

Engines and Systems



Exhaust Emission Legislation Diesel- and Gas engines

June 2006



Glossary

Exhaust emission components

NO _x	Nitrogen oxides (in diesel engine emissions mainly NO and NO ₂)
HC	Hydrocarbons
NMHC	Non-Methane- Hydrocarbons
CO	Carbonmonoxide
SO ₂	Sulfur dioxide
VOC	Volatile organic components (equals HC)

Regulations

TA-Luft	Technische Anleitung zur Reinhaltung der Luft (German clean-air standard for approval authorities)
CFR	Code of Federal Register (US regulations)
RheinSchUO	Rhine vessel inspection regulation

Authorities and Organizations

EU	European Union
EC	European Commission
ECE	Economic Commission for Europe (UN economic commission for Europe)
EPA	Environmental Protection Agency (US environmental authority)
CARB	California Air Resources Board
IMO	International Maritime Organization
CCNR	Central Commission for the Navigation on the Rhine
UIC	Union International des Chemins de Fer (International Union of Railways)

Engine Parameters

P _N	Engine rated power [kW]
n _N	Engine rated speed [rpm]
V _{h,z}	Swept volume per cylinder (cyl. displacement) [liter]
RTI	Rated thermal input (fuel consumption * heating value) [MW or kW]
MY	Model year

Overview

Content

- 1** Marine
- 9** Stationary Power Plants
- 18** Nonroad Mobile Machinery
- 23** Rail
- 25** Heavy-duty Vehicles
- 28** Test Cycles
- 37** Fuels
- 38** Conversion Formulas

No responsibility is taken for the correctness of this information.

This brochure is for information only. It does not replace any official laws, regulations or standards.

1 MARINE

EU - Nonroad Directive 97/68/EC (as amended by 2004/26/EC)

The emission limits are valid for propulsion engines of inland waterway vessels in EU watercourses (since 2004/26/EG). The limits and the classification of the engines correspond to stage 2 (Tier 2) of the US-EPA Final Rule for inland marine vessels. However, the time of adoption is two or accordingly three years later.

Category	Cylinder Displac. Power	CO g/kWh	HC + NO _x g/kWh	PM g/kWh	Date*
V 1:1	$V_{h,z} < 0,9l$	5,0	7,5	0,4	2007
	$P_N \geq 37kW$				
V 1:2	$0,9l \leq V_{h,z} < 1,2l$	5,0	7,2	0,3	2007**
V 1:3	$1,2l \leq V_{h,z} < 2,5l$	5,0	7,2	0,2	2007**
V 1:4	$2,5l \leq V_{h,z} < 5,0l$	5,0	7,2	0,2	2009
V 2:1	$5,0l \leq V_{h,z} < 15,0l$	5,0	7,8	0,27	2009
V 2:2	$15,0l \leq V_{h,z} < 20,0l$	5,0	8,7	0,5	2009
	$P_N < 3300kW$				
V 2:3	$15,0l \leq V_{h,z} < 20,0l$	5,0	9,8	0,5	2009
	$P_N \geq 3300kW$				
V 2:4	$20,0l \leq V_{h,z} < 25,0l$	5,0	9,8	0,5	2009
V 2:5	$25,0l \leq V_{h,z} < 30,0l$	5,0	11,0	0,5	2009

* Date for placing on the market; Type approvals one year earlier.

** Type approval will not be given from 01.07.05, if the limits are not fulfilled.

Exempted from the limits are the following ships:

- Vessels intended for passenger transport carrying no more than 12 people in addition to the crew
- Recreational craft with a length of less than 24 meters (see 94/25/EC)
- Service craft belonging to supervisory authorities
- Fire-service vessels
- Naval vessels
- Fishing vessels on the fishing vessels register of the Community
- sea-going vessels, including sea-going tugs and pusher craft operating or based on tidal waters or temporarily on inland waterways, provided that they carry a valid navigation or safety certificate.

For the national implementation of the directive, the exceptions have not been fully adopted by all member states.

- The limits apply to marine auxiliary engines above 560 kW. For other auxiliary engines the limits for nonroad mobile machinery apply.

- Alternatively, the limits of the Rhine Vessel Inspection Regulation may be applied (mutual recognition is agreed).
- Test cycles: ISO 8178-4, E2/E3/D2/C1 (according to engine operation)
- Test condition: air temperature 25°C / water temperature 25°C

Forecast:

Until 31.12.2007 the need to introduce a further set of limit values for engines to be used in inland waterway vessels will be considered, taking into account in particular the technical and economic feasibility of secondary abatement options in this application.

EU - Directive 94/25/EC (As amended by 2003/44/EC)

The directive includes construction- and design-prescriptions for **recreational crafts from 2,5 to 24 m hull length**. The emission limits are valid for new propulsion engines, which will be installed or are specifically intended for installation on or in recreational crafts and personal watercrafts, as well as for already built in engines, which are installed on or in these crafts and that undergo major engine modifications (Increasing the rated power of the engine by more than 15% or possible exceeding of the emission limits given in the directive). The directive does not apply for submersibles, air cushion vehicles, hydrofoils, racing boats (intended solely for racing), experimental craft (provided that they are not subsequently placed on the Community market), craft specially intended to be crewed and to carry passengers for commercial purposes and original historical craft and individual replicas (not in mass-production!) designed before 1950.

Limits (valid since 01.01.2005)

Type	CO [g/kWh]	HC [g/kWh]	NO _x [g/kWh]	PM [g/kWh]
Compression Ignition	5,0	$1,5 + 2/P_N^{0,5}$	9,8	1

All values in g/kWh, P_N = Engine rated power in kW

Exhaust emissions are measured according to the harmonised standard ISO 8178-1.

For engines above 130 kW the exhaust emissions can be measured either according to test cycle E3 (IMO) or E5 (water sports) of ISO 8178-4.

International Shipping – IMO (MARPOL Convention)

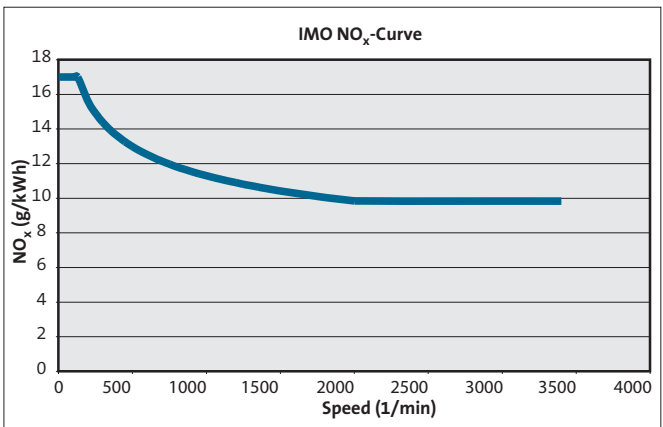
MARPOL (MARine POLLution) is an international convention for prevention of the pollution of the sea from ships. It establishes rules for the protection of the environment valid for international shipping. The text of the convention regulates the basic conditions while the practical relevant issues are handled in the annexes.

MARPOL has to be followed primarily by ships, that run under the flag of an IMO member country. If a ship runs under another authority but navigates in watercourses of member countries, this ship has to adopt MARPOL too.

Regulations concerning the emissions of nitrogen oxides::

All diesel engines, which are implemented aboard a ship, having a rated power of more than 130 kW and which are keel laid after the 1.1.2000 (engines which have been mainly converted after this date or which have been constructed after this date) are affected by these regulations. Engines, which are installed in life boats or other emergency equipment and ships that navigate exclusively in national watercourses, are excluded.

Speed n_N [rpm]	NO_x [g/kWh]
< 130	17,0
130 – 2000	$45,0 \cdot n_N^{-0,2}$
> 2000	9,8



- NO_x limit dependent on engine rated speed (n_N)
- No limits for HC, CO, particulates and soot
- Test cycle: ISO 8178-4, E2/E3/D2/C1 (according to engine operation)
- Test condition: 25°C air temperature / 25°C water temperature

Rhine Vessel Inspection Regulation

The emission limits of combustion engines are established in §8a of the Rhine vessel inspection regulation (RheinSchUO).

- Only combustion engines which use fuels with a flashpoint above 55°C shall be installed.
- Limits for engines, which run according to the principle of compression ignition (diesel engines), fall under the scope.
- The limits are valid for all engines with a rated power (P_N) at or above 37 kW, which are installed in vehicles or machines aboard, unless there are no corresponding directives of the European Union which affect the emission of gaseous pollutants or air pollutant particulates.

