TFTEI background informal technical document for the Review of the Gothenburg Protocol for Industrial Processes

Annexes IV, V, VI, X and XI

March 2022

Prepared by TFTEI Techno-Scientific Secretariat
Nadine Allemand (Citepa)
Simon Glöser-Chahoud (KIT)
Grégoire Bongrand (Citepa)
Valérie Imad (Citepa)

MINISTÈRE
DE LA TRANSITION
ÉCOLOGIQUE
Liberté
Égalité
Fraternité

CITEPA

KIT
Karlsruher Institut für Technologie

TFTEI background informal technical document for the Review of the Gothenburg Protocol for Industrial Processes

Annexes IV, V, VI, X and XI

For more information

TFTEI Techno-Scientific Secretariat
Dr. Nadine Allemand
Citepa
42 Rue de Paradis
75010 Paris
France
T: + 33 (0)1 44 83 68 83
E: nadine.allemand@citepa.org
Dr.-Ing. Simon Glöser-Chahoud
Karlsruhe Institute of Technology (KIT)
French-German Institute for Environmental Research (DFIU)
Hertzstraße 16
D-76187 Karlsruhe
Germany
T: +49 (0)721 608 44592
F: +49 (0)721 608 44682
E: simon.gloeser-chahoud@kit.edu

Content

Index of Tables

Index of Figures

List of abbreviations and acronyms

(A)GP	(Amended) Gothenburg Protocol
BAT	Best available technique
BAT AEL	Best available technique associated enviromental level
BC	Black carbon
BF	Baghouse filter
BREF	Best available technique reference document
CBC	case by case
CCAC	Climate and clean air coalition
CCGT	Combined cycle gas turbine
CFB	Circulating fluidised bed
CLP	Classification, labelling and packaging
CLRTAP	Convention on long-range transboundary atmospheric pollution
CN	Combined nomenclature
CPM	Condensable particulate matter
CPOA	Condensable organic aerosol
CPR	Construction products regulations
DLN	Dry low NOx (burner)
DPNB	Dipropylene glycol, n-butyl ether
DPTB	Dipropylene glycol tert-butyl ethers
DS	Dilution sampling
DSI	Duct sorbent injection
DT	Dilution tunnel
EBC	Equivalent black carbon
EC	European commission
EC	Elemental carbon
EGR/FGR	Exhaust/Flue-gas recirculation
ELV	Emission limit value
EMEP	European monitoring and evaluation programme
E-PRTR	European pollutant release and transfer register
ESP	Electrostatic precipitator
EU	European Union
FBC	Fluidised bed combustion

FCC	Fluid catalytic cracking
FGD	Flue gas desulphurization
FID	Flame ionisation detector
FPM	Filtrable particulate matter
FPOA	Filterable organic aerosol
GAINS	Greenhouse Gas and Air Pollution Interactions And Synergies
HRSG	Heat recovery steam generator
ICCI	International cryosphere climate initiative
IEA	International energy agency
IED	Industrial emission directive
IPA	Isopropanol
JRC	Joint research centre
LCP	Large combustion plant
LNB	Low-NOx burner
LPG	Liquefied petroleum gas
MCP(D)	Medium combustion plant (directive)
MSC-W	Meteorological Synthesizing Centre - West
NOx	Nitrogen oxides
OC	Organic carbon
OFA	Over-fire air
OGC	Organic gaseous carbon
OTNO	Other than normal operating conditions
PAH	Polycyclic aromatic hydrocarbon
PC	Pulverised combustion
PER	Perchloroethylene
PGtBE	Propylene glycol t-butyl ether
PM	Particulate matter
PP	Power plant
PPM	Primary particulate mater
RAC	Regenerated activated carbon
RFO	Refinery fuel oil
RTO	Regenerative thermal oxidiser
SCR	Selective catalytic reduction

