Emissions to air from engine driven power plants

Primary methods to decrease NO_x are:

- Liquid fired engine: base engine optimized for low NO_x, fuel injection retard, addition of water
- Spark ignited, dual fuel engine in gas mode: "lean burn" technique

The only secondary method applicable for diesel engines is SCR (Selective Catalytic Reduction).

- Regarding SO_2 and particulate the primary method is to use a low sulphur/ash fuel oil or gas.
- See appendix 1 for typical costs for secondary NO_x, SO_2 and particulate reduction methods.

A big (size > 500 KWe) reciprocating engine used in power plants has typically an excess oxygen in the range of: **13 … 15 vol-%** in flue gas. A secondary flue gas cleaning equipment works at "actual" conditions (flue gas excess air range and temperature). **Therefore it is important to give the reference oxygen close to the "actual" (= real) concentration i.e. at 15 vol-% for the emissions from the engine driven plant**. Below are measured values from selected power plants around the world. Tables 1 and 5 show typically achievable emission values.

Emissions measured in liquid fired engine plants

Table 1:

Typically achievable NO_x / particulate emissions are (Note: reference point 15 vol-% O_2, dry gas). Nm^3 is given at 0 degree C, 101.3 kPa. Steady state 85 …100 % load of engine.

NO_x:	**Emission (fuel: heavy fuel oil)**	**Remarks**
Base engine optimized for NO_x (generation I)	NO_x < 2300 mg/Nm^3	Standard diesel engine in production, until 2000
Base engine optimized for NO_x (generation II)	NO_x < 2000 mg/Nm^3	Standard diesel engine in production of today
Injection retard	Typically up to 10...20 % NO_x reduction (dependent on engine type)	Fuel consumption increase is dependent on injection retard degree, typically up to 3 %.
Addition of water	NO_x < 1300 … 1600 mg/Nm^3	Used mostly in ships, fuel consumption increases
SCR	NO_x < 750 mg/Nm^3, Lower levels can be achieved, but operating cost rises sharply.	Operating cost is very dependent on used reagent and NOx-level to achieve.
Particulate (fuel: heavy fuel oil)	**ISO 9096 standard or equivalent other method**	
Heavy fuel oil: > 1 wt-% S and < 0.08 wt-% ash	Particulate < 75 mg/Nm^3	
Heavy fuel oil: < 1 wt-% S and < 0.06 wt-% ash, CCR < 12 wt-%	Particulate < 50 mg/Nm^3	
Diesel oil (max. 0.02 wt-% ash)	Particulate < 30 mg/Nm^3	

In below tables (2, 3 and 4) (measurements from selected references) the following applies: emissions are in mg/Nm^3 (Nm^3 given at 0 degree C, 101.3 kPa) at dry gas, **15 vol-% O_2**. SO_2 is dependent on fuel oil sulphur content and particulate emission is mainly dependent on ash content of the fuel oil. Fuel is **heavy fuel oil (HFO)**, if not explicitly otherwise stated**.** Steady state full engine load.

Table 2

NO_x optimized engine used. Unit is mg/Nm^3 (**dry, 15 vol-% O_2, dry gas**).

Installation	**Fuel oil S wt-% or SO_2 (MCR = Micro Carbon Residue)**	**NO_x (as NO_2)**	**Dust (ISO 9096, or equivalent other method), average**	**Remarks**
Base Low-NO_x engine I opti-mized for NO_x	1.88 wt-% S, 0.05 wt-% ash, 13.8 wt-% MCR	2163 – 2178	56 … 60	70 MWe power plant in Caribbean
Base Low-NO_x engine II opti-mized for NO_x	1.83 wt-% S, 0.06 wt-% ash, 13.6 wt-% MCR	1739 …1881	54 …61	100 MWe plant ,in America

Table 3

A SCR is used. Emission unit is mg/Nm^3 (**dry, 15 vol-% O_2, dry gas**).

Installation	**Fuel oil S wt-% or SO_2**	**NO_x (as NO_2)**	**Dust (ISO 9096, or equivalent measurement method), average**	**Remarks**
SCR	0.45 wt-% S	325	44	30 MWe power plant in Asia

Table 4

A primary method: water addition is used. Unit mg/Nm^3 **(dry, 15 vol-% O_2**).

Installation	**Fuel oil S wt-% or SO_2**	**NO_x (as NO_2)**	**Dust (ISO 9096, or equivalent measurement method), average**	**Remarks**
Slow-speed engine + “water addition”	2 wt-% S HFO	1540	55	20 MWe power plant in Caribbean

Emissions in gas fired engine plants

Table 5

Typically achievable NO_x emission values. Nm^3 is given at 0 degree C, 101.3 kPa, steady state engine load 85 … 100 % of MCR.