The Rhine Vessel Inspection Regulation of the Central Commission for the Navigation on the Rhine (CCNR) defines the following exhaust emission limits:

Stage I (since 2003)

Power P_N kW	Speed n_N rpm	CO g/kWh	HC g/kWh	NO_x g/kWh	PM g/kWh
37 - 75	-	6,5	1,3	9,2	0,85
75 - 130	-	5,0	1,3	9,2	0,70
> 130	500 - 2800	5,0	1,3	$45 \cdot n_N^{(-0,2)}$	0,54
	≥ 2800	5,0	1,3	9,2	0,54

- For engines with a rated power less than 130 kW, the limits correspond to EU Directive 97/68/EC (mobile machinery), stage 1.
- For engines with a rated power of more than 130 kW and a rated speed between 500 and 2800 rpm, the NO_x limit corresponds to the IMO convention.
- Test cycle: ISO 8178-4, E2/E3/D2/C1 (according to engine operation)
- Test condition: air temperature 25°C / water temperature 25°C

5 MARINE

Stage II (as of the 01. July 2007 (Date of putting in service of the ship))

Power P_N kW	Speed n_N rpm	CO g/kWh	HC g/kWh	NO _x g/kWh	PM g/kWh
18 - 37	-	5,5	1,5	8,0	0,8
37 - 75	-	5,0	1,3	7,0	0,4
75 - 130	-	5,0	1,0	6,0	0,3
130 - 560	-	3,5	1,0	6,0	0,2
> 560	< 343	3,5	1,0	11,0	0,2
	343 - 3150	3,5	1,0	$45 \cdot n_N^{(-0,2)} - 3$	0,2
	≥ 3150	3,5	1,0	6,0	0,2

- Test cycles and test conditions as for stage I
- Alternatively, the limits for inland waterway vessel engines of EU Directive 97/68/EC, as amended by Directive 2004/26/EC, may be applied (mutual recognition is agreed).

Lake Constance Shipping Ordinance (BSO)

The compound of the detected carbone monoxide, of the detected hydrocarbons and of the detected nitrogen oxides, as well as the exhaust-gas opacity of diesel engines, may not exceed the following exhaust emission limits for diesel and gasoline engines, which are to be tested according to the prescriptions.

Stage I (Engines, which have been built before 31.12.1995)

Power P_N kW	CO		HC		NO _x	
	$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)	
	A	m	A	m	A	m
< 4	600	0,5	60,0	0,7747	15	0
4 – 100	600	0,5	39,39	0,4711	15	0
> 100	60	0	10,13	0,1761	15	0

P_N = rated power

The calculated mass-emissions of spark ignited engines of group A or group B, as well as the mass-emissions of diesel engines of group A may not exceed the following values:

- 4500 g/h for carbon monoxide CO
- 290 g/h for hydrocarbons HC
- 1100 g/h for nitrogen oxides NO_x

Smoke limit for diesel engines: The Bosch-Unit may not exceed 4,0 for naturally aspirated engines and 3,0 for supercharged engines.

Stage II (Engines, which have been built after 01.01.1996)

For gasoline engines, the following limits apply:

Power P_N kW	CO		HC		NO _x	
	$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)	
	A	m	A	m	A	m
< 4	400	0,6505	30	0,6505	10	0,1505
4 – 100	400	0,6505	30	0,6505	10	0,1505
> 100	20	0	3,375	0,1761	5	0

P_N = rated power

For diesel engines, the following limits apply:

Power P_N kW	CO		HC		NO _x	
	$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)		$A \cdot P_N^{-m}$ (g/kWh)	
	A	m	A	m	A	m
< 4	400	0,6505	30	0,6505	10	0
4 - 100	400	0,6505	30	0,6505	10	0
> 100	20	0	3,375	0,1761	10	0

P_N = rated power

The calculated mass-emissions of spark ignited engines of group A or group B, as well as the mass-emissions of diesel engines of group A may not exceed the following values:

- 1500 g/h for carbon monoxide CO
- 95 g/h for hydrocarbons HC
- 360 g/h for nitrogen oxides NO_x

Smoke limit for diesel engines: The Bosch-Unit may not exceed 3,5 for naturally aspirated engines and 2,5 for supercharged engines.

Test cycle: BSO-9-mode-test

Test condition: Air temperature 25°C

USA - EPA Marine Regulation

The compression ignition engines in ship applications are separated in five categories by the EPA:

Category	Rated power P_n	Cylinder displacement	Publication of the law
Small	< 37 kW	undetermined	1998
Commercial C1	≥ 37 kW	< 5 l	1999
C2		5 l ≤ 30 l	
C3		≥ 30 l	2003
Recreational C1	≥ 37 kW	< 5 l	2002

- **Small** marine diesel engines are regulated in the „Nonroad-Diesel Engine“ – directive (40 CFR 89) and are subject to the same emission limits as their land-based counterparts.
- For **category C1** engines, similar limits as the limits for land-based “Nonroad-Diesel Engines” are valid.
- Most of the limits for engines in **category C2** are identical with the emission limits for locomotive engines.
- Engines in **category C3** are very large propulsion engines for seagoing ships, and the emission limits are comparable with those of the IMO – MARPOL Convention.
- Engines for recreational boats must have a minimum rated power of 37 kW and a minimum displacement of 2,5 l per cylinder to fall under this Regulation.

Furthermore, the emission limits are divided in two stages (Tier 1 and 2), which become effective consecutively.

Stage 1 (Tier 1):

Cat.	Power Cyl. displac.	Speed rpm	as of MY	NO _x g/kWh	HC+NO _x g/kWh	PM g/kWh	CO g/kWh
Small	$P_N < 8$ kW	-	2000	-	10,5	1,0	8,0
	8 kW ≤ P_N < 19 kW	-	2000	-	9,5	0,8	6,6
	19 kW ≤ P_N < 37 kW	-	1999	-	9,5	0,8	5,5
C1, C2, C3, Rec.	$P_N ≥ 37$ kW and $V_{h,z} ≥ 2,5$ l	$n_N ≥ 2000$	2004	9,8	-	-	-
		$130 ≤ n_N < 2000$	2004	$45 \cdot n_N^{-0,2}$	-	-	-
		$n_N < 130$	2004	17,0	-	-	-

Stage 2 (Tier 2):

Cat. *	Cylinder Displacement	Power kW	MY	HC+NO _x g/kWh	PM g/kWh	CO g/kWh
Small	-	$P_N < 8$	2005	7,5	0,8	8,0
	-	$8 \leq P_N < 19$	2005	7,5	0,8	6,6
	-	$19 \leq P_N < 37$	2004	7,5	0,6	5,5
C1	$V_{h,z} < 0,9 \text{ l}$	$P_N \geq 37$	2005	7,5	0,4	5,0
	$0,9 \text{ l} \leq V_{h,z} < 1,2 \text{ l}$	-	2004	7,2	0,3	5,0
	$1,2 \text{ l} \leq V_{h,z} < 2,5 \text{ l}$	-	2004	7,2	0,2	5,0
	$2,5 \text{ l} \leq V_{h,z} < 5 \text{ l}$	-	2007	7,2	0,2	5,0
C2	$5 \text{ l} \leq V_{h,z} < 15 \text{ l}$	-	2007	7,8	0,27	5,0
	$15 \text{ l} \leq V_{h,z} < 20 \text{ l}$	$P_N < 3300$	2007	8,7	0,5	5,0
	$15 \text{ l} \leq V_{h,z} < 20 \text{ l}$	$P_N \geq 3300$	2007	9,8	0,5	5,0
	$20 \text{ l} \leq V_{h,z} < 25 \text{ l}$	-	2007	9,8	0,5	5,0
	$25 \text{ l} \leq V_{h,z} < 30 \text{ l}$	-	2007	11,0	0,5	5,0
Rec.	$V_{h,z} < 0,9 \text{ l}$	$P_N \geq 37$	2007	7,5	0,4	5,0
	$0,9 \text{ l} \leq V_{h,z} < 1,2 \text{ l}$	$P_N \geq 37$	2006	7,2	0,3	5,0
	$1,2 \text{ l} \leq V_{h,z} < 2,5 \text{ l}$	$P_N \geq 37$	2006	7,2	0,2	5,0
	$2,5 \text{ l} \leq V_{h,z} < 5,0 \text{ l}$	$P_N \geq 37$	2009	7,2	0,2	5,0

* There are no Tier 2 standards for category C3.

- Test cycle: ISO 8178-4, E2/E3/D2/C1 (according to engine operation)
- Test condition: air temperature 25°C / water temperature 25°C
- For recreational crafts test cycle E5, corresponding to the above mentioned ISO-Standard, is valid.
- NTE (Not to exceed): In certain sections of the engine performance map, emissions may not exceed 1,2 to 1,5 times the cycle limit. These requirements come into force with 2007 model year.
- ABT (Averaging, Banking and Trading): Emission credits (NO_x+HC and particulates) can be averaged, banked or traded.
- Voluntary Standards: Engines, which meet clearly lower limits (about 40% reduced), may use the "Blue Sky Series" label.

9 STATIONARY POWER PLANTS

Germany – TA Luft

The „Technische Anleitung zur Reinhaltung der Luft (TA-Luft)“ is a common administrative regulation of the German government referring to the „Bundes-Immissionsschutzgesetz“ (BImSchG). It contains limit values for emission and imission of pollutants from stationary plants and defines the respective measurement and calculation procedures.

Subject to TA-Luft are combustion engine power plants using

- oil residues and landfill gas independent from the rated power
- biogas, natural gas, purification gas with a RTI (rated thermal input) at or above 1 MW
- other fuels (e.g. diesel fuels) with a RTI at or above 1 MW
- The emission limits refer to dry exhaust gas with 5% residual oxygen.
- Dust means cumulative dust, including the part of cancer-producing, inheritance-changing and reproduction-toxic substances.