SDA	Spray dry absorber
SNCR	Selective non-catalytic reduction
SO2	Sulphur dioxide
SOA	Secondary organic aerosols
SP	Solid particle
SPM	Solid particulate matter
SRU	Sulphur recovery unit
STS	Surface treatment using solvents
TA	Technical annexes
TFTEI	Task force on techno-economic issues
TGTU	Tail gas treatment unit
TiO2	Titanium dioxide
TPM	Total particulate matter
TPP	Thermal power plants
TSP	Total suspended particles
ULE	Ultra-low emission
UNECE	United Nations Economic Commission for Europe
US EPA	United States environmental protection agency
US(A)	United States (of America)
(T)VOC	(Total) Volatile organic compounds
WB	Water based
WG	Working group
WGC	Waste gas management and treatment systems in the chemical sector

Executive Summary

The Decision 2019/4, taken by the Executive Body in December 2019, established the scope and content of the review of the Amended Gothenburg Protocol. The Group for the Review of the Gothenburg Protocol (GPG) developed the document “Preparations for the review of the Protocol to Abate Acidification, Eutrophication, and Ground-level ozone, as amended in 2012 (2020/3).”, adopted in December 2020. In the Annex I of such document, a list of questions concerning all the aspects to be considered during the review process, is reported. In particular the questions in section 1.6 are related to the Technical Annexes (TAs) to the AGP. In order to answer the questions in section 1.6, in 2021 TFTEI carried out an extensive review of the TAs and its associated Guidance Documents (GDs). The main conclusions of such review work were included in the GPG “Draft report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012” (ECE/EB.AIR/WG.5/2022/3) and, also, in the TFTEI co-chairs Report of the Task Force on Techno-economic Issues (ECE/EB.AIR/WG.5/2022/1), both official documents for WGSR, at its 60th session.

In the following sections, an extended and detailed report of the results regarding the review of the TAs to the Amended Gothenburg Protocol, and its associated GDs, carried out by TFTEI, is provided. In particular, the emission limit values (ELVs) in the existing TAs are compared to the emission levels achievable with state-of-the art abatement technologies. The current report in aimed at providing, a more comprehensive document with background information regarding BATs and related ELVs and it is made available, as informal dicument for WGSR, at its 60th session (11 - 14 April 2022).

In Table 1, the activities covered in the Annexes IV (SO_2), V (NOx), X (PM) are reported, meanwhile the activities covered in the Annexes VI (VOC from stationary sources) and XI (solvents in products) are in Table 2 and the activities related to the Annex VIII (mobile sources) in Table 3. All potential limit values and potential improvements through new, state-of-the art BATs are provided in the following sections with one chapter for each annex. The tables cover all activities in the existing Technical Annexes, limit values and potential updates. The document is aimed at providing, an overview, to the extent possible exhaustive, to all the Parties’ experts and representatives, in support to the discussion on the review of the Gothenburg Protocol,

Table 1: Processes and respective ELVs listed in the annexes IV (SO_2), V (NO_x), X (PM)

IV: Limit values for emissions of sulphur from stationary sources	**V: Limit values for emissions of nitrogen oxides from stationary sources**	**X: Limit values for emissions of particulate matter from stationary sources**
1. Limit values for SO_2 emissions from combustion plants 2. Limit values for the sulphur content of gas oil 3. Limit value expressed as a minimum sulphur recovery rate of sulphur recovery units 4. Limit values for SO_x emissions	1. Limit values for NOx emissions released from combustion plants 2. Limit values for NOx emissions released from onshore combustion turbines (including Combined Cycle Gas Turbine CCGT) 3. Limit values for NOx emissions released from	1. Limit values for dust emissions from combustion plants 2. Limit values for dust emissions released from mineral oil and gas refineries 3. Limit values for dust emissions released from cement production 4. Limit values for dust emissions released from lime production 5. Limit values for dust emissions released from primary iron and steel production 6. Limit values for dust emissions released from iron foundries 7. Limit values for dust emissions released from non-ferrous metals production and processing 8. Limit values for dust emissions released from glass production