Technique	**NO_x mg/Nm^3 (dry, 15 vol-% O_2)**	**Note !**
Spark ignited gas engine	190 (normal rating) 94 (Low-NO_x tuned)	- Optimal specific fuel consumption - Minimum unburned emissions - Increase of specific fuel consumption and unburned emissions
Dual fuel engine		LFO = light fuel oil

- Gas mode - Back-up mode (LFO)	190 2000	

In table 6 measured values from some selected references are given.

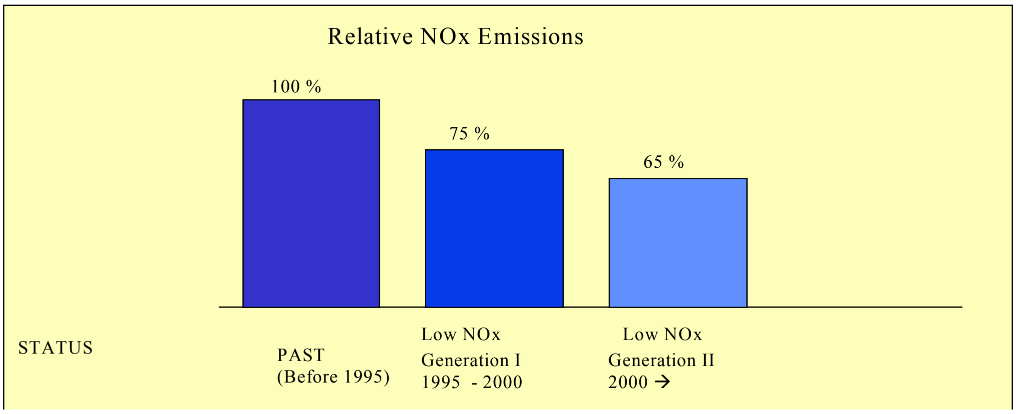
Table 6

Emission unit is in mg/Nm[3] (Nm[3] is given at 0 degree C, 101.3 kPa) at **15 vol-% O_2, dry gas**.
Steady state full engine load.

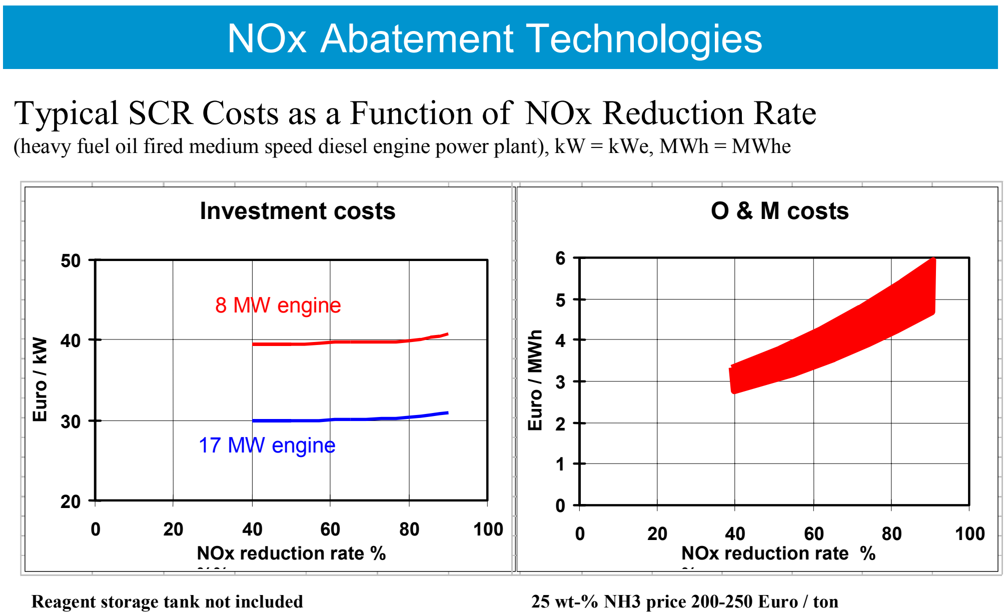
Installation	**Used fuel oil or SO_2 (MCR = Micro Carbon Residue)**	**NO_x (as NO_2)**	**Dust (ISO 9096 or equivalent other method), average**	**Remarks**
Gas Diesel, - **Gas mode**	**natural gas main fuel**, pilot fuel: heavy fuel oil (2.9 wt-% S, 0.05 wt-% ash, 9 wt-% MCR)	1584 – 1612	10 … 13	120 MWe power plant in Asia
Spark ignited gas engine, SG	N/A	161 – 190	N/A	5 MWe plant in Northern Europe
Spark ignited gas engine, SG (Low NO_x tuned)	N/A	71 – 83	N/A	40 MWe plant in Americas. Fuel consumption about 3 % higher compared to “normal” rated SG.
Dual fuel engine - Gas mode - LFO mode	 < 0.05 wt-% S, < 0.01wt-% ash	 147 – 177 1531 – 1751	 N/A 6 – 27	5 MWe plant in Northern Europe

Appendix 1

During the 90´s the NO_x-emission from big liquid fuel fired diesel engines has been reduced remarkably by primary measures as a result of an extensive R&D work on the engine alone compared to the previous values while maintaining the high efficiency of the engine.