Diesel engines

Plant RTI	Dust	CO	NO _x
MW	mg/m _N ³	mg/m _N ³	mg/m _N ³
< 3	20	300	1000
≥ 3	20	300	500

Gas engines

Gas type	Engine type	Plant RTI	CO	NO _x
		MW	mg/m _N ³	mg/m _N ³
Natural gas	Lean mix engine		300	500
	Others		300	250
Pit gas	Lean mix engine		650	500
	Others		650	250
Biogas / purification gas	Jet ignition	< 3	2000	1000
		≥ 3	650	500
	Spark ignition	< 3	1000	500
		≥ 3	650	500
Landfill gas	Lean mix engine		650	500
	Others		650	250

- Limit values applicable to normal operation (i.e. normally at rated power)
- For emergency plants and plants that are operated up to 300 hours per year to cover peak demands (e.g. power generation, gas or water supply) the dust limit is 80 mg/m_N³. The NO_x- and CO-limits do not apply.
- The NO_x-limit for two-stroke engines is 800 mg/m_N³
- The emission of formaldehyde in the exhaust gas must not exceed 60 mg/m_N³. There is no HC-limit.

Forecast:

Further reduction of pollutants shall be considered in accordance with the technological process (state-of-the-art).

Italy

Diesel engines

Plant RTI MW	NO _x	CO	HC*	SO ₂	Dust
	mg/m _N ³	mg/m _N ³	mg/m _N ³	mg/m _N ³	mg/m _N ³
< 3	4000	650	600	500	130
> 3	2000	650	600	500	130

* butane-heptane

- Limits comparable to the former German TA-Luft (before 2002)
- Pollutant content relating to dry exhaust gas with 5% residual oxygen
- Local regulatory authorities may demand more stringent limits (in accordance with the technical process/state-of-the-art).

Gas engines

NO _x	CO	HC*	SO ₂	Dust
mg/m _N ³	mg/m _N ³	mg/m _N ³	mg/m _N ³	mg/m _N ³
500	650	600	500	130

* butane-heptane

11 STATIONARY POWER PLANTS

UN-ECE Gothenburg Protocol

In the Convention on Long-range Transboundary Air Pollution (CLRTAP), which was adopted in 1979, emission ceilings for the Parties to the Protocol are set and NO_x limit values for facilities with stationary engines have been defined. The Gothenburg Protocol is intended to abate acidification, eutrophication and ground-level ozone. The Protocol has been adopted in 1999, became effective on 17.05.2005, and sets tight limit values for specific emission sources. Parties to the Protocol are all EU countries, Eastern Europe states, USA and Canada.

Limit values (Annex 5, issue 12)

Engine type	Fuel type / Mode of operation	NO _x
		mg/m _N ³
Spark ignition (gas engines) RTI* > 1 MW	Lean burn engines	250
	Others	500
Compression ignition (Diesel / Dual fuel) RTI* > 5 MW	Natural gas (Jet ignition engines)	500
	Heavy fuel oil	600
	Diesel or gas oil	500

* RTI = Rated thermal input

- Regenerative gases like biogas, purification gas and landfill gas have not been specially considered.
- Limit values do not apply to engines running less than 500 hours a year.
- The O₂ reference content is 5%.
- As an alternative, a Party to the Protocol may apply different emission reduction strategies that achieve equivalent overall emission levels for all source categories together

Finland

The emission guideline of the Finish environmental protection agency from October 2003 defines limits on SO₂-, NO_x- and particle emissions of **small combustion plants**, which shall be reached by using so called “best available techniques”. A small combustion plant within this regulation means a plant unit, consisting of one or more combustion components (steam boilers, engines, gas turbines) on a single location with a **maximum RTI (rated thermal input) of 50 MW** and a flue gas evacuation through a common stack. This guideline is **not a law, only a recommendation**, because in Finland local authorities assign the operating licence for plants of this size. The authorities should orientate on the following limits. All limits refer to a 15% residual oxygen content in the exhaust gas.

Limits for **new** diesel and gas engines

Engine type	NO _x Primary		NO _x Secondary		SO ₂		Particulates	
	mg/m _N ³	mg/MJ	mg/m _N ³	mg/MJ	mg/m _N ³	mg/MJ	mg/m _N ³	mg/MJ
Oil diesel	< 1400*	< 1600*	< 650**	< 750**	< 500	< 600	< 50	< 60
Gas diesel	< 1400*	< 1600*	< 650**	< 750**				
Spark ign.	< 150	< 175						
Dual fuel	< 150	< 175						

* primary methods: engine internal measures (for normal applications)

** secondary methods: methods outside the engine (for special application, e.g. urban areas)

Limits for **already existing** diesel and gas engines

Engine type	NO _x		SO ₂		Particulates	
	mg/m _N ³	mg/MJ	mg/m _N ³	mg/MJ	mg/m _N ³	mg/MJ
Oil diesel	< 2000	< 2300	< 500	< 600	< 60	< 70
Gas diesel	< 1500	< 1750				
Spark ignition	< 160	< 185				
Dual fuel	< 160	< 185				

There are no specific test-cycles. The limits are given for 100% load as maximum measured values or as values, which can be reached if the reduction of the emissions is based on a “best available technique”.

13 STATIONARY POWER PLANTS

France

The French Arrêté 2910 defines emission limits for stationary diesel engines and gas engines.

Limit values

Operating time h/year	Power MW _{th}	NO _x			CO	NMHC	Dust
		mg/m _N ³			mg/m _N ³	mg/m _N ³	mg/m _N ³
		Nat. gas	Liquid fuel	Dual Fuel			
> 500	20 - 100	350	1000	1000	650	150	100
	> 100	250	600	750	650	150	100
≤ 500	20 - 100	875	2500	2500	650	150	100
	> 100	625	1500	1875	650	150	100

- The emission limits refer to dry exhaust gas with 5% residual oxygen.
- The NO_x limit for plants operated up to 500 hours per year is multiplied with the coefficient 2,5.
- If the plant is operated as a combined heat and power generation plant, the respective limit value in the table above can be exceeded by 30 mg/m_N³.
- The NO_x limit for plants which have been licensed before 04.12.2000 and which consume liquid fuel amounts 1900 mg/m_N³ (independent from the power of the plant).
- The NO_x limit for plants that have been licensed before 04.12.2000 and that consume natural gas can be defined by a person in charge from the responsible regulating authority up to 500 mg/m_N³ if the operator of the plant can prove by a techno-economic analysis that it is impossible to observe the emission limit in the table above.
- If special fuel is used (e.g. biogas or coke oven gas), the person in charge of the responsible authority can define the maximum limit values separately.
- The limit for VOC in the exhaust gas is 20 mg/m_N³, for plants with more than 50 MW_{th} per year and a mass flow of organic compounds of more than 0,1 kg/h.

Limit values for sulphur oxide SO

Fuel type	Natural gas	Fuel oil	Heavy fuel
limit value [mg/m _N ³]	35	300	1500

India

The Central Environmental Protection Agency, which is mandated by the Ministry of Environment and Forest, is responsible for the emission limit regulation. The following content refers to Diesel engines for power generation.

Limit values for engines up to 800 kW rated Power

Rated engine power	Implementation	NO _x	HC	CO	PM	Smoke opac.*
		g/kWh	g/kWh	g/kWh	g/kWh	m ⁻¹
≤ 19 kW	01.07.2005	9,2	1,3	3,5	0,3	0,7
19 – 50 kW	01.01.2004	9,2	1,3	5,0	0,5	0,7
	01.07.2004	9,2	1,3	3,5	0,3	0,7
50 – 176 kW	01.01.2004	9,2	1,3	3,5	0,3	0,7
176 – 800 kW	01.11.2004	9,2	1,3	3,5	0,3	0,7

* light absorption coefficient measured at full load

All other values are measured according to test-cycle ISO 8178-4 D2, 5-Mode

Limit values for engines with more than 800 kW rated power

Date of order	NO _x	NMHC	CO	PM
	ppmV	mg/m _N ³	mg/m _N ³	mg/m _N ³
Before 01.07.2003	1100	150	150	75
Between 01.07.2003 and 01.07.2005	970	100	150	75
After 01.07.2005	710	100	150	75

The following two agencies are able to implement type approvals:

- Automotive Research Association of India, Pune
- Vehicle Research and Development Establishment, Ahmednagar
- The emission limits refer to dry exhaust gas with 15% residual oxygen.

15 STATIONARY POWER PLANTS

Japan

Diesel engines

Bore	NO _x	NO _x	Particulates	Particulates
mm	ppm (13% O ₂)	mg/m _N ³ (5% O ₂)	mg/m _N ³ (13% O ₂)	mg/m _N ³ (5% O ₂)
< 400	950	3900	100*	200
≥ 400	1200	4900	100*	200

* in certain regions 80 mg/m_N³ (13% O₂)

- Diesel engine plants with fuel consumption > 50 l/h
- Local limits may be lower
(Example: Tokyo: NO_x = 470 mg/m_N³ (5% O₂))

Gas engines

NO _x	NO _x	Particulates	Particulates
ppm (0% O ₂)	mg/m _N ³ (5% O ₂)	mg/m _N ³ (0% O ₂)	mg/m _N ³ (5% O ₂)
600	940	50*	38

* in certain regions 40 mg/m_N³ (0% O₂)

- Local limits may be lower!
(Example: Tokyo: NO_x = 310 mg/m_N³ (5% O₂))
- Gas engine plants with fuel consumption > 35 l/hr

Switzerland – Clean Air Directive

According to the Clean Air Directive (Luftreinhalteverordnung) dated December 16, 1985 (status: 12.07.2005) the following emission limits are valid for stationary combustion engines with a RTI (rated thermal input) above 100 kW per engine

Fuel type	NO _x	CO	Dust
	mg/m _N ³	mg/m _N ³	mg/m _N ³
Gas fuels*	400	650	50
Other fuels	250	650	50

* Biogas, purification gas, landfill gas, natural gas

- The pollutant content refers to dry exhaust with 5% residual oxygen.
- For emergency engines that are operated up to 50 hours per year, the limits above are not valid.
- Specifications for fuels that are used in stationary combustion engines have to be considered.