released from titanium dioxide production	cement clinker production 4. Limit values for NOx emissions released from new stationary engines 5. Limit values for NOx emissions released from iron ore sinter plants 6. Limit values for NOx emissions from nitric acid production excluding acid concentration units	9. Limit values for dust emissions released from pulp production 10. Limit values for dust emissions released from waste incineration 11. Limit values for dust emissions released from titanium dioxide production 12. Recommended limit values for dust emissions released from new solid fuel combustion installations with a rated thermal input < 500 kWth to be used with product standards 13. Recommended limit values for dust emissions released from boilers and process heaters with a rated thermal input of 100 kWth–1 MWth 14. Recommended limit values for dust emissions released from boilers and process heaters with a rated thermal input of 1 MWth–50 MWth

Table 2: Processes and respective ELVs listed in the annexes VI (VOC from stationary sources) and XI (VOC content of products)

VI: Limit values for emissions of volatile organic compounds from stationary sources	**XI: Limit values for volatile organic compounds content of products**
1. Limit values for VOC emissions from storage and distribution of petrol, excluding the loading of seagoing ships (stage I) 2. Limit values for VOC emissions for car refueling at service station (stage II) 3. Limit values for adhesive coating 4. Limit values for wood and plastic lamination 5. Limit values for coating activities in the vehicle industry 6. Limit values for coating activities in various industrial sectors 7. Limit values for leather and winding wire coating 8. Limit values for coil coating 9. Limit values for dry cleaning 10. Limit values for manufacturing of coatings, varnishes, inks and adhesives 11. Limit values for printing activities 12. Limit values for manufacturing of pharmaceutical products 13. Limit values for conversion of natural or synthetic rubber 14. Limit values for surface cleaning 15. Limit values for extraction of vegetable and animal fat and refining of vegetable oil 16. Limit values for impregnation of wood	1. Maximum VOC content for paints and varnishes 2. Maximum VOC for vehicle refinishing products

Table 3: Processes and respective ELVs listed in the annex VIII (fuels and mobile sources)

VIII: Limit values for fuels and new mobile sources

1. Limit values for passenger cars and light-duty vehicles
2. Limit values for heavy-duty vehicles steady-state cycle load-response tests
3. Limit values for heavy-duty vehicles – transient cycle tests
4. Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (stage IIIB)
5. Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (stage IV)
6. Limit values for spark-ignition engines for non-road mobile machines
7. Limit values for engines used for propulsion of locomotives
8. Limit values for engines used for propulsion of railcars
9. Limit values for engines for propulsion of inland waterways vessels
10. Limit values for engines in recreational crafts
11. Limit values for motorcycles (> 50 cm^3 ; > 45 km/h)
12. Limit values for mopeds (< 50 cm^3 ; < 45 km/h)
13. Environmental specifications for marketed fuels to be used for vehicles equipped with positive-ignition engines
14. Environmental specifications for marketed fuels to be used for vehicles equipped with compression-ignition engines

.

1. Introduction

The rationale behind the proposal of potential updating of the limit values from Annex IV (limit values for emissions of sulphur from stationary sources), Annex V (limit values for emissions of NO_x from stationary sources), Annex VI (limit values for emissions of VOC from stationary sources), Annex X (limit values for emissions of particulate matter from stationary sources) and Annex XI (solvents in products) are provided in the following chapters. All the processes have been examined and information is provided for potential updatable limit values (ELVs). An "Update Index" (1-3), has been defined to express the level of update which can be potentially introduced in the technical annexes, according to the results of the research carried out by the TFTEI Technical Scientific Secretariat, on the available technologies (1 is high level of update, 3 means no update available/possible). ELVs and the related information on BATs, for emission abatement, are provided in this technical document.

A second informal document will follow shortly focused on mobile sources, as in the Technical Annex VIII.

2. Short description of techniques covered in the assessment

In order to abate pollutant emissions from stationary and mobile sources, some reduction techniques can be implemented depending on the installation operations, characteristics, size, products used and other specific conditions.

