty):

- **Simple design**
- **Low cost**
- **Base load – power production**



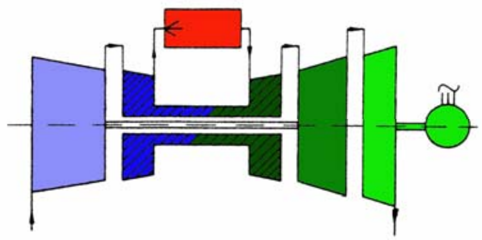
Two shaft:

- **More complex**
- **Higher efficiency**
- **More flexible – load change**
- **Power turbine on separate shaft**



Three shaft:

- **High compression ratio**
- **Increased flexibility**
- **Better surge margin – load changes**
- **Low pressure compressor – medium pressure turbine on separate shaft**

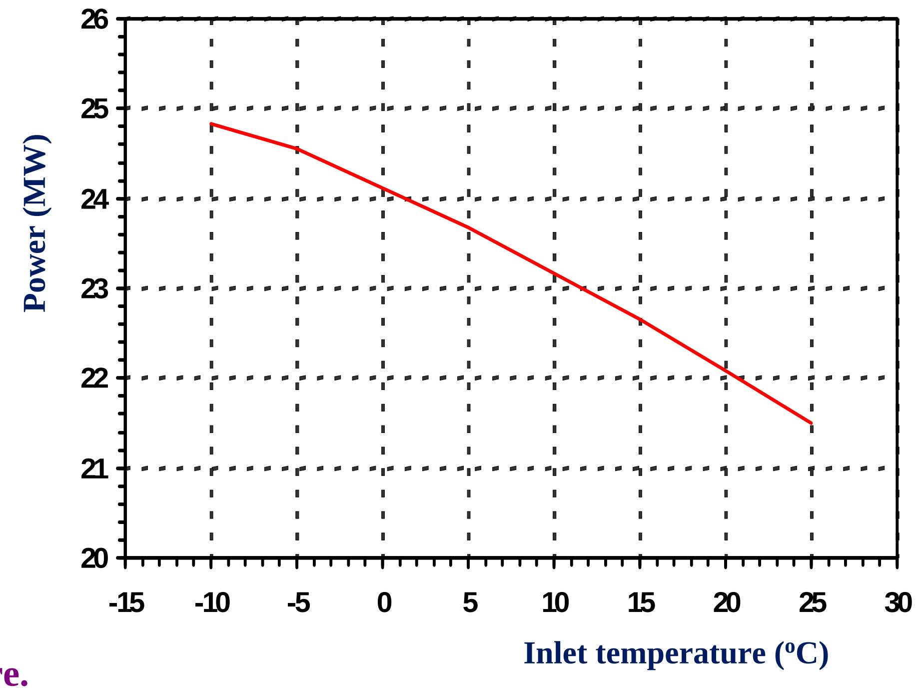


Gas turbines – Performance

The performance of gas turbines are influenced by the following factors:

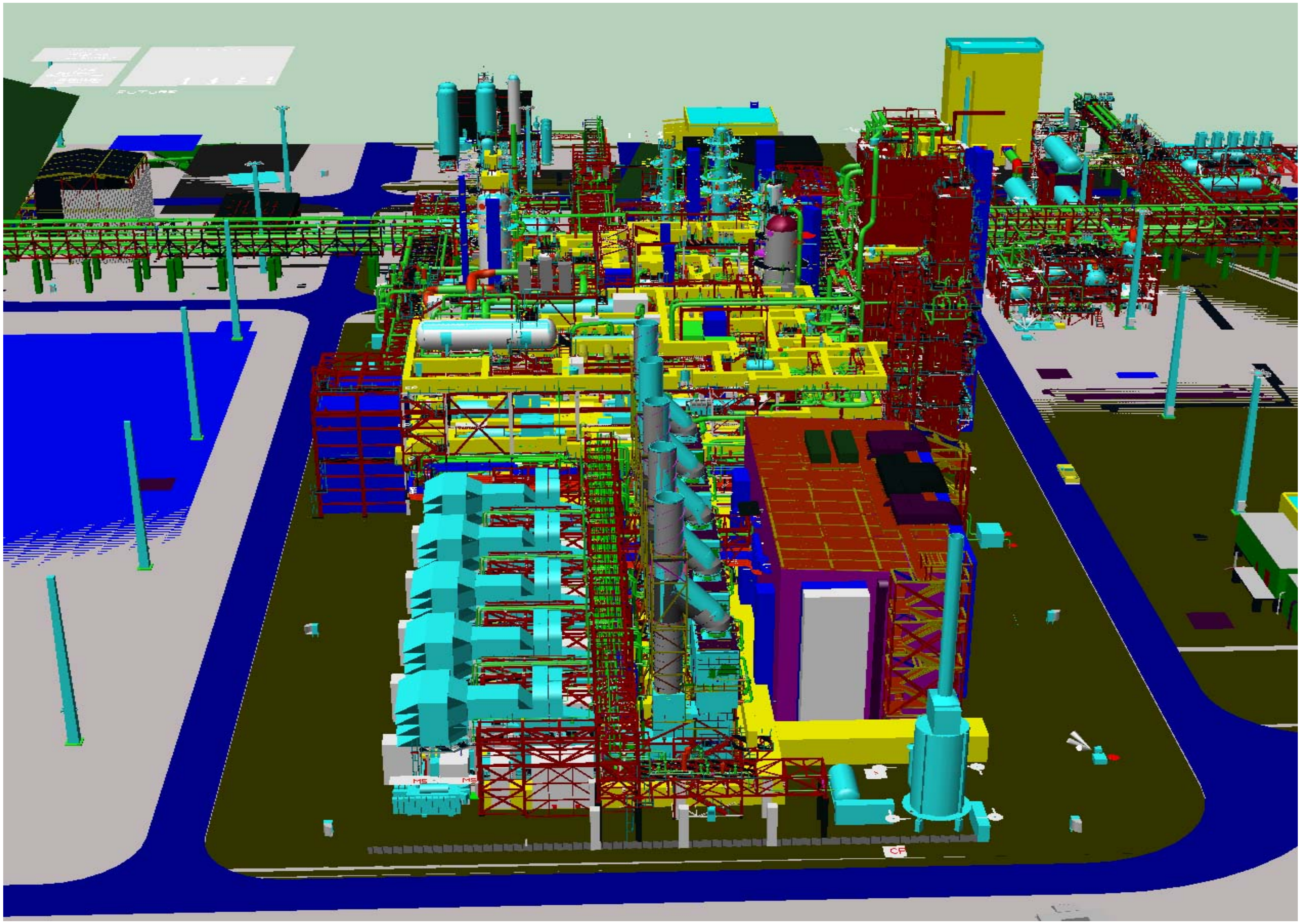
- Pressure loss in the compressor inlet system:
  - Filter, silencer, inlet duct – reduces performance due to decreased mass flow and reduced compressor discharge pressure
- Pressure loss in the turbine outlet system:
  - Silencer, heat recovery system, outlet duct – reduces performance due to reduced pressure ratio across the turbine
- Elevation above sea level:
  - Decreased air density lowers the mass flow. At 1000 m the power is reduced by 10%
- Compressor inlet temperature:
  - Decreased inlet temperature – Turbine power increases by around 1% for each ^oC lower temperature. At lower temperatures, the anti-icing system acts to increase the inlet temperature to avoid icing in the intake system. This is obtained by directing hot air from the compressor to the inlet system
- Deterioration:
  - Fouling – incrustation due to oil vapour, smoke, salt etc. reduces the flow area and might block the cooling channels. This can reduce the power production by up to 10%. Counteracted by washing
  - Corrosion and erosion – this causes roughening of the surface and increases the flow losses. The danger of blade failure also increases. These effects can be greatly reduced by thorough filtering

The operational characteristics of a gas turbine is typically given as shown in the figure (here GE LM2500PE):