World Bank Group – Guidelines for new thermal power plants

The World Bank Group consists of five organisations. Their main issue is to boost the economic development of the less developed member countries with financial and technical help and consulting.

Within these five organisations, the IFC (International Finance Corporation) has the mission to boost the private economic development with shareholding in companies.

Generally, the limit values shall comply with the specific laws of the country, in which the plant is built. Though, the measured values have to be accepted by the IFC to receive financial and technical help. The values given below apply as a standard which is normally accepted by the IFC.

The limit values are valid for power plants with an electric capacity of **more than 50 MWe**.

All values have to be observed for **95% of the total operating time**. The rest of 5% is time where the plant is powered up for example.

The limit values correspond to engine driven power plants, which can be either four-stroke or two-stroke engines.

Financing received	PM	SO ₂	NO _x
	mg/m _N ³	mg/m _N ³	mg/m _N ³ (g/kWh)*
Before 01.07.2000	≤ 50	≤ 2000	< 2300 (17)
After 01.07.2000	≤ 50	≤ 2000	< 2000 (13)

* Pollutant content referred to dry exhaust gas with 15% residual oxygen

The NO_x limit for plants which are not covered here is 400 mg/m_N³ (Pollutant content referred to dry exhaust gas with 15% residual oxygen).

17 STATIONARY POWER PLANTS

USA

At present the emission limit values for stationary plants in the USA are not regulated consistently. The emission limit values of the respective state is valid. The EPA plans to define minimum requirements for stationary diesel engines and issued a proposal on July 11, 2005.

For new, non-emergency diesel engines, the following limits shall apply:

Cyl. displ. Power	MY	NO _x	HC	CO	PM
		g/kWh	g/kWh	g/kWh	g/kWh
V _{h,z} < 10 l	as of 2007	like EPA-Nonroad (Tier 2 to Tier 4 acc. to MY and Power, see chapter 3)			
P _N ≤ 2237kW					
V _{h,z} < 10 l	2007 -2010	9,2	1,3	11,4	0,54
P _N > 2237kW	as of 2011	like EPA-Nonroad (Tier 4 int. to Tier 4 acc. to MY and Power, see chapter 3)			
10 l ≤ V _{h,z} < 30 l	as of 2007	like EPA-Marine (Tier 2, see chapter 1)			

- For new diesel engines for emergency use and for fire pump engines less stringent emission limits apply (no exhaust after-treatment).
- Depending on local pollution situations more stringent emission limits may apply, e.g. the California Air Resources Board (CARB) has passed a regulation for the approval of plants stating the following limits (relating to electric power):

Diesel and Gas engines (California):

Date	NO _x	VOC	CO	Unit
2003	0,50*	1,00	6,00	lbm/MW-hr
	0,23	0,45	2,70	g/kWh
2007**	0,07	0,02	0,10	lbm/MW-hr
	0,03	0,01	0,05	g/kWh

* For cogeneration the limit increases to 0,7

** For cogeneration heat is treated like electrical power

- Particulate emissions not higher than those for natural gas with a sulphur content of 1 grain / 100 scf (i.e. PM < 0,5 mg/kWh).

EU – Nonroad - Directive 97/68/EC (as amended by 2004/26/EC)

Diesel engines

Power P_N kW	NO _x g/kWh	HC g/kWh	CO g/kWh	Particulates g/kWh	Date*
	NO _x + NMHC				
Stage I					
37 ≤ P_N < 75	9,2	1,3	6,5	0,85	Apr 99
75 ≤ P_N < 130	9,2	1,3	5,0	0,70	1999
130 ≤ P_N ≤ 560	9,2	1,3	5,0	0,54	1999
Stage II					
18 ≤ P_N < 37	8,0	1,5	5,5	0,8	2001
37 ≤ P_N < 75	7,0	1,3	5,0	0,4	2004
75 ≤ P_N < 130	6,0	1,0	5,0	0,3	2003
130 ≤ P_N ≤ 560	6,0	1,0	3,5	0,2	2002
Stage III A					
19 ≤ P_N < 37	7,5		5,5	0,6	2007
37 ≤ P_N < 75	4,7		5,0	0,4	2008
75 ≤ P_N < 130	4,0		5,0	0,3	2007
130 ≤ P_N ≤ 560	4,0		3,5	0,2	2006
Stage III B					
37 ≤ P_N ≤ 56	4,7		5,0	0,025	2013
56 ≤ P_N < 75	3,3	0,19	5,0	0,025	2012
75 ≤ P_N < 130	3,3	0,19	5,0	0,025	2012
130 ≤ P_N ≤ 560	2,0	0,19	3,5	0,025	2011
Stage IV					
56 ≤ P_N < 130	0,4	0,19	5,0	0,025	Oct 2014
130 ≤ P_N ≤ 560	0,4	0,19	3,5	0,025	2014

* Date for placing the engine on the market, type approval one year earlier

- Engines above 560 kW are not regulated.
- Stationary test cycle: ISO 8178-4, C1/D2 (according to engine operation)
- Transient test cycle: NRTC (mandatory for stage IIIB)
- Test condition: Air temperature 25°C
- **NTE** (Not to Exceed): Starting with stage IIIB limits in the performance map will be applied (maximum 100% above cycle limit).
- For constant speed engines (e.g. mobile gensets) the limits of stage II will be applied as of 2007, the limits of stage IIIA as of 2011 (Stage IIIB and IV not yet fixed for these engines).
- For agricultural tractors Directive 2000/25/EC (as amended by 2005/13/EC) is valid. The emission limits are equivalent to those in Directive 97/68/EC.
- As of stage III A compliance with the limits must be demonstrated over the useful lifetime of the engine.
- As of 2006, rail and marine engines are included into 97/68/EC (see „Marine“ and „Rail“).

19 NONROAD MOBILE MACHINERY

USA – EPA Nonroad Regulation (40 CFR 89, 40 CFR 1039 and 40 CFR 1068)

Diesel engines

Power P_N kW	NO _x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date as of MY
	NO _x + NMHC				
Tier 1					
$P_N < 8$	10,5		8,0	1,0	2000
$8 \leq P_N < 19$	9,5		6,6	0,8	2000
$19 \leq P_N < 37$	9,5		5,5	0,8	1999
$37 \leq P_N < 75$	9,2	-	-	-	1998
$75 \leq P_N < 130$	9,2	-	-	-	1997
$130 \leq P_N < 560$	9,2	1,3	11,4	0,54	1996
$P_N > 560$	9,2	1,3	11,4	0,54	2000
Tier 2					
$P_N < 8$	7,5		8,0	0,8	2005
$8 \leq P_N < 19$	7,5		6,6	0,8	2005
$19 \leq P_N < 37$	7,5		5,5	0,6	2004
$37 \leq P_N < 75$	7,5		5,0	0,4	2004
$75 \leq P_N < 130$	6,6		5,0	0,3	2003
$130 \leq P_N < 225$	6,6		3,5	0,2	2003
$225 \leq P_N < 450$	6,4		3,5	0,2	2001
$450 \leq P_N \leq 560$	6,4		3,5	0,2	2002
$P_N > 560$	6,4		3,5	0,2	2006
Tier 3					
$P_N < 8$	no further reduction				
$8 \leq P_N < 19$	no further reduction				
$19 \leq P_N < 37$	no further reduction				
$37 \leq P_N < 75$	4,7		5,0	0,4	2008
$75 \leq P_N < 130$	4,0		5,0	0,3	2007
$130 \leq P_N \leq 560$	4,0		3,5	0,2	2006
$P_N > 560$	no further reduction				
Tier 4 interim					
$19 \leq P_N < 37$	7,5		5,5	0,30	2008
$37 \leq P_N < 56$	4,7		5,0	0,30	2008
$56 \leq P_N < 130$	3,4	0,19	5,0	0,02	2012
$130 \leq P_N \leq 560$	2,0	0,19	3,5	0,02	2011
$P_N > 560$	3,5	0,4	3,5	0,10	2011
Tier 4 interim - Genset					
$P_N > 900$	0,67	0,4	3,5	0,1	2011

Power P_N kW	NO _x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date as of MY
	NO _x + NMHC				
Tier 4					
$P_N < 8$	7,5		8,0	0,4*	2008
$8 \leq P_N < 19$	7,5		6,6	0,4	2008
$19 \leq P_N < 37$	4,7		5,5	0,03	2013
$37 \leq P_N < 56$	4,7		5,0	0,03	2013
$56 \leq P_N < 130$	0,4	0,19	5,0	0,02	2015**
$130 \leq P_N \leq 560$	0,4	0,19	3,5	0,02	2014***
$P_N > 560$	3,5	0,19	3,5	0,04	2015
Tier 4 - Genset					
$P_N > 560$	0,67	0,19	3,5	0,04	2015