***Picture 1**. NO_x-emission development for a 17 MWe four stroke medium speed diesel engine during the 90´s, the NO_x-emission has almost decreased 40 %.*



***Picture 2.** Typical investment and O&M-costs for the SCR-system. No tax is included in the price.*

Operation & maintenance cost of the SCR system is very dependent on the used reagent price. If, urea granulate (**note** to be of high quality (table 1A), dito for blending water table (1B)) is used, the O&M cost (with a urea granulate cost of 225 ... 250 Euro/tonnes) can typically be decreased up to 40 ... 45 % compared to above shown curve. SCR is a sensitive method: a certain minimum temperature of the exhaust gas is needed in order to avoid salt formation (SO_2-sensitivity) on the catalyst elements, some trace metals which might be present in the fuel oil act as "catalyst poisons" and deactivate the catalyst. A soot blowing system is to be installed in the reactor containing the catalyst elements. The SCR has an upper technical reduction limit. At high reduction rates the control system is critical, due to operation within a narrow window. At high reduction rates the size of the SCR-reactor increases, more complicated premixing and reagent injection systems are needed, which increase the investment cost. High NH_3/NO_x-ratio is needed at high NO_x-reduction rates, high NH_3/NO_x-ratios may lead to increased ammonia slip.

Table 1A
Urea granulate quality specification.

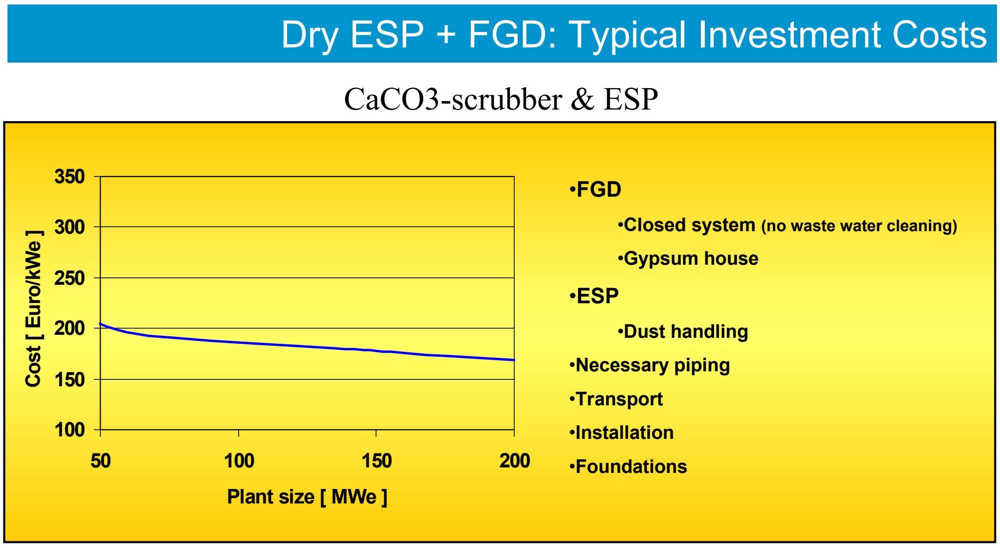
Composition	Unit
Nitrogen minimum	46.5 wt-%
Water maximum	0.4 wt-%
Biuret maximum	0.8 wt-%
Particulate size	1 – 3 mm
Fe maximum	0.3 mg/kg
Substances insoluble in water	10 mg/kg

Table 1B*:* *Water (blending) quality specification*.