The pollutant abatement methods can act on reducing the emissions of either one or several substances, simultaneously. In addition, some techniques can tackle one specific substance emissions meanwhile increasing the emissions of another compound due to the use of a specific process or product (e.g., NH_3 emissions increase while using ammonia or urea solutions, in abatements devices).

Pollutant reduction techniques are usually distinguished in two categories: primary techniques, which consist of acting directly on the process or the fuels used, and secondary techniques which consist of the treatment of exhaust gases.

General techniques can decrease simultaneously all the emissions of pollutant such as the process or combustion modification and optimization, the use of advanced control and monitoring system or other energy efficiency techniques such as flue-gas condenser or a management system to recycle the process gases (e.g., iron and steel process gases or refinery gas).

2.1. Sulphur oxides reduction techniques for stationary sources

2.1.1. Primary techniques

- **Sulphur content of fuels:**

The SO_2 emissions from the combustion of fuels are directly related to their sulphur content. Therefore, switching to low sulphur fuels such as distillate oils, natural gas or LPG or any very low content fuels, can enable to reduce SO_2 emissions.

2.1.2. Secondary techniques

- **Boiler sorbent injection:**

This technique consists of injecting dry alkaline sorbent or adding magnesium- or calcium-based solution into the combustion chamber or process furnace so that it reacts with and neutralizes SO_2 in the fluidized bed or exhaust gas. It is often combined with dust abatement techniques.

- **Duct sorbent injection (DSI):**

This method is similar to boiler sorbent injection but the sorbent, which can be sodium bicarbonate or hydrated lime or other alkaline sorbents, is injected directly into the exhaust duct and reacts with the acid gases. The solid reaction product is then removed through dust abatement technologies.

- **Spray dry absorber (SDA):**

In a similar way as DSI, a suspension or solution of alkaline agent is dispersed into the exhaust gas stream in order to neutralize SO_2 emissions and form solid compounds which are treated by dust removal techniques. The SO_2 removal efficiency is larger than in DSI.

- **Circulating fluidised bed (CFB) dry scrubber:**

This technology consists of making the SO_2-rich flue gas flows through the CFB dry scrubber, in the form of a Venturi scrubber, where water and a solid sorbent are injected separately to tackle the SO_2 emissions.

- **Seawater scrubber:**

This technique consists of making the exhaust gas flows through the scrubber where seawater is sprayed to capture and absorb the acidic compounds thanks to its alkalinity. This technique can also remove the solid compounds present in the flue-gas, decreasing simultaneously the particle matter. The wastewater resulting from this operation is then treated separately.

- **Wet scrubber/flue-gas desulphurisation (FGD):**

This technology is the same as seawater scrubber but, instead of seawater, an alkaline solution is used. At the same residence time and reagent consumption, this technology has a higher removal efficiency than seawater scrubbing.

2.2. Nitrogen oxides reduction techniques for stationary sources

2.2.1. Primary techniques

- **Combustion optimization:**

Optimizing the combustion process through measures to maximise energy efficiency, by setting properly the combustion temperature, the air intake or the residence time, can improve the emissions of pollutants such as NO_x.

- **Air staging:**

This technique consists of optimising the fuel combustion by creating two combustion zones with different oxygen contents (one with air deficiency and the other with excess).

- **Fuel staging:**

Similarly to air staging, several combustion zones are created through different fuel injection points and flows in order to decrease the flame temperature, hence the thermal NO_x formation.

- **Flue-gas/Exhaust gas recirculation (FGR/EGR):**

This technique consists of recycling part of the exhaust gas and making it flow back through the combustion chamber, after cleaning it from dust and acid gases to prevent the engine corrosion and clogging, in order to reduce the combustion temperature and oxygen content, and therefore the NO_x generation.

- **Low-NO_x burners:**

Low-NO_x burner principle is to mix the air and fuel before injecting it into the combustion chamber so that it decreases the oxygen availability and peak flame temperature. This technique enables to maintain the energy efficiency and increase the heat transfer meanwhile reducing NO_x formation.