* hand-startable, air cooled direct injection engines may be certified to Tier 2 standards through 2009 and to an optional PM standard of 0,6 g/kWh starting in 2010

** PM/CO: full compliance from 2012; NO_x/HC: Option 1 (if banked Tier 2 credits used) – 50% engines must comply in 2012-2013; Option 2 (if no Tier 2 credits claimed) – 25% engines must comply in 2012-2014, with full compliance from 31.12.2014

*** PM/CO: full compliance from 2011; NO_x/HC: 50% engines must comply in 2011-2013

Optional for Tier 3 / 4: 37-56 kW, PM = 0,3 g/kWh as of 2008; 56-560 kW Phase in / Phase out

- Additionally to particulate measurement, a transient smoke test is required. As of Tier 4 this is only necessary if particulate emissions exceed 0,07 g/kWh. Engines which are operated at constant speed are generally excluded.
- Stationary test cycle: ISO 8178-4, C1/D2/E3. As of Tier 4 the appropriate Ramped Mode Cycle (see chapter 6) may be used alternatively.
- Transient test cycle: NRTC; all engines as of Tier 4, except engines above 560kW and constant speed engines of any power category.
- Test condition: Air temperature 25°C
As of Tier 4: Air temperature 20°C – 30°C,
Ambient pressure 0,8 – 1,03 bar
- Compliance with the emission limits has to be guaranteed over the useful lifetime of the engine.
- **ABT** (Averaging, Banking and Trading): Emission credits (CO, NO_x+HC and particulates) can be averaged, banked or traded
- **NTE** (Not to Exceed): As of Tier 4, the emissions may not exceed 1,25 to 1,5 times the cycle limit.
- The regulations of Tier 4 allow open crankcase ventilation if these emissions are measured and added to the exhaust emissions.

21 NONROAD MOBILE MACHINERY

India

Power P_N kW	NO _x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date
	NO _x + HC				
Stage I					
$18 \leq P_N < 37$	18,0	3,5	14,0	-	Aug 02
$37 \leq P_N < 75$	18,0	3,5	14,0	-	Aug 02
$75 \leq P_N < 130$	18,0	3,5	14,0	-	Aug 02
$130 \leq P_N \leq 560$	18,0	3,5	14,0	-	Aug 02
Stage II					
$18 \leq P_N < 37$	9,2	1,3	6,5	0,85	Apr 07
$37 \leq P_N < 75$	9,2	1,3	6,5	0,85	Apr 07
$75 \leq P_N < 130$	9,2	1,3	5,0	0,70	Apr 07
$130 \leq P_N \leq 560$	9,2	1,3	5,0	0,54	Apr 07
Stage III					
$18 \leq P_N < 37$	7,5		5,5	0,6	Apr 11
$37 \leq P_N < 75$	4,7		5,0	0,4	Apr 11
$75 \leq P_N < 130$	4,0		5,0	0,3	Apr 11
$130 \leq P_N \leq 560$	4,0		3,5	0,2	Apr 11

Limits for agricultural tractors

	NO _x + HC g/kWh	CO g/kWh	Particulates g/kWh	Date
Stage II	15,0	9,0	1,0	Jan 05
Stage III	9,5	5,5	0,8	Oct 05

- Test cycle: ISO 8178, C1
- Suggested (but not finally implemented) is the adoption of the EU – Nonroad – limits, stage II as of 2007, stage IIIA as of 2011.

Japan

Emission limits from the Ministry of Transport (MOT) for “special motor vehicles”, which require a registration plate because they are used in public road traffic.

Power P_N kW	NO_x g/kWh	CO g/kWh	HC g/kWh	PM g/kWh	Smoke %	Date
Stage I						
$19 \leq P_N < 37$	8,0	5,0	1,5	0,80	40	Oct 04
$37 \leq P_N < 75$	7,0	5,0	1,3	0,40	40	Oct 04
$75 \leq P_N < 130$	6,0	5,0	1,0	0,30	40	Oct 04
$130 \leq P_N \leq 560$	6,0	3,5	1,0	0,20	40	Oct 04
Stage II						
$19 \leq P_N < 37$	6,0	5,0	1,0	0,40	40	Oct 07
$37 \leq P_N < 56$	4,0	5,0	0,7	0,30	35	Oct 08
$56 \leq P_N < 75$	4,0	5,0	0,7	0,25	30	Oct 08
$75 \leq P_N < 130$	3,6	5,0	0,4	0,20	25	Oct 07
$130 \leq P_N \leq 560$	3,6	3,5	0,4	0,17	25	Oct 06

- Test cycle: ISO 8178-4, C1
- Smoke measurement according to JCMAS T-004.
- As of 01.04.06 the emission limits of stage I are also valid for “nonroad special motor vehicles” not requiring a registration plate.

Emission limits from the Ministry of Construction (MOC) for construction machines (e.g. excavator, concrete mixer, generator sets, air compressors, ...)

Power P_N kW	NO_x g/kWh	CO g/kWh	HC g/kWh	PM g/kWh	Date
Stage II					
$8 \leq P_N < 19$	9,0	5,0	1,5	0,8	Oct 2003
$19 \leq P_N < 37$	8,0	5,0	1,5	0,8	Oct 2003
$37 \leq P_N < 75$	7,0	5,0	1,3	0,4	Oct 2003
$75 \leq P_N < 130$	6,0	5,0	1,0	0,3	Oct 2003
$130 \leq P_N \leq 560$	6,0	3,5	1,0	0,2	Oct 2004

- Test cycle: ISO 8178-4, C1
- The emission limits for engines with 19-560 kW are identical to those of the Ministry of Transport (MOT) stage I, but have been put into force one year earlier.

Directive 97/68/EC (as amended by 2004/26/EC)

Applies for compression ignition engines installed on railway vehicles with a rated power of more than 130 kW for propulsion engines, and at least 19 kW for engines running at constant speed. For engines that are operated at constant speed the limits apply as of December, 31st 2006.

Locomotive propulsion engines

Stage	Power P_N Cylinder displ.	NO_x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date*
IIIA	$130 \leq P_N \leq 560$ kW	4,0		3,5	0,2	2007
	$560 < P_N \leq 2000$ kW	6,0	0,5	3,5	0,2	2009
	$P_N > 2000$ kW $V_{h,z} > 5$ l	7,4	0,4	3,5	0,2	2009
IIIB	$P_N > 130$ kW	4,0		3,5	0,025	2012

Railcar propulsion engines

Stage	Power P_N	NO_x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date*
IIIA	$P_N > 130$ kW	4,0		3,5	0,2	2006
IIIB	$P_N > 130$ kW	2,0	0,19	3,5	0,025	2012

*Date for placing on the market of engines, type approval one year earlier.

- No stage I and II
- Test cycle: ISO 8178-4, C1 (railcars) respectively F
- Test condition: air temperature 25°C
- As of stage III B there are limits in the performance map (NTE).
- Compliance with the limits must be demonstrated over the useful lifetime of the engine.

International Union of Railways - UIC

UIC code 624V establishes emission limits for railway propulsion engines, which are mandatory for all UIC members. The UIC stage III corresponds to the stage IIIA of the EU – Nonroad – Directive 97/68/EC (see above).

Stage	Power P_N Speed n_N	NO_x g/kWh	HC g/kWh	CO g/kWh	PM g/kWh	Date
UIC II	$P_N \leq 560$ kW	6,0	0,6	2,5	0,25	01.01.2003
	$P_N > 560$ kW $n_N > 1000$ rpm	9,5	0,8	3,0	0,25	01.01.2003
	$P_N > 560$ kW $n_N \leq 1000$ rpm	9,9	0,8	3,0	0,25	01.01.2003

- UIC II: test cycle ISO 8178-4, F
- UIC III: test cycle ISO 8178-4, F (C1 for railcars, corresponding to EU – Nonroad – Directive 97/68/EC)
- Test fuel corresponding to ISO 8178-5
- Test condition: air temperature 25°C
- Exempted are engines with a rated power of less than 100 kW as well as engines installed in special locomotives (e.g. refinery- or mining-locomotives).

USA – EPA – Rail – Regulation 40 CFR 92

Locomotive engines with a rated power ≥ 750 kW

	NO_x	HC	CO	PM	Smoke (opacity)		
	g/kWh	g/kWh	g/kWh	g/kWh	station.	30s	3s
Tier 1 as of 2002							
Line-haul cycle	9,9	0,74	2,9	0,60	0,25	0,4	0,5
Switch cycle	14,7	1,61	3,3	0,72	0,25	0,4	0,5
Tier 2 as of 2005							
Line-haul cycle	7,4	0,4	2,0	0,27	0,20	0,4	0,5
Switch cycle	10,9	0,8	3,2	0,32	0,20	0,4	0,5

- Engines below 750 kW are subject to the EPA Nonroad – directive (40 CFR 89 resp. 40 CFR 1039).
- Test cycle: US – Locomotive cycle
- Test condition: air temperature 7 – 41°C, ambient pressure 0,88 – 1,05 bar
- Compliance with the limits has to be demonstrated over the useful lifetime of the engine.
- The opacity is measured during the transition from one running notch to the next.
- ABT (Averaging, Banking and Trading): Emission credits can be averaged, banked or traded.