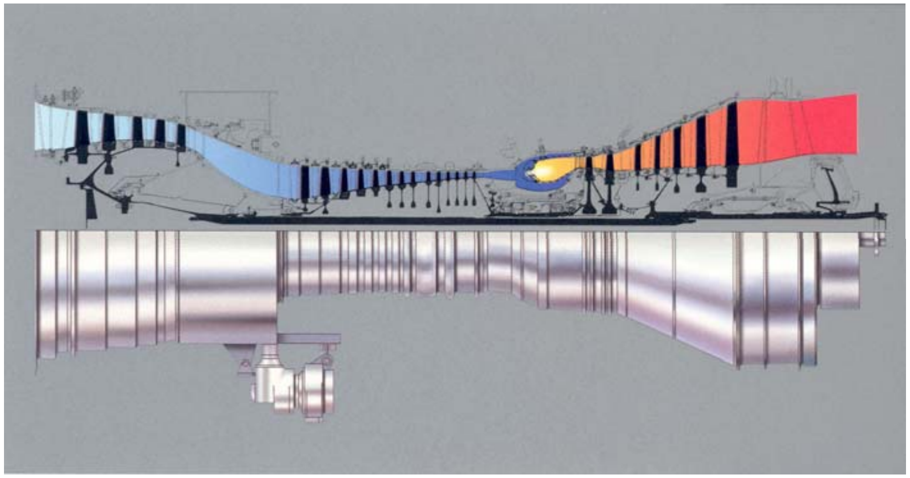
Snøhvit - Gas turbines

The power required by the LNG plant at Melkøya is produced locally by five gas turbines each with hot oil heat recovery units for process heat supply



Snøhvit - Gas turbines

The power required for running the LNG plant at Melkøya is delivered by 5 GE LM6000 PD DLE gas turbines:

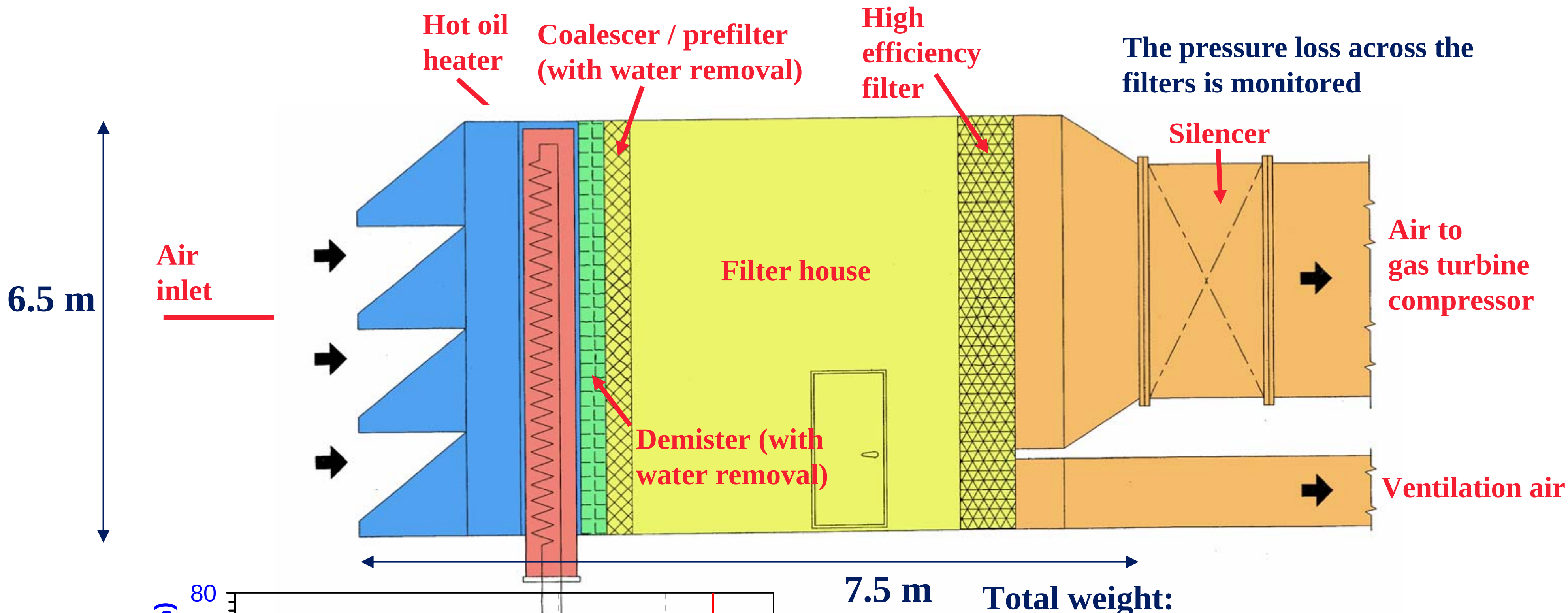


- Vendor: GE Nuovo Pignone
- Gas turbine cold end drive
- Speed reduction load gear: 3600/1500 RPM - El. frequency 50 Hz
- Proven in Electrical power generation
- Site rated (+4 Deg. C). Power output (new turbines) at generator terminals - 45.83 MW.
  Total power output - 229 MW
- Thermal efficiency - 42%
- Annular combustor w/Dry Low NOx system - 25 ppmVd @ 15 % O_2
  - Dry low NOx combustor (DLE) guaranteeing a NOx level of 25 ppm (only between 55 and 100% load):
    - The control system for the LM6000 machines will include low NOx optimization algorithm to obtain lowest possible NOx emissions (below 90% load, emissions can be reduced to around 15 ppm)
    - Further development in GE to develop 15 ppm combustor (guaranteed). Retrofit to existing machines.
- Inert gases in fuel - 7.96 %V (2.65 % N2 + 5.31 % CO2)
  - The control system is capable of handling fast fuel composition changes (heat value changes) – the gas turbine includes a calorimeter to obtain this
- Quick start - 10 minutes to max power
- 25000 hour repair intervals (3 years)
- Titanium anti-icing heat exchanger, medium: Hot oil (5 x Hot Oil WHRU's, Vendor: Alstom)

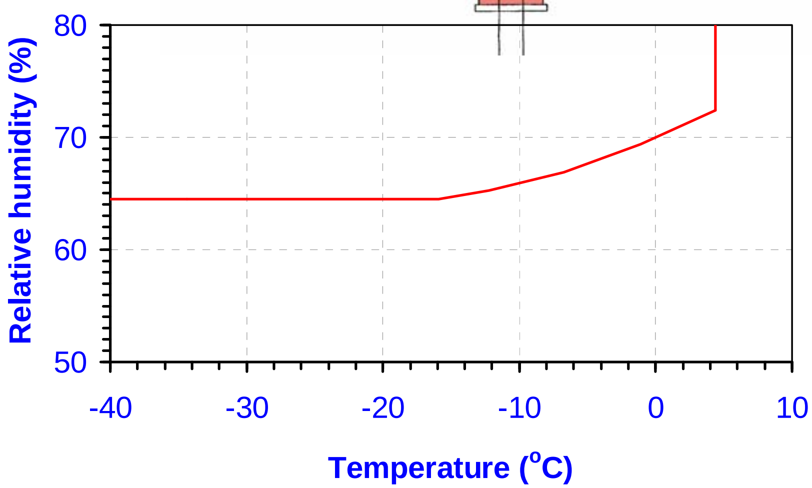
The gas turbine package have auxiliary systems like:

- air inlet system
- water wash system
- starting system
- lube oil system
- enclosure vent system
- fuel gas system

Snøhvit - Gas turbines – air intake system



The pressure loss across the filters is monitored



Total weight:

19 ton

At low temperature the anti-icing system (hot oil heater) is utilised according to the figure to the left