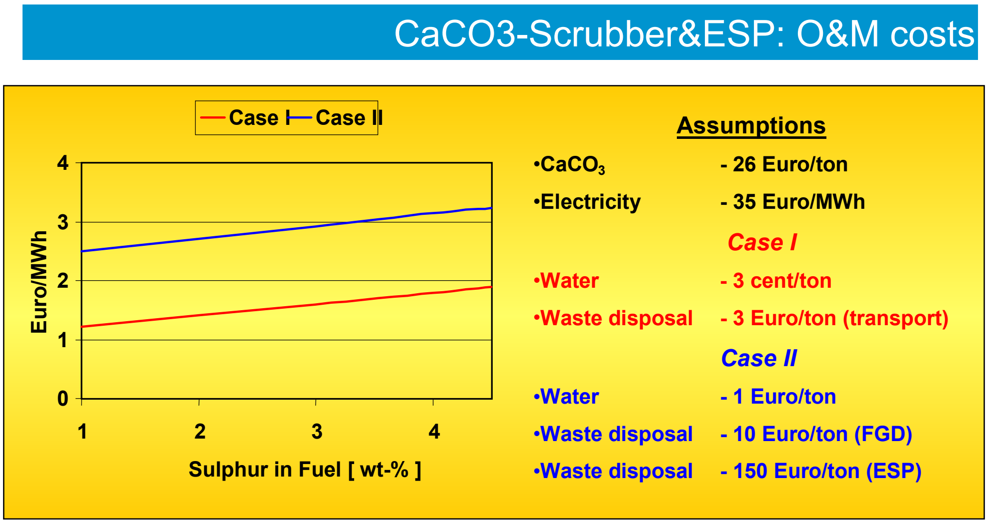
Parameter	Max. value
Conductivity	< 50 mS/m
Hardness	< 10 degree dH
Silica	< 50 mg/l
Chlorides	< 80 mg/l
Sulphates	< 150 mg/l
Suspended solids	< 10 mg/l

"Addition of water" methods are used in some ships, only a few power plant references exist with this application. Several different "water addition" methods are existing or are under development (water emulsion, direct water injection or air humidification dependent on engine manufacturer). A big amount of raw water is needed for high NO_x-reductions. As a rule of thumb can be said that 1 … 2 % water input flow (related to fuel consumption) will decrease NO_x with 0.5 .. 1 %. Investment and O&M costs are very dependent on the available raw water quality/amount and therefore no general price can be given without knowing the actual raw water specification. Used water is to be of good quality: filtered fresh water, free from foreign matters, pH close to 7, with a low hardness and a low chloride ion content, etc. Achievable NO_x reduction is typically up to 30 .. 50 % dependent on chosen method/engine type, available water amount and allowed increase in fuel consumption. The fuel consumption increase is typically in the order 2 .. 3 % dependent on the method and reduction rate. At high NO_x reduction rates unburned emissions (CO, HC) and particulate tend to increase.

In pictures 3 and 4 typical investment and O&M costs (not including taxes, interest rate, etc.) are given for a $CaCO_3$-FGD (Flue Gas Desulphurization) system. Investment costs are very dependent on chosen material in the FGD-system (dependent on raw water chloride content, etc.), automation level, sulphur dioxide reduction rate, etc. and can therefore vary a lot. In below example case it is assumed that raw water (make-up water) chloride (Cl^-) content is max. 40 mg/l, no reheat system is included in the price. The main difference in the O&M costs are due to the different raw water price. SO_2 removal efficiency is about 90 % for shown curves.



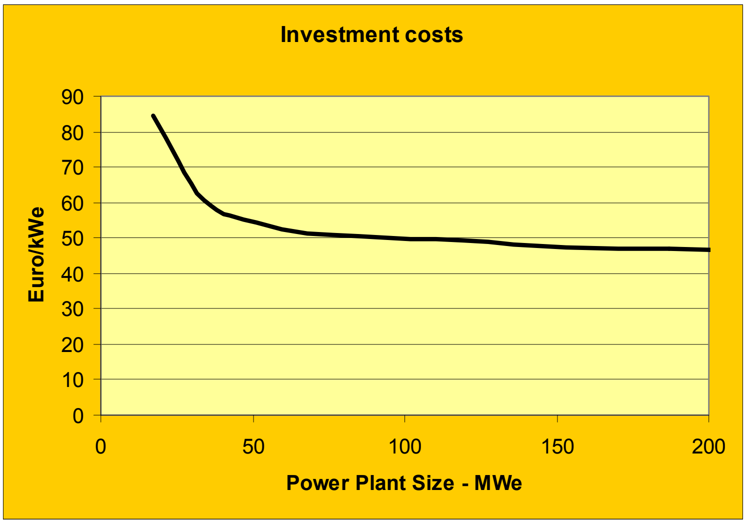
Picture 3. *Typical investment costs for a $CaCO_3$-plant.*



Picture 4. *Typical O & M costs for a $CaCO_3$-plant. MWh = MWhe.*

Secondary cleaning equipment for particulate is new in context with big oil fired diesel engines. Due to different temperature and oxygen content of the diesel flue gas, the electrical properties of the diesel particles are different compared to particles from a boiler flue gas. In picture 5 the investment costs are given for a dry electrostatic precipitator (ESP).

Dry ESP: Typical Investment Costs



• ESP + fly ash conveyor and silo + wet unloading system; Price for installed system
• With typical HFO - Outlet particles max. 50 mg/Nm3 (dry, at 15 % O_2)

Picture 5. *Typical investment costs*

Typical O&M costs are 0.35 Euro/MWhe, with following assumptions: electricity price 35 Euro/MWhe, disposal cost 150 Euro/tonnes for the erased dust.