25 HEAVY-DUTY VEHICLES

EU – Directive 88/77/EEC (as amended by 2005/78/EC)

Applies to heavy-duty vehicles with a gross weight over 3,5t. Compression ignition and gas engines are treated as propulsion engines within this directive.

Limits for ESC- and ELR-test:

Stage	CO g/kWh	HC g/kWh	NO _x g/kWh	PM g/kWh	Smoke m ⁻¹	Date**
Euro III	2,1	0,66	5,0	0,10 0,13*	0,80	01.10.2001
Euro IV	1,5	0,46	3,5	0,02	0,50	01.10.2006
Euro V	1,5	0,46	2,0	0,02	0,50	01.10.2009
EEV***	1,5	0,25	2,0	0,02	0,15	

* For engines with a displacement below 0,75 dm³ per cylinder and a rated power speed of more than 3000rpm.

** Date for placing on the market, type approval one year earlier.

*** EEV: Facultative limits for very environment-friendly vehicles.

Limits ETC-test:

Stage	CO g/kWh	NMHC g/kWh	CH ₄ ** g/kWh	NO _x g/kWh	PM *** g/kWh	Date*
Euro III	5,45	0,78	1,60	5,0	0,16 0,21 ****	01.10.2001
Euro IV	4,00	0,55	1,10	3,5	0,03	01.10.2006
Euro V	4,00	0,55	1,10	2,0	0,03	01.10.2009
EEV	3,00	0,40	0,65	2,0	0,02	

* Date for placing on the market, type approval one year earlier.

** Only for natural gas engines.

*** Not valid for gas-driven engines of stages III, IV and V.

**** For engines with a displacement of less than 0,75 dm³ per cylinder and a rated power speed of more than 3000rpm.

In stage Euro III only diesel engines with a particulate filter and/or a DeNO_x catalytic converter are additionally subjected to the ETC-test. In stages Euro IV and Euro V all engines are additionally subjected to the ETC-test.

Gaseous emissions of gas engines are measured using the ETC-test.

From stage Euro IV all new vehicle types have to be equipped with an "On-Board-Diagnosys-System" (OBD) or an "On-Board-Monitoring-System" (OBM) to control the exhaust emissions during operation.

From stage Euro IV for new vehicles and engines the operational reliability of emission-relevant components has to be guaranteed for the useful lifetime of the vehicle or the engine to get the corresponding type approval.

USA

The limits apply for heavy-duty vehicles with a gross weight of more than 3,856 t (8500 lbm). The vehicles are separated in the following **sub-categories**:

- Light heavy-duty diesel engines:
8500 lbm (California: 14500 lbm) < LHDDE < 19500 lbm
- Medium heavy-duty diesel engines:
19500 lbm ≤ MHDDE ≤ 33000 lbm
- Heavy heavy-duty diesel engines (including urban buses):
HHDE > 33000 lbm

Compliance of the limits has to be demonstrated over the **useful lifetime** of the engine, respectively **mileage** (depending on which occurs first):

- LHDDE: 110000 miles / 10 years
- MHDDE: 185000 miles / 10 years
- HHDE: 435000 miles / 10 years / 22000 hours

Limits

Model year MY	NO _x g/kWh	HC g/kWh	NO _x + NMHC g/kWh	CO g/kWh	PM g/kWh
2004			3,2*	20,8	0,130
2007	0,27	0,19		20,8	0,013

*optionally 3,4 g/kWh if NMHC < 0,7 g/kWh

- Test standard: US-FTP transient test procedure for heavy-duty diesel engines as of 2007, additionally SET (Supplemental Emission Test). In addition to the particulate measurement, a transient smoke test is required.
- For urban buses, lower particulate limits apply. Fleet-emission should be decreased about 85% (compared to the emissions in January 2002) until 2007 (on alternative fuels until 2009).
- NO_x- and NMHC-limits for MY 2007 will be introduced gradually. As of 2007 a minimum of 50% of all sold vehicles must comply with these limits (for the rest, the limits of model year 2004 apply), as of 2010 all vehicles have to comply with the limits of model year 2007.
- **NTE** (Not to exceed): In a certain map area (operating range), pre-defined upper emission limits must not be exceeded.
- **ABT** (Averaging, Banking and Trading): Emission credits (NO_x+HC and particulates) can be averaged, banked or traded.
- **NCP** (Non-conformance penalties): Compensation payment is possible if the limits are exceeded.

27 HEAVY-DUTY VEHICLES

Japan

The limits apply to heavy-duty vehicles with a gross weight of more than 3,5 tons (2005) respectively 2,5 tons (2003).

Date** of type test	CO g/kWh	HC g/kWh	NO _x g/kWh	PM g/kWh
Oct. 2003	2,22	0,87	3,38	0,180
Oct. 2005	2,22	0,17*	2,00	0,027

* Non-methane hydrocarbons

** Different dates for different weight classes

- Testing with the Japanese 13-mode test, respectively from 2005 with the Japanese transient test JE05 (Duration: 1800s, measuring point defined as speed of the vehicle at certain points of time.)
- In addition a smoke limit must be met.

TEST CYCLES

ISO 8178 – Part 4

- Part 4 of ISO 8178 “Reciprocating internal combustion engines – Exhaust emission measurement” deals with the “test cycles for different engine applications”.
- The test cycles for the measurement and evaluation of gaseous and particulate exhaust emissions in reciprocating internal combustion engines are established, if the power is determined with a dynamometer.
- The tests are carried out under steady state operation.
- Engines for motor vehicles primarily designed for road use are excluded.
- The weighting factors only apply, if the results are expressed in **g/kWh**.
- The **engine** has to **warm-up** to the rated power used in the test cycle, according to the recommendations of the manufacturer, to **stabilise** the engine **operating-parameters**.
- The **test conditions** are established in ISO 8178-1 and ISO 8178-2.

Classification of the test cycles:

- A** Heavy-duty diesels in road vehicles (compare ECE R49)
- B** Universal, includes all test modes of cycles A, C, D, F, E1 and E2 without weighting, and can be used as the basis for calculating emissions for these test cycles
- C** Vehicles (except on-road vehicles) and industrial equipment
 - C1** Nonroad vehicles and industrial equipment with diesel engines
 - C2** Nonroad vehicles and industrial equipment with spark-ignition engines and rated power above 20 kW
- D** Constant speed
 - D1** Gensets, irrigation pumps
 - D2** Units with intermittent load
- E** Marine engines
 - E1** Diesel engines for craft less than 24 m, except engines for tug/push boats
 - E2** Heavy-duty, constant-speed engines for marine propulsion, without restriction of vessel length
 - E3** Heavy-duty engines running on the propeller curve for marine main propulsion, without restriction of vessel length.
 - E4** Spark-ignition engines for craft less than 24 m, except engines for tug/push boats
 - E5** Diesel engines for craft less than 24 m, except for tug/push boats
- F** Rail engines
- G** Engines with a rated power usually less than 20 kW, for utility, lawn and garden equipment
 - G1** Non hand-held applications with intermediate speed
 - G2** Non hand-held applications with rated speed
 - G3** Hand-held applications with rated speed

29 TEST CYCLES

Weighting factors (mean pressure referenced to full-load curve)

Test mode B-cycle	Speed	Mean pr. $p_{me}/p_{me,max}$	Cycle						
			C1	C2	D1	D2	E1	E2	F
1	Rated speed	1	0,15		0,3	0,05	0,08	0,2	0,25
2		0,75	0,15		0,5	0,25	0,11	0,5	
3		0,5	0,15		0,2	0,3		0,15	
4		0,25		0,06		0,3		0,15	
5		0,1	0,1			0,1			
6	Intermediate speed	1	0,1	0,02					
7		0,75	0,1	0,05			0,19		
8		0,5	0,1	0,32			0,32		0,15
9		0,25		0,3					
10		0,1		0,1					
11	Low idle	0	0,15	0,15			0,3		0,6

Intermediate speed:

- For engines which are designed to operate over a speed range on a full-load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60 % and 75 % of rated speed.
- If the declared maximum torque speed is less than 60 % of rated speed, then the intermediate speed shall be 60 % of the rated speed.
- If the declared maximum torque speed is greater than 75 % of the rated speed then the intermediate speed shall be 75 % of rated speed.
- For engines which are not designed to operate over a speed range on the full load torque curve at steady state conditions, the intermediate speed will typically be between 60 % and 70 % of the maximum rated speed.
- For engines to be tested on cycle G1, the intermediate speed shall be 85 % of the maximum rated speed.