Snøhvit - Gas turbines – air intake system

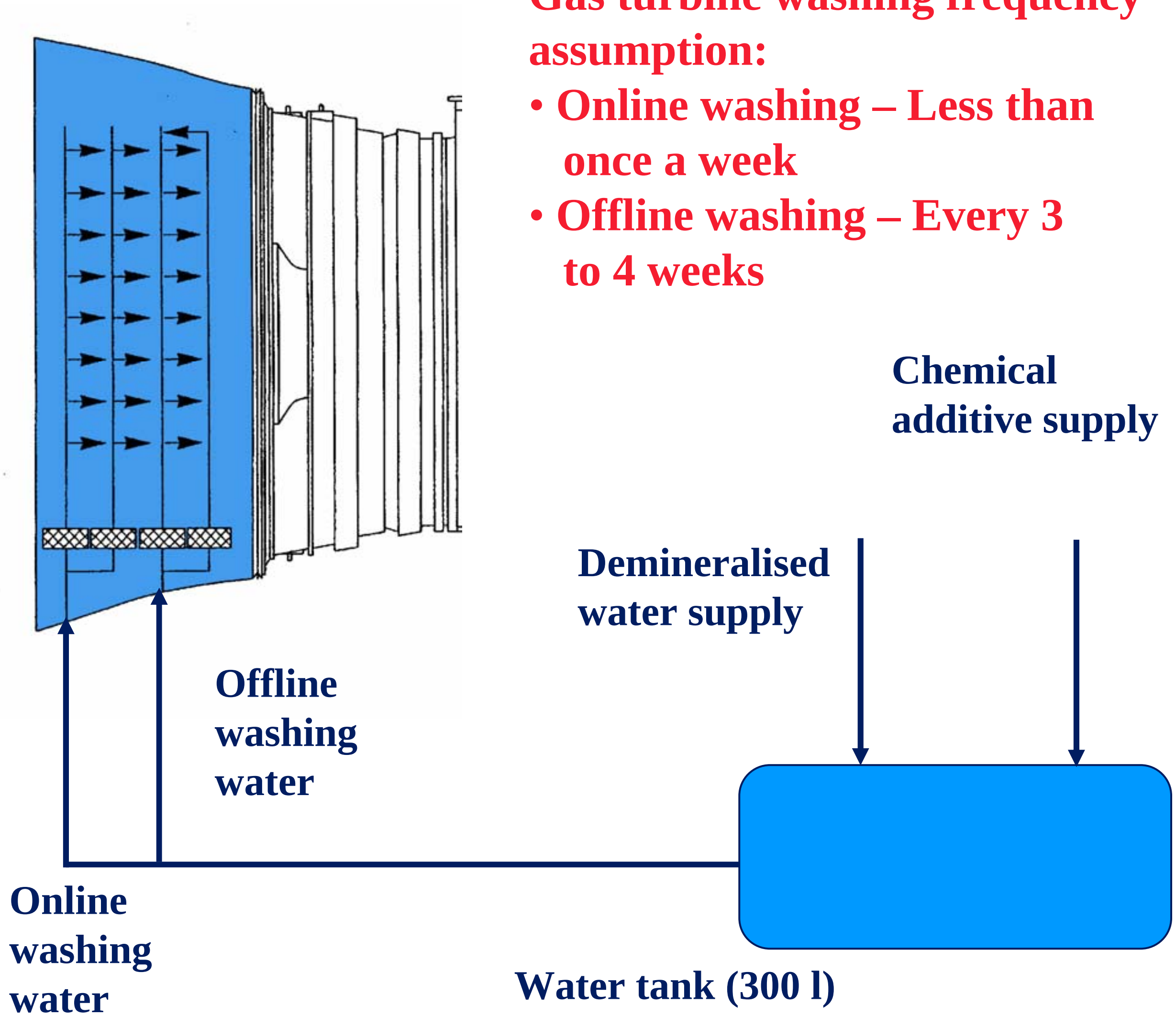
Inlet to filter

Inlet filter

Snøhvit - Gas turbines – water wash system

Gas turbine washing frequency assumption:

- **Online washing – Less than once a week**
- **Offline washing – Every 3 to 4 weeks**



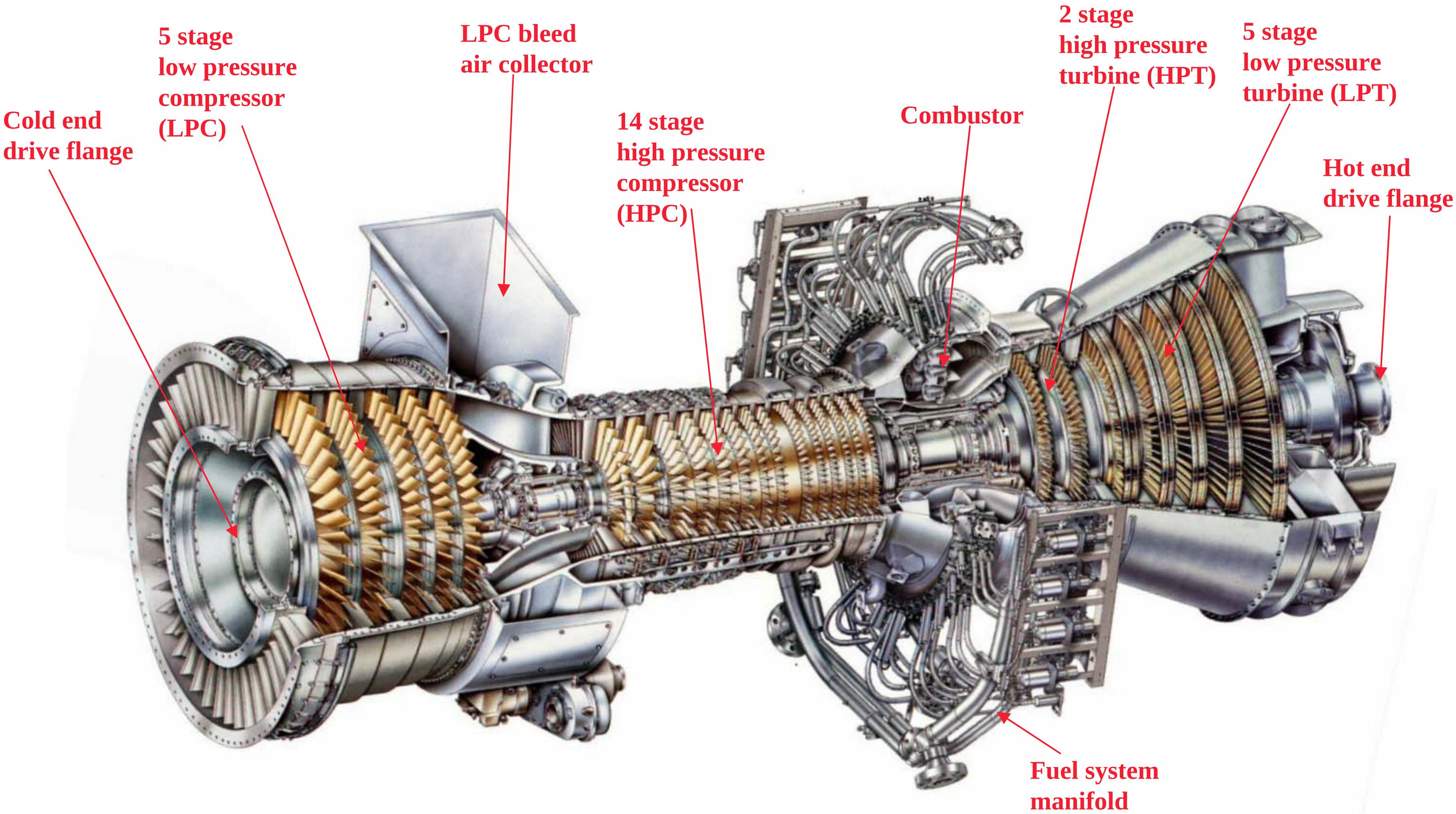
Snøhvit - Gas turbines, design

The LM 6000 gas turbine is based on the CF6-80 jet engine used in Boeing 747-400 (4) and Airbus A310 829 (2).