Ultra-low NO_x burner technology consists of combining LNB with air staging and FGR.

- **Water/steam addition:**

Water or steam can be used as diluent in order to decrease the combustion temperature and NO_x formation. Water or steam can be directly injected into the combustion chamber or premixed with the fuel before (e.g., emulsion or humidification).

- **Lean-burn concept:**

This technique is applicable only to engines and consists of controlling the peak flame temperature through the decrease of the fuel-to-air ratio in order to reduce the thermal NO_x generation.

2.2.2. Secondary techniques

- **Selective non-catalytic reduction (SNCR):**

SNCR technology consists of injecting urea or an ammonia solution at high temperatures (about 800-1000°C for optimal reaction) into the exhaust duct so that the NO_x compounds present in the flue-gas are reduced to nitrogen via the chemical reaction, without catalyst. As ammonia solution is used as a reductive agent, there is a risk of slip which could induce NH_3 emissions.

- **Selective catalytic reduction (SCR):**

SCR is the same technique as SNCR but, in addition, the chemical reaction occurs in presence of a catalyst. The optimum operating temperatures are lower than SNCR and range from 300 to 450 °C. This technology is more efficient than SNCR and a higher efficiency can be obtained with a larger number of catalyst layers.

2.3. Dust reduction techniques for stationary sources

2.3.1. Primary techniques

Some primary techniques exist to reduce dust emissions but consist mostly in burning cleaner fuels or burning a lower amount of fuel.

- **Fuel choice:**

Using fuels with a low ash or metal content such as natural gas or distillate fuels is a great means to minimize particulate matter (PM) emissions.

- **Combustion optimization:**

Optimizing the combustion process and maximising the energy efficiency imply lower PM emissions.

2.3.2. Secondary techniques

The best means to reduce significantly PM emissions are technologies which treat the dust-rich flue-gas such as:

- **Multicyclones:**

In multicyclones, particles are separated from the flue-gas through centrifugal force in one or several chambers.

- **Electrostatic precipitator (ESP):**

ESP filters consist first of charging electrically the particles in the flue-gas so that they can be removed while passing through the electrical field. The removal efficiency varies depending on the number of electrical fields, the residence time and the catalyst properties. For most recent technologies, the number of electrical fields ranges from 2 to 7.

- **Baghouse/Fabric filter:**

Baghouse/fabric filters are porous ceramic or felted fabric substrates on which particles get trapped while the exhaust gas flow through it. The filtering material used must be chosen appropriately depending on the flow-gas characteristics and operating temperature ranges to prevent the corrosion and wear of the filter. A means to clear the particles and soot accumulating at the filter surface is required as well in order to maintain the removal efficiency.

In addition, most of the exhaust-gas techniques aimed to tackle SO_2 emissions can benefit simultaneously to PM emissions: boiler sorbent injection, duct sorbent injection, spray dry absorber, circulating fluidised bed scrubber, or seawater or wet FGD.

3. Annex IV: limit values for emissions of sulphur from stationary sources

3.1. Limit values for SO_2 emissions released from combustion plants

In the Amended Gothenburg Protocol (AGP) [1], combustion plants are defined as installations with a rated thermal power input capacity higher than 50 MWth. The rated thermal input of the combustion plant is calculated as the sum of the input of all units connected to a common stack. Individual units below 15 MWth shall not be considered when calculating the total rated thermal input (ELV are applied to all unit even those bellow 15 MWth).

The following table summarizes the assessment of the current emission limit values (ELVs) given in the AGP, the potential technologies applicable to achieve similar or lower levels and their applicability in this sector, as well as potential updates of the ELVs for consideration in the review of the AGP.

In the light of the current regulations, this analysis is presented per pollutant, fuel type, thermal input power range and installation status (new or existing). For the latter, a “new” stationary source is considered as an installation for which construction or modification initiated before the expiry of one year from the date of entry into force for a Party.

After this summary table, a more-detailed assessment of each of the following ELV and their potential update is given.