Weighting factors (for test cycles based on the propeller curve)

Test mode	Speed n/n_N	Power P/P_N	Cycle	
			E3	E5
1	1,00	1,00	0,20	0,08
2	0,91	0,75	0,50	0,13
3	0,80	0,50	0,15	0,17
4	0,63	0,25	0,15	0,32
5	Idle	0,00		0,30

ECE R49 – Test cycle

Stationary heavy-duty vehicle test (Euro II) corresponding to ISO 8178, A-cycle

Test mode	Speed n/n_N	Mean pressure $p_{me}/p_{me,max}$	Weighting factor
1	Low idle	0,00	0,25/3
2	Intermediate speed	0,10	0,80
3		0,25	0,08
4		0,50	0,08
5		0,75	0,08
6		1,00	0,25
7	Low idle	0,00	0,25/3
8	Rated speed	1,00	0,10
9		0,75	0,02
10		0,50	0,02
11		0,25	0,02
12		0,10	0,02
13	Low idle	0,00	0,25/3

ECE/EU Smoke measurement (ECE R 24/03 and 97/20/EC respectively)

Measurement of the light-absorption coefficient (opacity) of the exhaust-gas for all vehicles with diesel engines (commercial vehicles up to Euro II)

1. Testing at constant speeds under full load

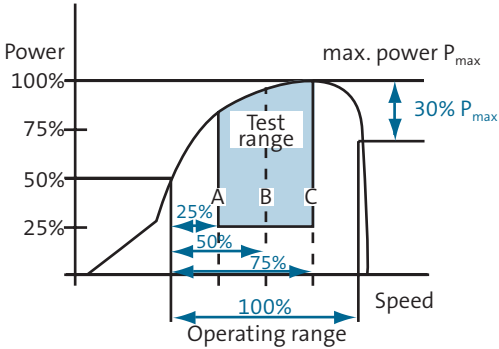
- Measurement of the full-load smoke at six different constant speeds between rated speed and 45 % of the rated speed, or at 1000 rpm.
- For ECE R 24/03: the 7th measuring point at maximum torque.

2. Testing at free acceleration

- Measurement of smoke at free acceleration of the engine from idle to maximum speed.
- Limit specified only for engines with turbocharger.

ESC – European Steady State Cycle

Stationary heavy-duty vehicle test cycle (Euro III and IV). Operating range, test range and test speeds A, B and C are defined as follows within the full-load curve.



Test range	Speed	Mean pr. $P_{me}/P_{me,max}$	Weighting factor	Test time minutes
1	Low idle	0	0,15	4
2	A	1,00	0,08	2
3	B	0,50	0,10	2
4	B	0,75	0,10	2
5	A	0,50	0,05	2
6	A	0,75	0,05	2
7	A	0,25	0,05	2
8	B	1,00	0,09	2
9	B	0,25	0,10	2
10	C	1,00	0,08	2
11	C	0,25	0,05	2
12	C	0,75	0,05	2
13	C	0,50	0,05	2

NO_x emission is measured at three additional points in the test range. The values measured at these points may exceed the values interpolated from the four neighbouring points by max. 10%.

ELR – European Load Response Test

- Transient smoke test for diesel engines of commercial vehicles with a gross weight of more than 3,5 tons (Euro III and IV).
- Torque-increasing of 10 percent on the maximum torque at each constant testing-speeds A, B and C (compare with ESC-test).
- Additionally, smoke is to be tested at a speed between A and C and another speed that is freely selectable by the tester.
- Measurement is to be repeated three times.
- The exhaust-opacity is measured in m^{-1} .
- The opacity which is measured at the free selectable speed may not exceed the value of the neighbouring speeds more than 20 percent and may not exceed the limit value more than 5 percent.

ETC – European Transient Cycle

- Transient test cycle for diesel engines from commercial vehicles with a gross weight more than 3,5 t (Euro III and IV), consisting of 1800 secondly changing load stages with specification of rotation speed and engine torque.
- The city, country and super-highway/motorway engine loads are simulated.
- Power and exhaust-gas emissions are integrated over the cycle.
- As of Euro III the ETC-test is mandatory only for engines with particulate filter and/or DeNO_x catalytic converter. As of Euro IV the ETC-test is mandatory for all engines

RMC – Ramped Mode Cycle

- Stationary Nonroad test cycle, created by the EPA (for Nonroad-engines, Tier 4).
- The test modes of the ISO test cycles are connected by transition periods of 20 seconds (ramps).
- The whole test sequence has to be performed in a specified time without interruption.

NRTC – Nonroad Transient Cycle

- Dynamic test for mobile machinery.
- Is valid in the USA (Tier 4) for measurement of particulate and gaseous emission.
- To use for the EU-stages III B and IV for measurement of particulate emission at all engines for mobile machinery except engines with constant speed, rail engines and propulsion engines of inland navigation vessels.
- The manufacturer can use this test also for measurements in EU-stage IIIA and for measurement of gaseous pollutants in EU-stages III B and IV.

US – Smoke test (commercial vehicles and nonroad engines)

- Measurement of the exhaust-gas opacity at transient engine operation on a test stand.
- Starting at idle, the engine is accelerated in two phases with a brief interruption (acceleration-mode).
- The engine is then operated at rated speed and power and subsequently lugged down through increasing of the load until the intermediate speed (Lugging-mode).
- Thereupon, the engine is decelerated to idle speed.
- This cycle is repeated three times. From the values measured during all three runs, the average opacity for acceleration, lugging and the maximum figure (peak) are calculated.

US transient test (FTP) for commercial vehicle engines

- Since 1985, a dynamic testing procedure in the USA is used for engines of commercial vehicles.
- The test cycle lasts 1200 seconds, whereas speed and clutch-torque are defined for each second.
- The city traffic operation modus as well as highway driving should be represented.
- The major operation frequency focus on eight points in the performance map, which are dedicated primarily to the rated speed and speeds above idle.
- The speed at maximum torque, which has a high weighting factor in ECE R49, practically does not exist.

US stationary test (SET) for commercial vehicle engines

The Supplemental Emission Test (SET) corresponds to the European ESC test and will be mandatory in the US as of MY 2007.

US locomotive test cycle

As a result of the special operating conditions of locomotives in the USA, EPA has worked out a separate test cycle.

Test mode	Throttle setting	Duration (minutes)	Weighting factor Line-haul cycle	Weighting factor Switch cycle
Warm-up	Notch 8	5 ± 1	0*	0*
Warm-up	Lowest idle	max. 15	0*	0*
1a	Low idle**	6	0,190	0,299
1	Normal idle***	6	0,190	0,299
2	Dynamic braking	6	0,125	0
3	Notch 1	6	0,065	0,124
4	Notch 2	6	0,065	0,123
5	Notch 3	6	0,052	0,058
6	Notch 4	6	0,044	0,036
7	Notch 5	6	0,038	0,036
8	Notch 6	6	0,039	0,015
9	Notch 7	6	0,030	0,002
10	Notch 8	max. 15	0,162	0,008

* no measurement

** not applicable if equipped differently

*** for applications with only one idle speed, the weighting factor is doubled

Cycle value calculation

The cycle value E_x (g/kWh) is calculated as follows using the pollutant mass flows M_{xi} (g/h) that are measured at the cycle points 1 to i with power P_i and weighting factor W_i :

$$E_x = \frac{\sum_{i=1}^n M_{xi} \cdot W_i}{\sum_{i=1}^n P_i \cdot W_i}$$

Lake Constance Shipping Ordinance (BSO) 9-mode test

- The test is executed on a **power-absorption roller**. Outboard-engines are put in a water tank and the propeller-driveshaft is connected with the power-brake (with removed propeller).
- In the **heating-phase**, the engine is firstly operated 10 minutes with free selectable part load. Then it is operated 20 minutes with full load at 50 (+/- 5) percent of the rated rotation speed.
- In the **first step** of the test, the warm engine is operated from measuring point 1 to measuring point 9, whereas all required data are measured.
- In the **second step** of the test, the warm engine is operated from **measuring point 9 to measuring point 1**, whereas all required data are measured.
- Hydrocarbons HC, carbon monoxide CO, carbon dioxide CO₂ and nitrogen oxides NO_x have to be measured. Furthermore the power and the fuel consumption has to be measured at every operating state.
- At diesel engines the exhaust-gas opacity has to be measured simultaneous or directly after the test.
- Depending on the engine operation, the test is run at the propeller- or the generator-curve (propeller curve $P - n^{2,5}$).

Propeller curve

Measuring point	Rotation speed min ⁻¹	Power kW	Weighting factor
1	Idle	0	0,30
2	0,4 • n _N	0,1012 • P _{VN}	0,10
3	0,5 • n _N	0,1768 • P _{VN}	0,10
4	0,6 • n _N	0,2789 • P _{VN}	0,10
5	0,7 • n _N	0,4100 • P _{VN}	0,20
6	0,8 • n _N	0,5724 • P _{VN}	0,05
7	0,9 • n _N	0,7684 • P _{VN}	0,05
8*	n _N	P _{VN}	0,05
9*	n _{Pmax}	P _{max}	0,05

* Measuring points 8 and 9 are combined, if P_{VN} differs not more than 5 percent of P_{max} (weighting factor 0,1)

n _N	Rated speed
P _{VN}	Not reducible full-load power at rated speed
n _{Pmax}	Speed at maximum power
P _{max}	Not reducible maximum power

The exhaust-gas opacity (smoke) has to be measured at full load (rotation speed at full power, thus at point 8 or 9) with the filtering-method.

Generator curve:

Operation at the same power levels but all with rated speed.
Power in point 9 should be 1,1 times P_{VN} .

FUELS

EU - Directives 98/70/EC (as amended by 2003/17/EC) and 2005/33/EC

- **Diesel fuels:** Gasoils which belong to KN-Code 27 10 19 41 and which are used for propulsion of vehicles for the purpose of the directives 70/220/EEC and 88/77/EEC.
- The Member States ensure, that at the latest on **01. January 2005** diesel fuel with a maximum sulphur content of 10 ppm is placed on the market in their sovereign territory. In all other aspects, the fuel has to comply to the specifications stated below.
- As of **01. January 2009** only diesel fuel may be placed on the market, which complies with the specifications below and has a maximum sulphur content of 10 mg/kg (= 10 ppm).