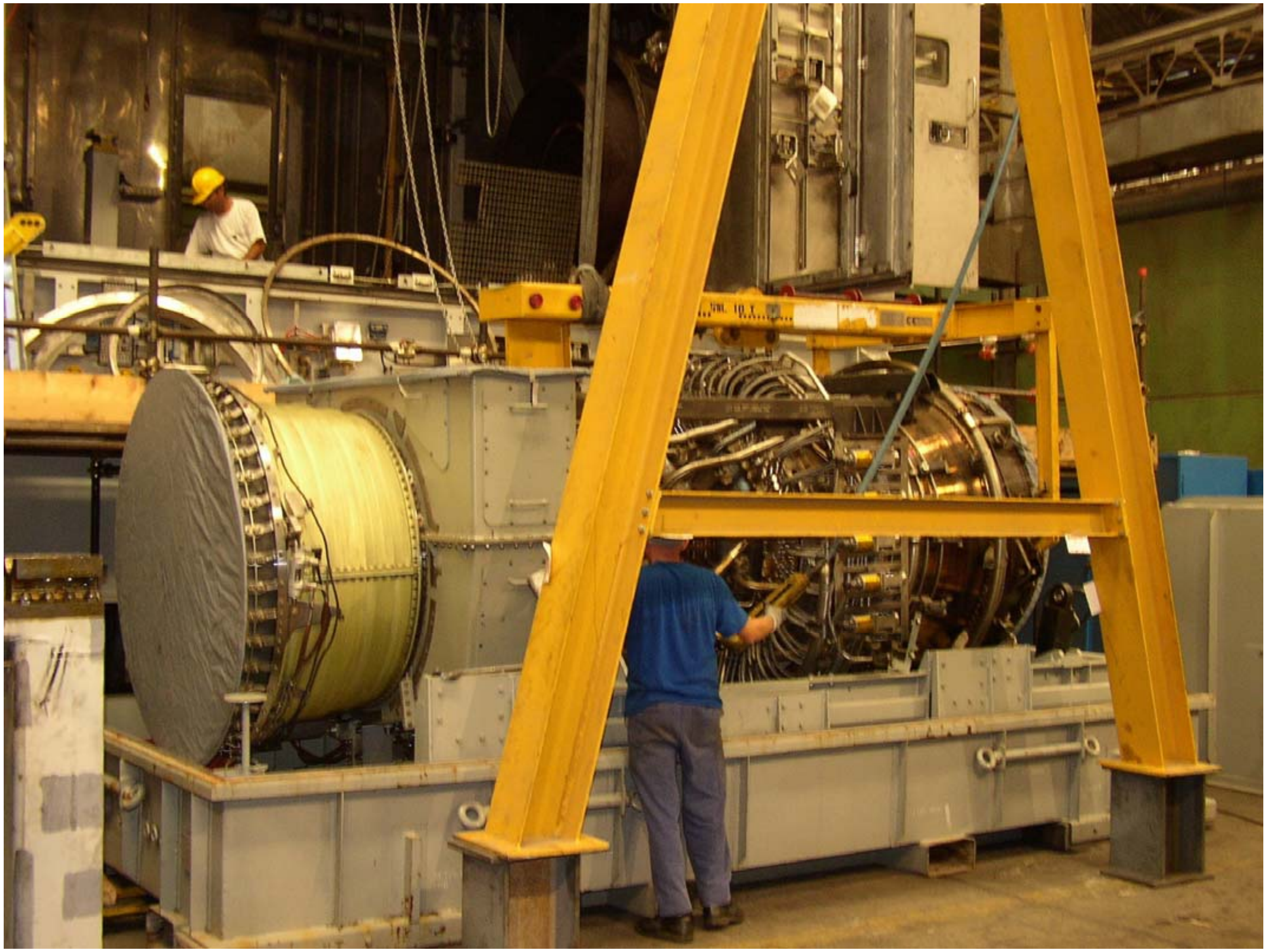
The LM6000 is a two shaft machine.

- Low pressure compressor connected to the power turbine
- High pressure compressor connected to the high pressure turbine – these units constitute the gas generator

The construction of the gas turbine is shown below:



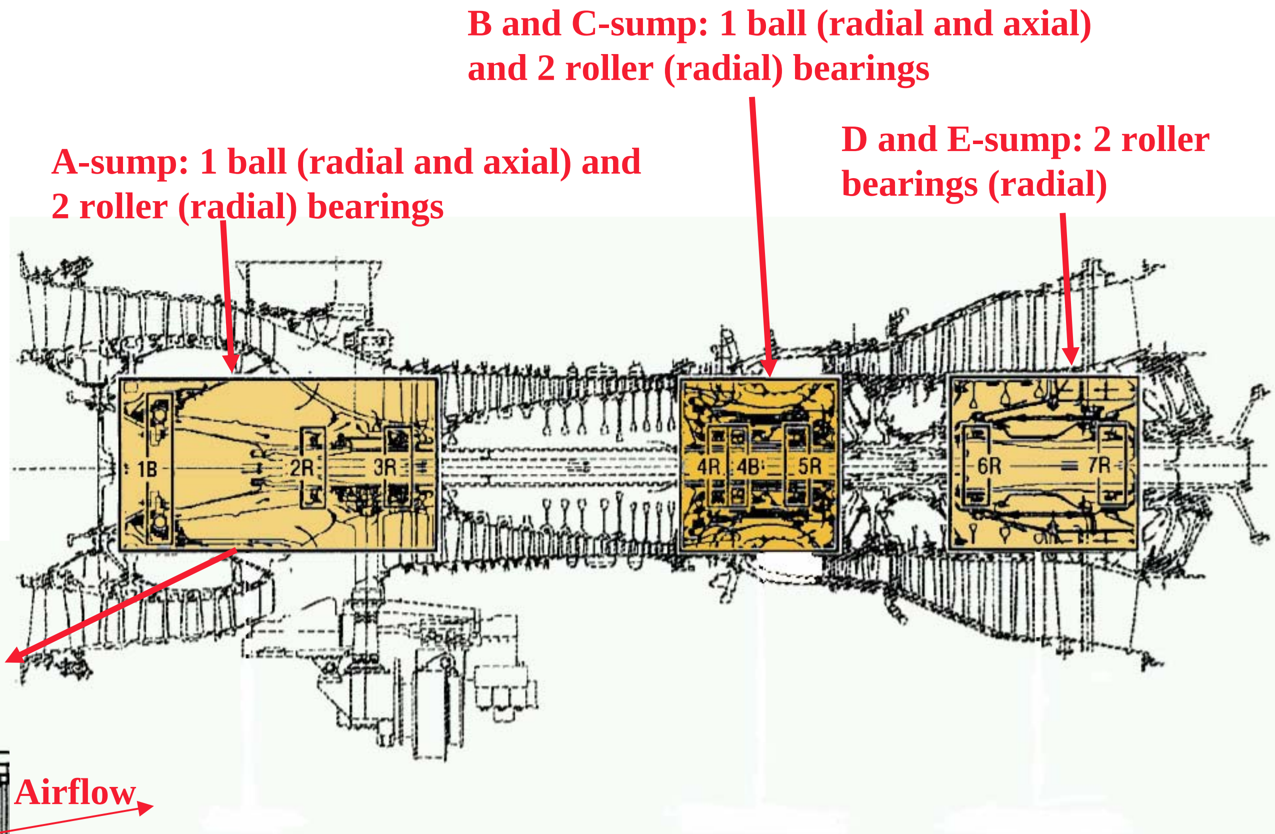
Snøhvit - Gas turbines, design



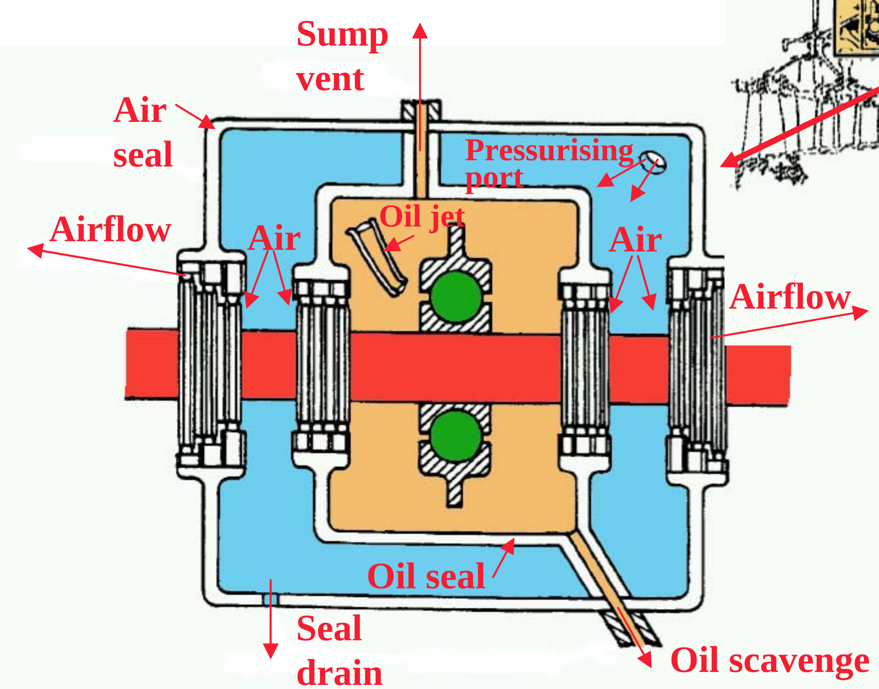
Total weight: 8.7 ton

Size (LxWxH): 5.6x2.6x2.5 m

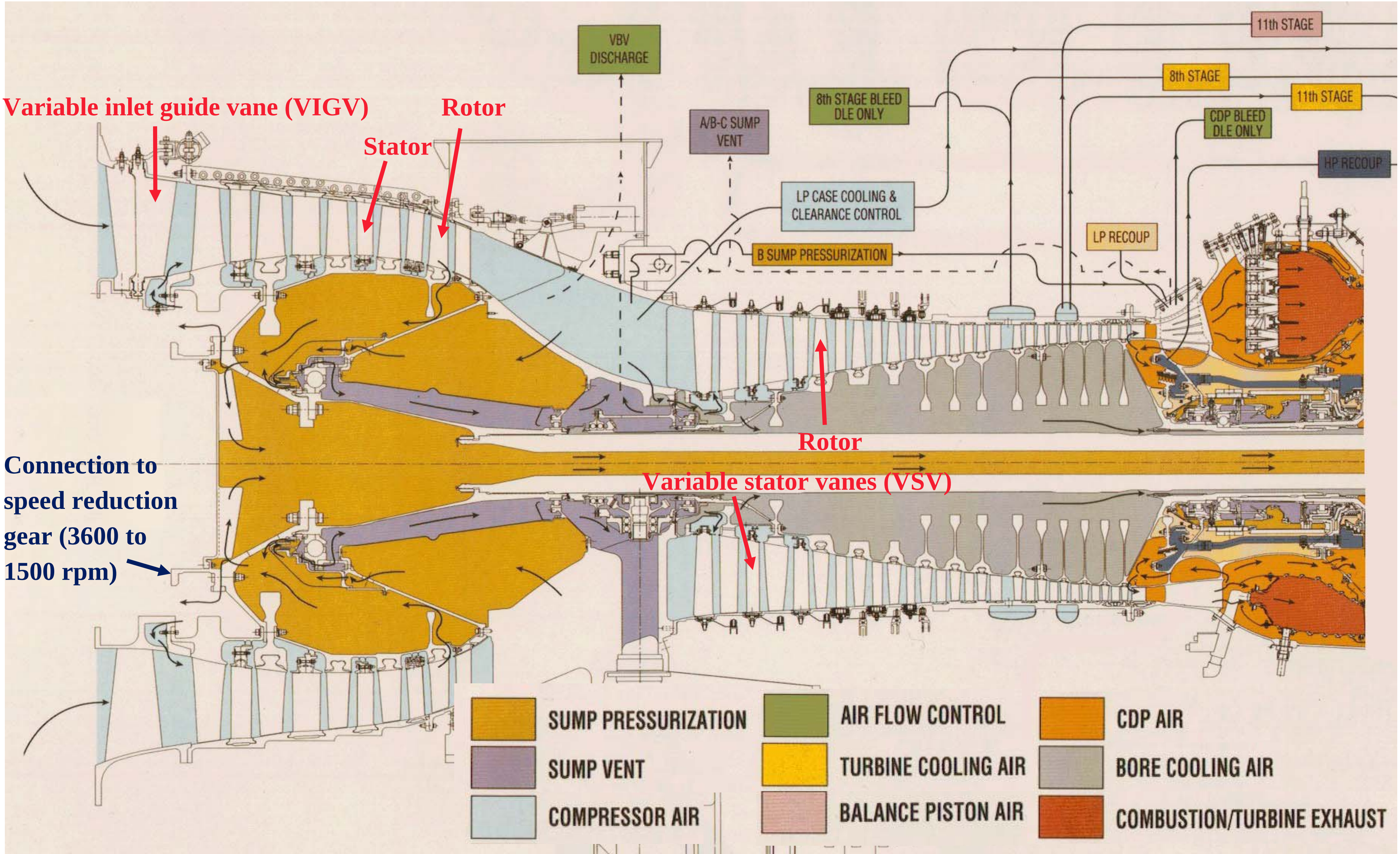
Snøhvit - Gas turbines, – bearings and lubrication



Sump details

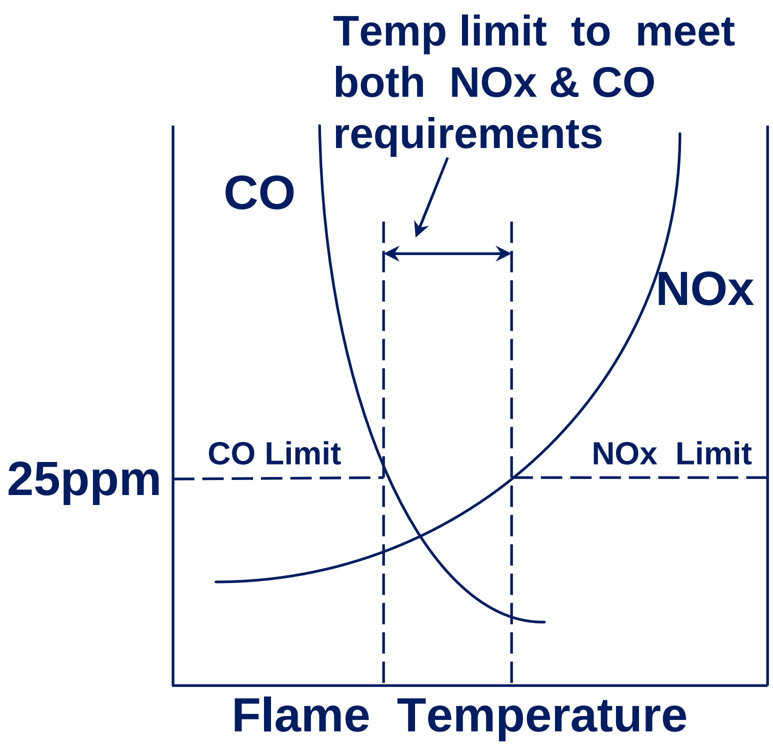


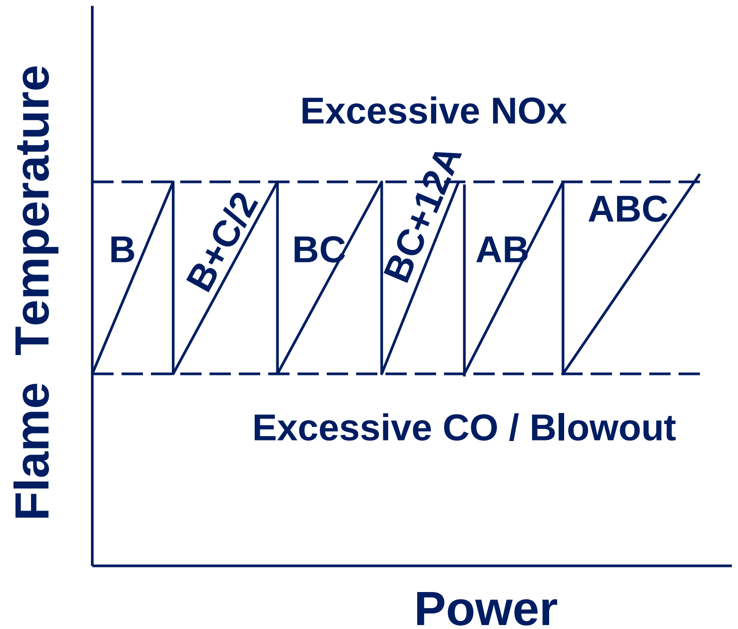
Snøhvit - Gas turbines, compressor , combustor and air flow



Snøhvit - Gas turbines, detailed design - Combustor

Combustion principles to meet low emissions





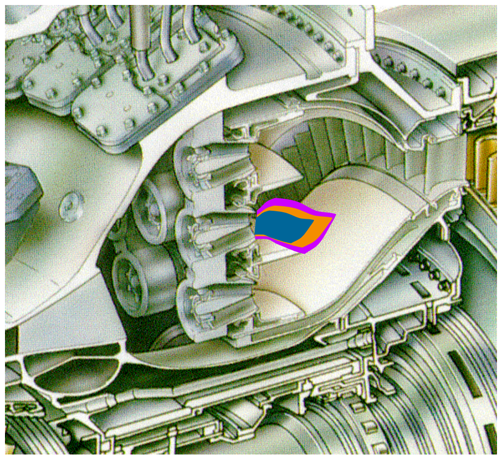
- Low NOx and CO emissions occur in a narrow band of flame temperatures
- With Diffusion Combustors (SAC) this can be achieved with water/steam injection

- GE LM Gas Turbines use Lean Pre-mixed Combustion with Fuel Staging to maintain the narrow flame temperature window (DLE)

Snøhvit - Gas turbines, detailed design - Combustor

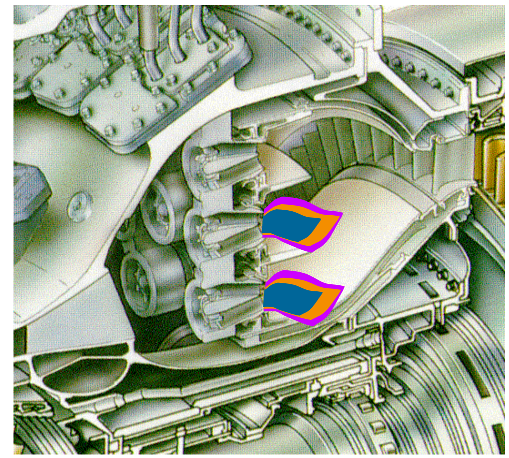
LM6000 PD DLE Combustor Staging Modes (6):