Table 4: Table 1, Annex IV, proposal of potential updates of limit values for emissions of sulphur from combustion plants

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
37-38	**Table 1:** Limit values for SO_2 emissions released from combustion plants				
	Coal, lignite and other solid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW* *New and existing plants:* **400** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity between 100 and 300 MW:* New plants: **200** mg/m^3 at 6 % O_2 **[Update Index 2]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[1][3]*: - boiler sorbent injection - duct sorbent injection (DSI) - spray dry absorber (SDA) - circulating fluidised bed (CFB) dry scrubber - wet scrubbing - wet flue-gas desulphurisation (FGD) - seawater FGD	Almost 100 %. Some limitations may exist for FGD if: - the plant operates less than 500 hours per year, - it is for retrofitting on existing combustion plant operating less than 1,500 hours per year, - the combustion plant is less than 300 MW$_{th}$, there may be technical and economic restrictions	**Coal, lignite and other solid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW (as daily average) [2][3]:* New plant: **170-220** mg/m^3 at 6 % O_2 Existing plant: **170-400** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW (as daily average)[2][3]:*

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Existing plants: **250** mg/m^3 at 6 % O_2 **[Update Index 2]** *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: **150** mg/m^3 at 6 % O_2 (200 mg/m^3 at 6 % O_2 if fluidised bed boiler) **[Update Index 1]** Existing plants: **200** mg/m^3 at 6 % O_2 **[Update Index 1]**				New plants: **135-200** mg/m^3 at 6 % O_2 Existing plants: **135-220** mg/m^3 at 6 % O_2 (the upper value of the range is 250 mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014) *Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]:* PC boilers: New plants: **25-110** mg/m^3 at 6 % O_2 Existing plants: **25-165** mg/m^3 at 6 % O_2 (the upper value of the range is **205** mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014) Fluidised bed boilers: New plants: **25-110** mg/m^3 at 6 % O_2 Existing plants: **50-220** mg/m^3 at 6 % O_2
	Solid biomass and peat: *Combustion plant with a thermal input capacity between 50 and 100 MW – New and existing plants:* Peat: **300** mg/m^3 at 6 % O_2 **[Update Index 1]** Biomass: **200** mg/m^3 at 6 % O_2 [**Update Index 1**] *Combustion plant with a thermal input capacity between 100 and 300 MW – New and existing plants:*	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - boiler sorbent injection - duct sorbent injection (DSI) - spray dry absorber (SDA) - circulating fluidised bed (CFB) dry scrubber - wet scrubbing - flue gas condenser - wet flue-gas desulphurisation (FGD)	Almost 100 %. Some limitations may exist for FGD if: - the plant operates less than 500 hours per year, - it is for retrofitting on existing combustion plant operating less than 1,500 hours per year, there may be technical and economic restrictions	**Solid biomass and peat:** *Combustion plant with a thermal input capacity between 50 and 100 MW as daily average) [2][3]*: New plant: **30-175** mg/m^3 at 6 % O_2 Existing plant: **30-215** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW as daily average) [2][3]*:

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Peat: **300** mg/m^3 at 6 % O_2 **[Update Index 1]** Biomass: **200** mg/m^3 at 6 % O_2 [Update Index 1] *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: Peat: **150** mg/m^3 at 6 % O_2 (200 mg/m^3 at 6 % O_2 if fluidised bed boiler) **[Update Index 1]** Biomass: **150** mg/m^3 at 6 % O_2 **Update Index 1]** Existing plants: Peat: **200** mg/m^3 at 6 % O_2 **[Update Index 1]** Biomass: **200** mg/m^3 at 6 % O_2 **[Update Index 1]**				New plant: **20-85** mg/m^3 at 6 % O_2 Existing plant: **20-175** mg/m^3 at 6 % O_2 (the upper value of the range is 215 mg/m^3 if average sulphur content of fuel is 0.1 wt% or higher) *Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]*: New plant: **20-70** mg/m^3 at 6 % O_2 Existing plant: **20-85** mg/m^3 at 6 % O_2 (the upper value of the range is 165 mg/m^3 if average sulphur content of fuel is 0.1 wt% or higher, or 215 mg/m^3 if, in addition, the plant is put into operation no later than 7 January 2014 or is FBC boiler burning peat)
	Liquid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW – New and existing plants:* **350** mg/m^3 at 3 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity between 100 and 300 MW:* New plant: **200** mg/m^3 at 3 % O_2 **[Update Index 2]** Existing plant: **250** mg/m^3 at 3 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - duct sorbent injection (DSI) - spray dry absorber (SDA) - flue-gas condenser - wet flue-gas desulphurisation (FGD) - seawater FGD	Almost 100 %, except FGD for plants operating less than 500 hours per year. Some limitations may exist for FGD if: - it is for retrofitting on existing combustion plant operating less than 1,500 hours per year, - the combustion plant is less than 300 MW_{th}, there may be technical and economic restrictions.	**Liquid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW – New and existing plants (as daily average) [2][3]*: **150-200** mg/m^3 at 3 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW* *New and existing plants (as daily average) [2][3]*: **150-200** mg/m^3 at 3 % O_2

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Combustion plant with a thermal input capacity exceeding 300 MW: New plant: **150** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: **200** mg/m^3 at 3 % O_2 **[Update Index 1]**				*Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]*: New plant: **50-120** mg/m^3 at 3 % O_2 Existing plants: **150-165** mg/m^3 at 3 % O_2 (the upper value of the range is 175 mg/m^3 if the plant is put into operation no later than 7 January 2014) *Combustion plant in refineries Existing and new plants* (*as monthly average) [37]:* Multi-fuel fired combustion units in refineries: **35-600** mg/m^3 at 3 % O_2
	Gaseous fuels: *Combustion plant with a thermal input capacity exceeding 50 MW – New and existing plants:* Gaseous fuels in general: **35** mg/m^3 at 3 % O_2 **[Update Index 3]** Liquefied gas: **5** mg/m^3 at 3 % O_2 **[Update Index 3]** Iron and steel process gas Coke oven gas: **400** mg/m^3 at 3 % O_2 **[Update Index 1]** Blast furnace gas: **200** mg/m^3 at 3 % O_2 **[Update Index 2]**	For iron and steel process gases only: Upgraded current abatement techniques are available	For iron and steel process gases only *[1][3]*: The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - process gas management system and auxiliary fuel choice (use low sulphur content auxiliary fuels), - desulphurisation by absorption systems, - wet oxidative desulphurisation	For iron and steel process gases only: Desulphurisation by absorption and wet oxidative desulphurisation are only applicable to cove-oven gas combustion plants.	**Gaseous fuels:** *Combustion plant with a thermal input capacity exceeding 50 MW New and existing plants:* Iron and steel process gas *[2][3]*: *(as daily average)*: new and existing installations **50-200** mg/m^3 at 3 % O_2 (the upper value of the range is **300** mg/m^3 at 3 % O_2 if a high share of coke oven gas is present in the fuel mix used)

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Gasified refinery residues new plant: **35** mg/m^3 at 3 % O_2 [**Update Index 2**] existing plant: **800** mg/m^3 at 3 % O_2 **[Update Index 1]**				Combustion units in refineries: Refinery fuel gas *[37](*as monthly average): New and existing units: **5-35** mg/m^3 at 3 % O_2 Multi fired combustion units (except gas turbines and stationary engines) New or existing plants: **35-600** mg/m^3 at 3 % O_2
	Chemical industry process fuels: **[Update Index 1]** for boilers in the chemical industry; no distinction				**Chemical industry process fuels** New and existing plants operating more than 500 hours per year *[2][3]*: *(as daily average):* **90-200** mg/m^3 at 3 % O_2

3.1.1. Coal, lignite and other solid fuels:

For combustion plants burning coal-type solid fuels, the emission limit values for SO_2 from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 5: Emission limit values of SO_2 for coal-type solid fuels from the AGP, expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [1]