Attribute*	Unit	Minimum**	Maximum**
Cetane number		51	-
Density at 15°C	kg/m ³	-	845
Boiling characteristics: 95% (v/v) re-extracted at	°C	-	360
Polycyclic aromatic hydrocarbons	% m/m	-	11
Sulphur content	ppm	-	50
			10***

* Test procedure according to EN 590:1999

** „Effective Values“ according to ISO 4259

*** As of 01. January 2009 the regulated maximum sulphur content has to be satisfied by every diesel fuel that is placed on the market.

37 FUELS

- Furthermore, the Member States shall assure that the gasoils which are placed on the market for use in **mobile machinery** or in **agricultural tractors** have a maximum sulphur content of 2000 mg/kg (= 2000 ppm).
- As of **01. January 2008** the maximum sulphur content of the above mentioned gasoils is 1000 mg/kg (= 1000 ppm).
- As of **01. January 2010** the maximum sulphur content of fuels for inland navigation vessels is 1000 mg/kg (= 1000 ppm) as regulated in the directive 2005/33/EC.
- For seagoing vessels the directive 2005/33/EC regulates for special areas (so called **SO_x Emission Control Areas (SECA)**) the following limits for the sulphur content: 1,5% sulphur content for the North Sea (August 11, 2007) and the Baltic Sea and also for passenger ships at regular service between Community Ports (August 11, 2006); 0,1 % for all ships at berth in Community Ports (January 1, 2010).

Marine – USA 40 CFR

- For mobile machinery the sulphur limit is 500 ppm as of 2007 and 15 ppm as of 2010.
- For trains and ships the sulphur limit is 15 ppm as of 2012.

Marine - fuels IMO

- World-wide the IMO limits the sulphur mass content of marine fuel to 4,5 %.
- The Baltic Sea and the North Sea (inclusive the British Channel) are defined as special areas where the sulphur content may not exceed 1,5 %.
- In the Baltic Sea this regulation is valid for as of **May 19, 2006**.
- In the North Sea and the British Channel this regulation is valid as of **November 22, 2007**.

Conversion Formulas

For sulfur free diesel fuel (10 ppm sulfur) corresponding to EN 590 with a density of $\rho = 830 \text{ kg/m}^3$ (15° C), the following applies approximately:

Conversion of g/m_N^3 (5% O_2) to g/kWh :

$$EP_i = EA_i \cdot b_{\text{eff}} \cdot \frac{m_N^3}{73\text{g}} \qquad EA_i = EP_i \cdot \frac{73\text{g}}{m_N^3 \cdot b_{\text{eff}}}$$

Conversion with differing residual oxygen content (as per „TA-Luft“):

$$EA_i = EX_i \cdot \frac{21-5}{21-X}$$

Conversion of ppm to g/kWh :

$$EP_i = EV_{i,d} \cdot \frac{M_i}{M_{\text{Exh,d}}} \cdot \frac{\dot{m}_{\text{Exh,d}}}{P_{\text{eff}}} = EV_{i,w} \cdot \frac{M_i}{M_{\text{Exh,w}}} \cdot \frac{\dot{m}_{\text{Exh,w}}}{P_{\text{eff}}}$$

- EP_i Pollutant mass, i, referenced to P_{eff} (g/kWh)
- EA_i Pollutant mass, i, referenced to exhaust volumes based on dry exhaust with 5% residual oxygen under standardized conditions (g/m_N^3)
- EX_i Pollutant mass, i, referenced to exhaust volumes based on dry exhaust with X% residual oxygen under standardized conditions (g/m_N^3)
- EV_i Exhaust emission value of components, i, as volume share (ppm)
- M_i Mol mass of the components, i, (kg/kmol)
- M_{Exh} Mol mass of the exhaust (kg/kmol)
- \dot{m}_{Exh} Exhaust mass flow (kg/h)
- P_{eff} Power output (kW)
- b_{eff} Specific fuel consumption (g/kWh)

Index d: dry, Index w: wet

Component	Mol mass kg/kmol	Remarks
NO₂	46,006	NO _x treated as NO ₂
CO	28,0104	
HC	13,876	HC 1
SO₂	64,061	
Exhaust dry	30,21 / 29,84	5% O ₂ / 9,6% O ₂
Exhaust wet	28,84 / 28,82	5% O ₂ / 9,6% O ₂

39 CONVERSION FORMULAS

- At 5% residual oxygen (corresponding to an excess air ratio of 1,3 : 1) and $b_{\text{eff}} = 210 \text{ g/kWh}$, the following applies approximately:

$$\frac{\dot{m}_{\text{Exh,d}}}{P_{\text{eff}}} = 3873 \text{ g/kWh} \qquad \frac{\dot{m}_{\text{Exh,w}}}{P_{\text{eff}}} = 4160 \text{ g/kWh}$$

- 1000 ppm NO_x ,
measured wet, corresponds to $2310 \text{ mg/m}_N^3, \text{ d, 5\%}$ (6,60 g/kWh)
 - 100 ppm HC,
measured wet, corresponds to $70 \text{ mg/m}_N^3, \text{ d, 5\%}$ (0,20 g/kWh)
 - 100 ppm CO,
measured dry, corresponds to $125 \text{ mg/m}_N^3, \text{ d, 5\%}$ (0,36 g/kWh)
- At an excess air ratio of 1,8 : 1 (residual oxygen content corresponding to 9,6%) and $b_{\text{eff}} = 210 \text{ g/kWh}$ the following applies approximately:

$$\frac{\dot{m}_{\text{Exh,d}}}{P_{\text{eff}}} = 5400 \text{ g/kWh} \qquad \frac{\dot{m}_{\text{Exh,w}}}{P_{\text{eff}}} = 5710 \text{ g/kWh}$$

- 1000 ppm NO_x ,
measured wet, corresponds to $9,10 \text{ g/kWh}$ ($3150 \text{ mg/m}_N^3, \text{ d, 5\%}$)
- 100 ppm HC,
measured wet, corresponds to $0,27 \text{ g/kWh}$ ($95 \text{ mg/m}_N^3, \text{ d, 5\%}$)
- 100 ppm CO,
measured dry, corresponds to $0,51 \text{ g/kWh}$ ($176 \text{ mg/m}_N^3, \text{ d, 5\%}$)

Units:

Energy	1 J	= 1 Nm	= 1 Ws	= 1 VAs
	1 Wh	= 3,6 kJ		
	1 kWh	= 3,6 MJ		
Power	1 W	= 1 VA	= 1 J/s	= 1 Nm/s
Force	1 N	= 1 kgm/s ²		
Pressure	1 Pa	= 1 N/m ²		
	1 bar	= 10 ⁵ Pa		

Conversion of non – SI units:

Length

Inch	1 in	= 25,4 mm	
Foot	1 ft	= 304,8 mm	= 12 in
Yard	1 yd	= 914,4 mm	= 3 ft
Statute mile	1 mi	= 1609,34 m	= 1760 yd
Nautical mile	1 nm	= 1852 m	

Surface

Square inch 1 sq in = 645,16 mm²

Volume

Cubic inch 1 cu in = 0,016387 Liter

Gallon (US) 1 gal (US) = 3,78541 Liter

Gallon (UK) 1 gal (UK) = 4,54609 Liter

Liquid barrel (US) 1 liq bbl = 119,24 Liter

Barrel Petroleum 1 bbl = 158,99 Liter

Mass

Grain 1 gr = 64,7989 mg

Ounce 1 oz = 28,3495 g

Pound mass 1 lbm = 0,45359 kg = 16 oz = 7000 gr

Hundredweight (US) 1 cwt (US) = 45,3592 kg = 1 short cwt = 100 lbm

Hundredweight (UK) 1 cwt (UK) = 50,8023 kg = 1 long cwt = 112 lbm

Ton (US) 1 ton (US) = 907,185 kg = 1 short ton = 2000 lbm

Ton (UK) 1 ton (UK) = 1016,05 kg = 1 long ton = 2240 lbm

Force

Pound force 1 lbf = 4,44822 N

Pressure

Atmosphere 1 atm = 1,01325 bar

Water column 1 mm WS = 9,80665 Pa

Mercury column 1 mm Hg = 133,322 Pa = 1 Torr

Psi 1 lbf / in² = 6894,76 Pa pound per square inch

Energy

Calorie 1 kcal = 4186,8 J

Foot pound-force 1 ft lbf = 1,35582 J

British thermal unit 1 Btu = 1055,06 J

Mineral coal unit 1 kg SKE = 29,3076 MJ = 8,141 kWh

Oil equivalent 1 kg OE = 41,868 MJ = 11,63 kWh

Power

Horsepower (metric) 1 PS = 735,499 W

Horsepower (US) 1 bhp = 745,70 W = 550 ft. lbf/s

Temperature

T (K) = t (°C) + 273,15

t (°C) = 5/9 • (t(°F) – 32)

VDMA

Engines and Systems

Lyoner Straße 18

60528 Frankfurt am Main

Contact: Diana Schnith

Phone: +49 69 66 03-13 78

Fax: +49 69 66 03-23 78

Email: mus@vdma.org

Internet: www.vdma.org/motoren

Editorial team:

Markus Heseding

Panagiotis Daskalopoulos

www.vdma.org/motoren