1. B Mode
30 premixers
Starting only



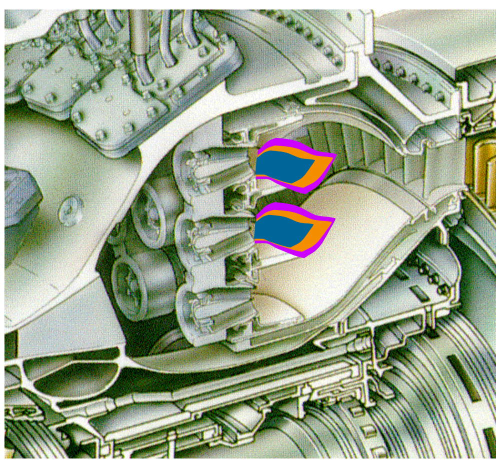
2. B+C/2
38 premixers
0% to 12% load

3. B+C Mode
45 premixers
7% to 29% load

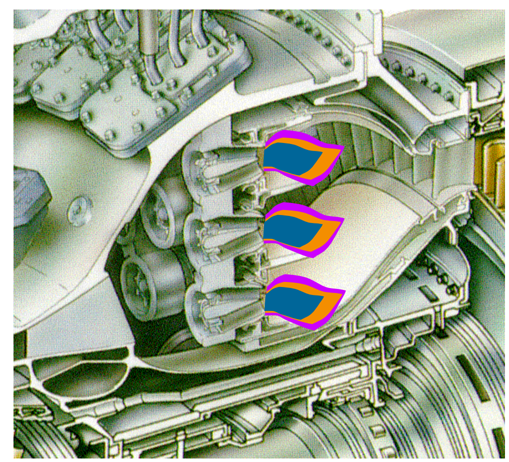


4. B+C+12A
57 premixers
25% to 58% load

5. A+B Mode
60 premixers
30% to 75% load

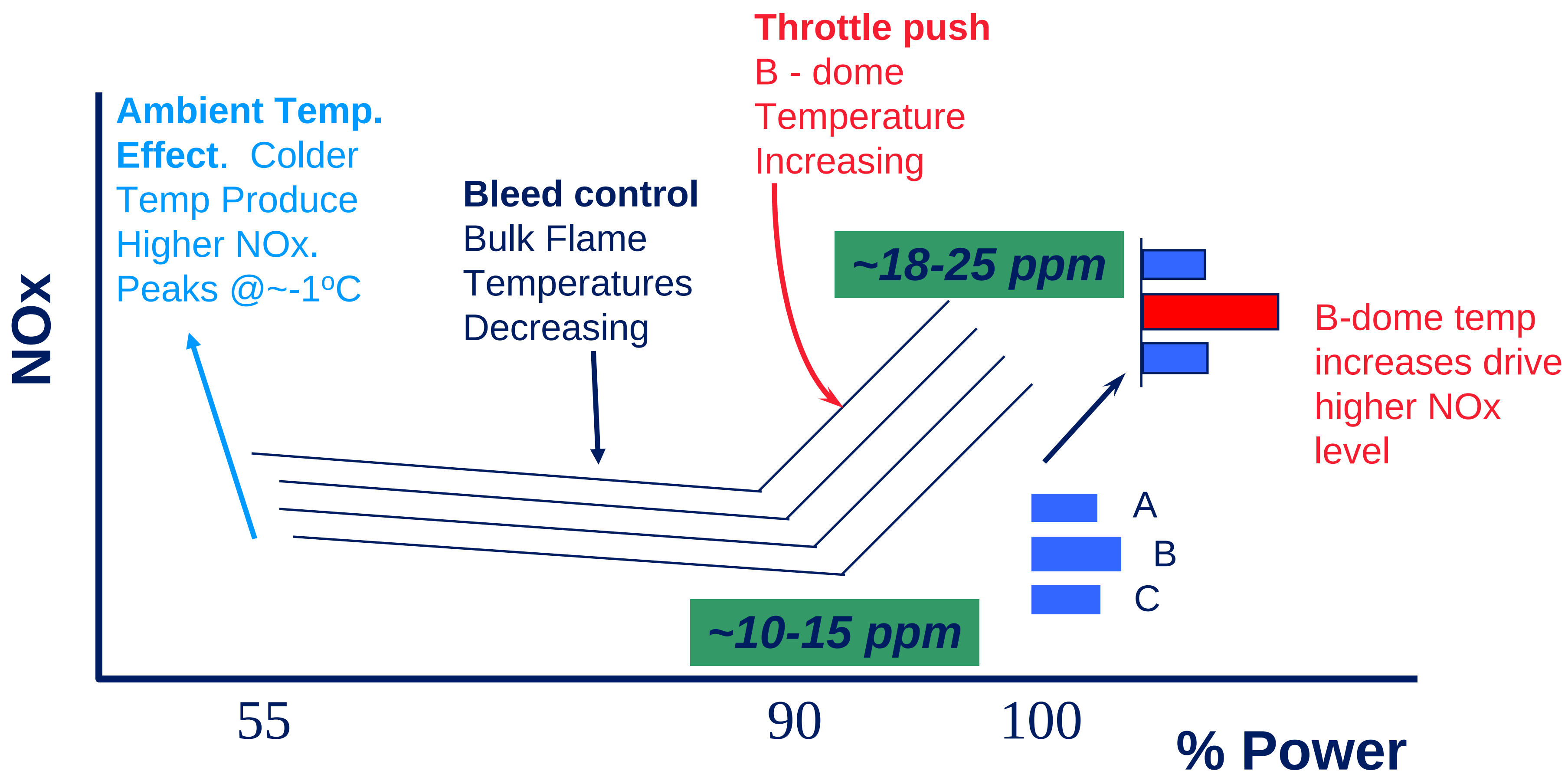


6. A+B+C Mode
75 premixers
50% to 100% load



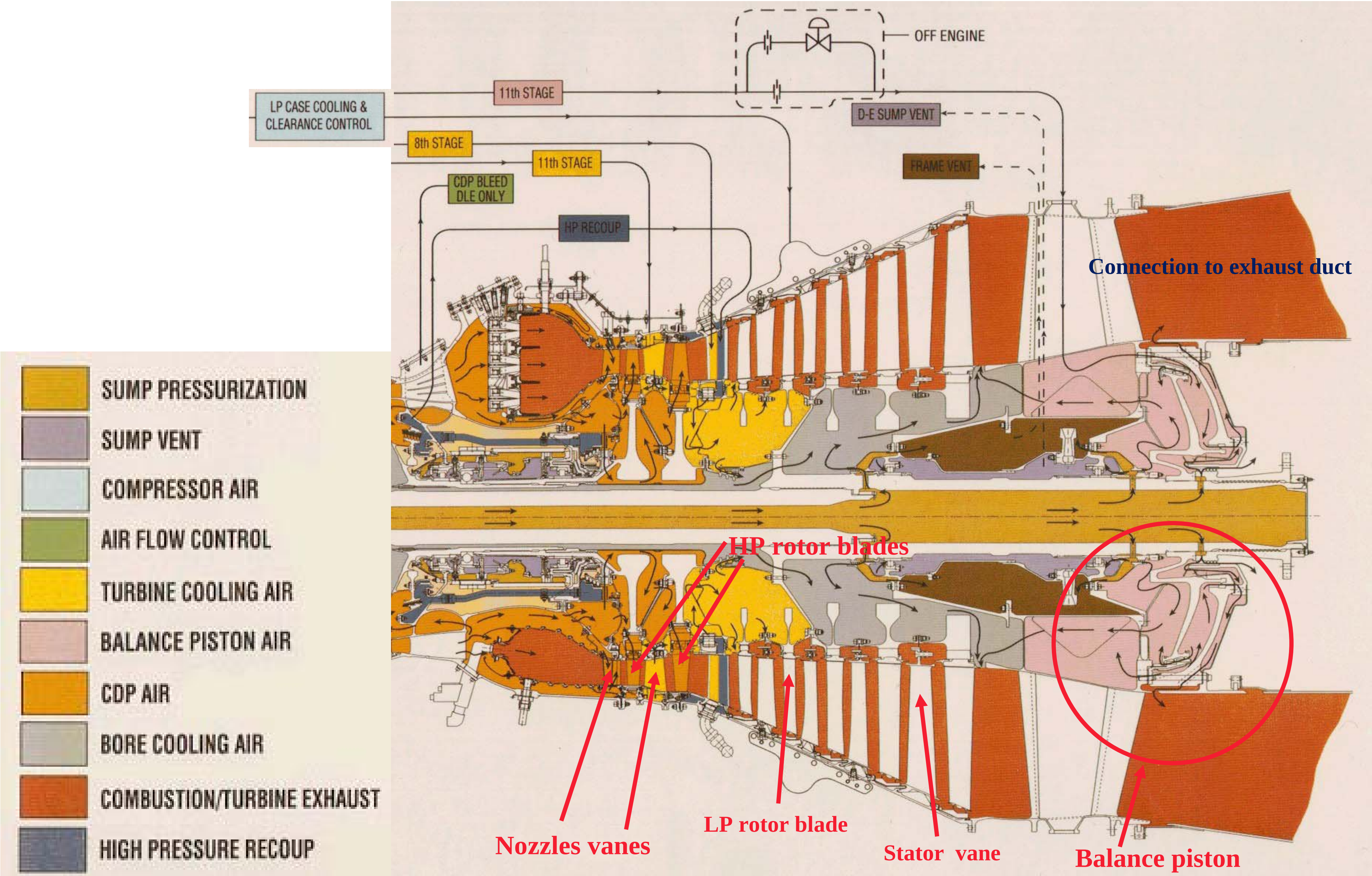
Snøhvit - Gas turbines, detailed design - Combustor

DLE Combustor NOx Characteristics

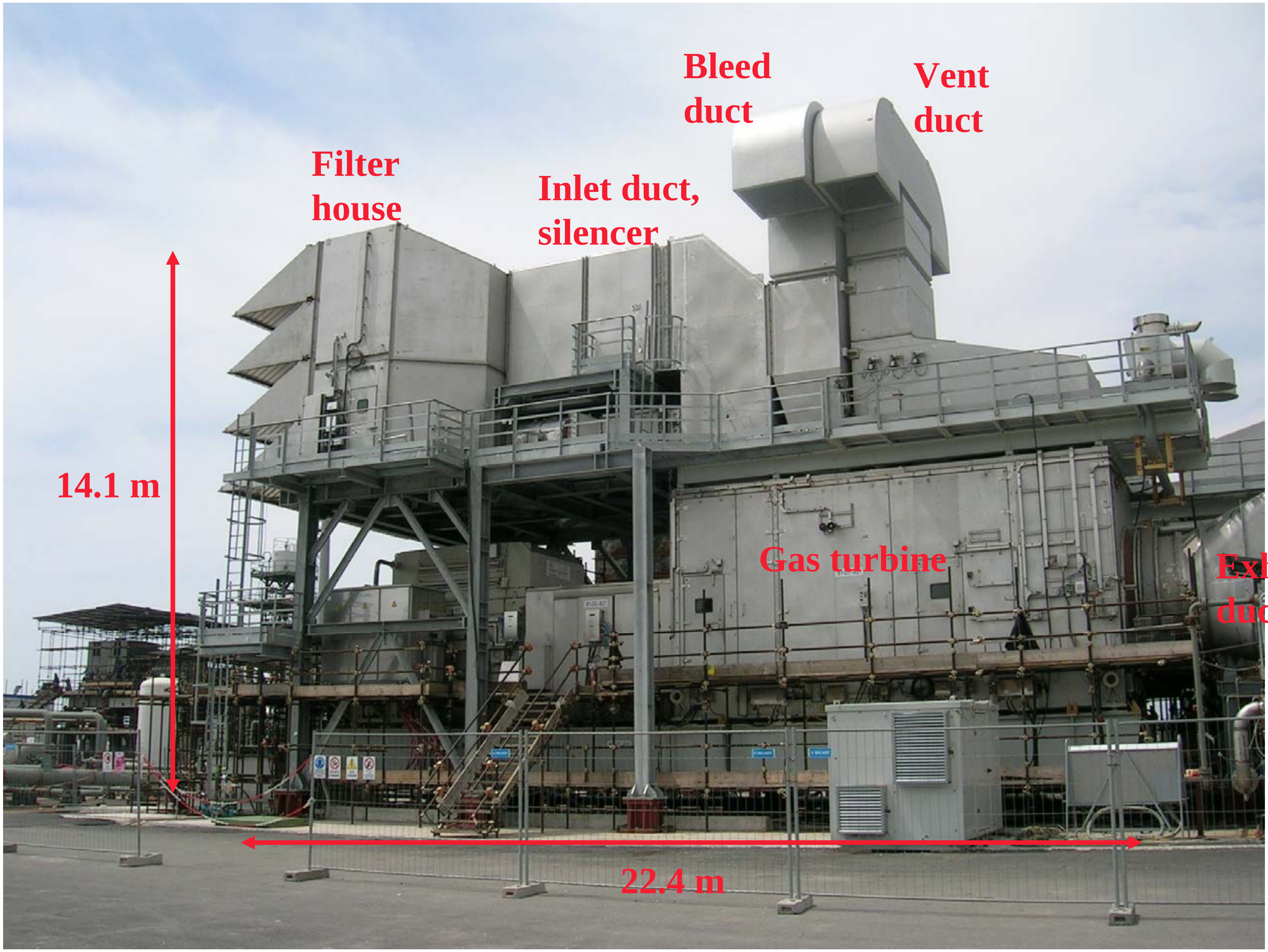


From 90 to 100% power, most of the NOx is generated in the B dome

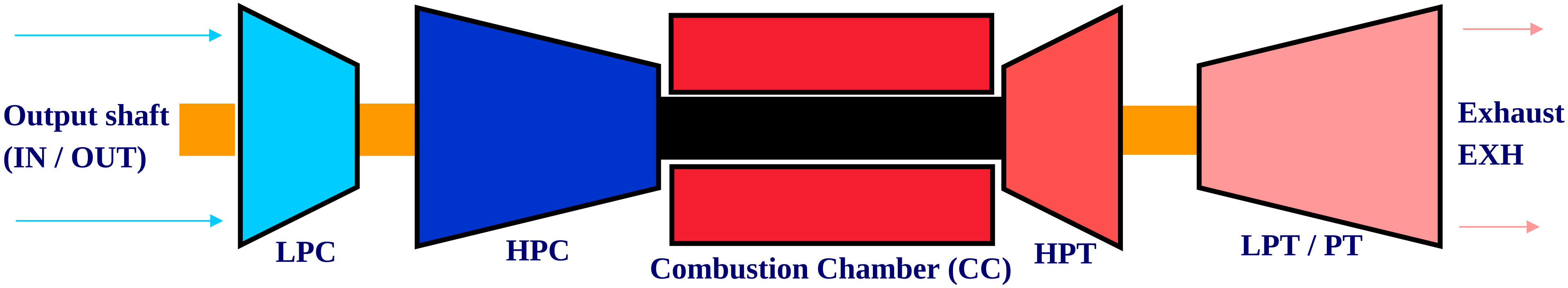
Snøhvit - Gas turbines, HP and LP turbines



Snøhvit - Gas turbine system



Snøhvit - Gas turbines, typical performance



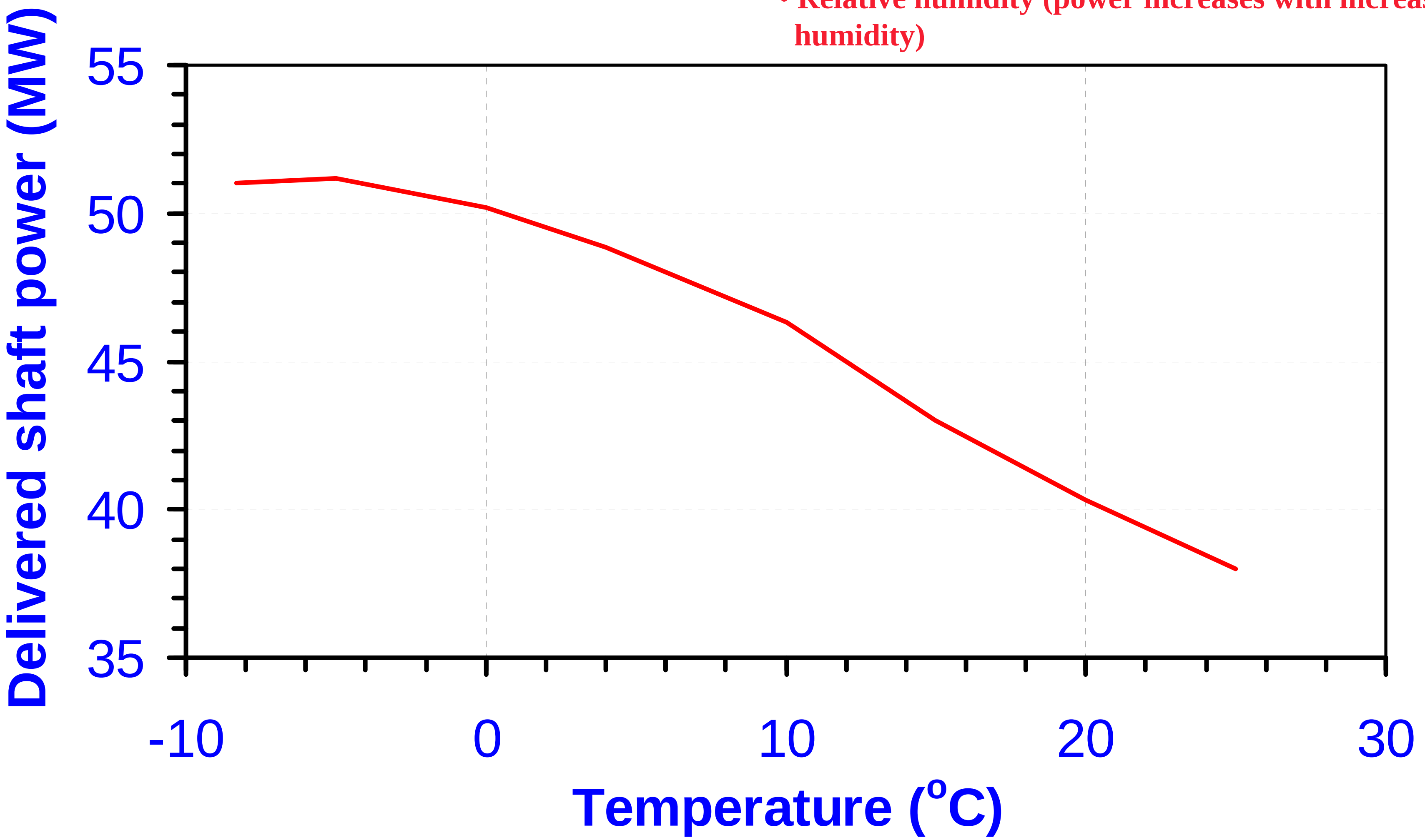
	IN / OUT	LPC		HPC		CC		HPT		LPT / PT	EXH
Power [MW]	43	12.9		53		102		53		55.9	59
Work [kJ /kg]		101		417		803		417		440	465
p [bara]	1		2.4		29		28		7.5		1
T [ºC]	15		115		500		1180		838		450
Flow [kg/s]	127										127
Efficiency [%]		82		90				90		89	

$$\text{Thermal efficiency}: \quad \eta = \frac{\text{Power delivered}}{\dot{m}_{fuel} \cdot \Delta H} = \frac{43 \cdot 100}{102} = 41.7\%$$

Snøhvit - Gas turbines, typical performance

Power delivered as a function of ambient temperature.
Corrections must be made due to:

- **Inlet pressure loss (air filter and heater)**
- **Exhaust pressure loss (WHRU – hot oil)**
- **Ambient pressure (power increases with increasing pressure)**
- **Relative humidity (power increases with increasing humidity)**



Expanders

Expanders are of rotodynamic or displacement design just as compressors and pumps, the difference is that the fluid flows in the opposite direction. Any design that can be used for compression can also be used for expansion. The design of expanders are easier than the design of compressors because the fluid flows in the same direction as the pressure gradient.

In the process industry expanders are used for:

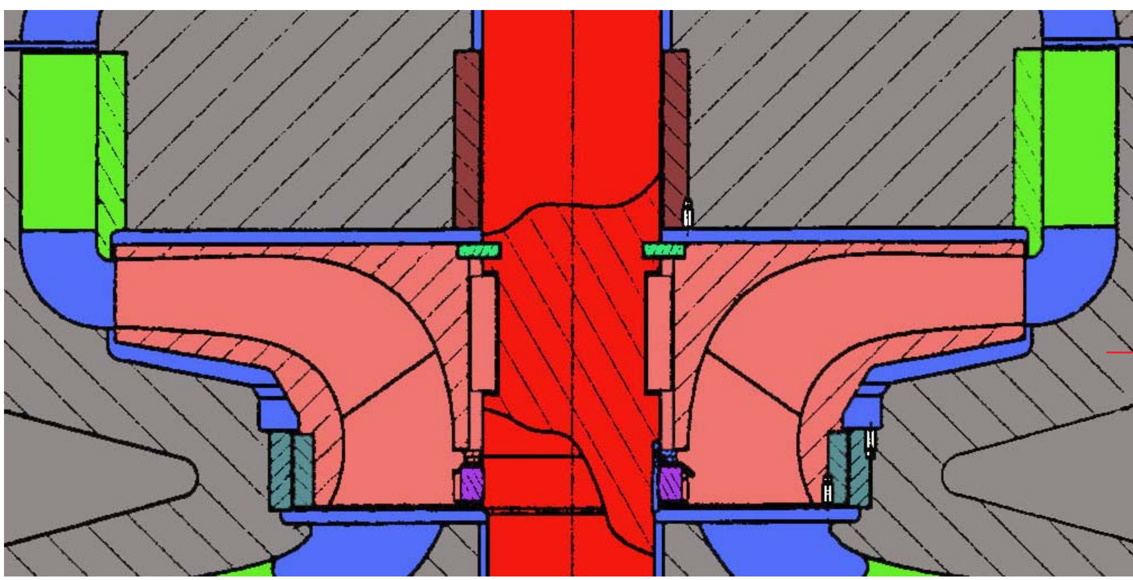
- Gas conditioning – to meet water and HC dew point requirements or for extracting heavier hydrocarbons from natural gas. Expanders are used together with compressor for recompression to save energy
- In refrigeration cycles for depressurising the cooling medium

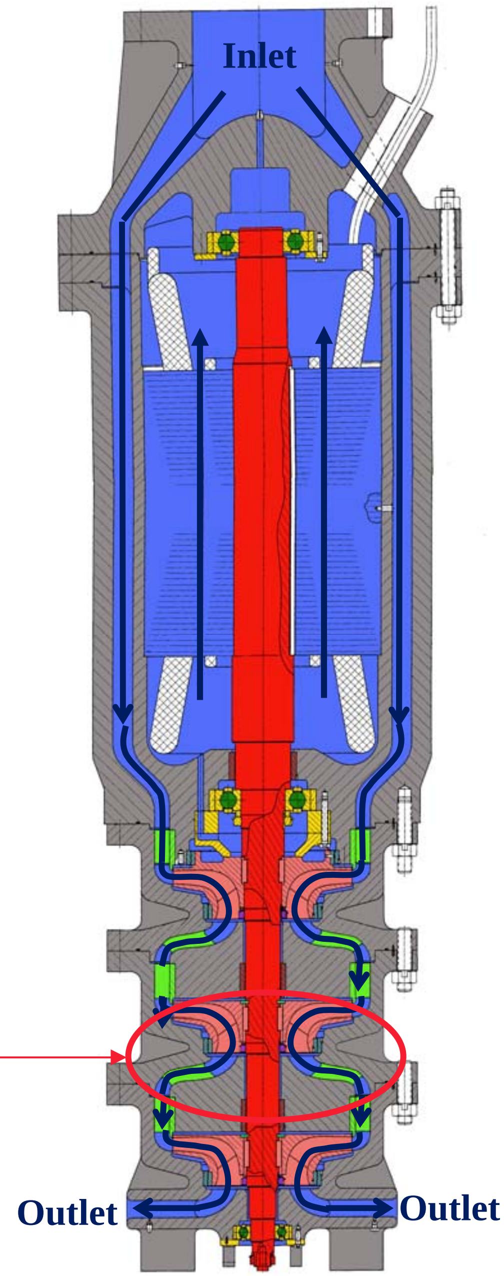
Alternatively, a throttle valve (called Joule-Thompson valve) can be used to obtain required operating conditions. Expanders reach lower temperatures than Joule-Thompson valves and thereby saves energy.

Snøhvit – LNG expansion turbine

Design:

- **Submerged turbines – generator and turbine are submerged in liquid inside a pressure vessel**
- **Orientation is vertical with generator on top**
- **Centrifugal units with radial inflow – 3 impellers with guide vanes**
- **Cooling of generator and lubrication of bearings by a small portion of the liquid being expanded**





Snøhvit – LNG expansion turbine and subcooling cycle liquid expansion turbine

- **1 x LNG expansion turbine 25-CT-102**
  - **Vendor: Ebara**
  - **Model:10 TG153**
  - **# of impellers: 3**
  - **Molecular Weight: 17.58 (LNG, Nitrogen)**
  - **Ball bearings (3)**
  - **Speed: 3000 rpm**