	ELV of SO_2 for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	400	400
100-300 MW	200	250
Higher than 300 MW	150 (200 if FBC*)	200

*: fluidised bed combustion boilers

In the European Best Available Techniques (BAT) Conclusions for large combustion plants (LCP, which are defined as combustion plants in the AGP) [3], the BAT associated environmental levels (AELs) for LCP burning coal or lignite, expressed as daily averages at 6% O_2, are as in the following:

Table 6: BAT AELs of SO_2 for coal or lignite from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of SO_2 for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	170-220	170-400
100-300 MW	135-200	135-220^1
Higher than 300 MW	25-110	25-165 if PC*, 50-220 if FBC

^{1}: 250 mg/Nm^3 if put into operation no later than Jan. 2014

*: pulverised combustion boilers

In the US regulation, “Subpart Da – Standards of performance for Electric Utility Steam Generating Units” [32], the emission limit values are given per energy input or output but converting them given the approximative thermal efficiencies of the combustion plants and taking the stoichiometric dry flue-gas volumes given in the BREF document on LCP [2], the SO_2 ELV for LCP > 73 MWth burning solid fuels range from about 133 to 184 mg/Nm^3 at 6% O_2, on a monthly average basis, depending on the date of construction or modification of the plant.

In the Chinese regulation, “Emissions standards of air pollutant for thermal power plants” [33], the ELV of SO_2 for all LCP burning solid fuels are of 100 mg/Nm^3 for new facilities and 200 mg/Nm^3 for existing ones, at 6% O_2. For specific key regions, which are more sensitive to atmospheric pollution and its impact, the emission limit value is set at 50 mg/Nm^3 for both existing and new plants [33]. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

Another Chinese programme has introduced “ultra-low emission (ULE) standards” for coal-fired thermal power plants (TPP) which imposes an ELV for SO_2 at 35 mg/Nm^3 [51], starting from 2015 onwards for new units and 80 % of the total coal-fired capacity must comply with it by 2030.

In the Indian regulation “Emission standards of air pollutant for thermal power plants” [34], the SO_2 ELV applied are of 600 mg/Nm^3 for TPP with a rated thermal input power lower than 500 MWth and 200 mg/Nm^3 if > 500 MW, if installed in the period of 2004-2016, and of 100 mg/Nm^3 for all sizes of TPP installed in 2017 and afterwards, at 6% O_2. However, as for Chinese regulation, no mention is made if the ELV are daily, monthly or annual averages.

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: boiler sorbent injection, duct sorbent injection (DSI), spray dry absorber (SDA), circulating fluidised bed (CFB) dry scrubber, or wet scrubber. The potential applicability of these techniques is of almost 100%. Wet flue-gas desulphurization (FGD) implementation on existing plants (i.e., retrofitting) or on installations < 300 MWth may rise some technical and economic limitations.

It needs to be noted that the dimensioning of the flue-gas treatment unit as well as the residence time of the flue-gas (i.e., the treatment duration), and the reagent consumption can be primordial in order to achieve lower emission levels for one specific reduction technique.

In the literature, one study reports that the mean SO_2 concentration achieved for the whole Chinese coal-fired TPP capacity was of 35.3 mg/Nm^3 in December 2017, following the introduction of the ultra-low emission standard programme [51]. In order to achieve such a low emission level, old and small TPP have been shut down meanwhile new, larger ones were built and equipped with pollution control techniques, and some old existing plants were retrofitted with mitigation techniques. Almost the whole Chinese coal TPP capacity is equipped with SO_2 removal systems which they operate more than 97% of the time: 88% with limestone wet FGD, 5% with dry scrubbers, 2.5% with seawater scrubbers and the rest with ammonia absorption [51]. From 2015 to the end of 2017, 96 GW of coal-fired capacity has been built with an average stack concentration of 27.3 mg/Nm^3. Between 2014 and 2017, thanks to the implementation of this ULE standards, the monthly emission factor of Chinese PP declined by more than 75% as shown in Figure 1 [51].

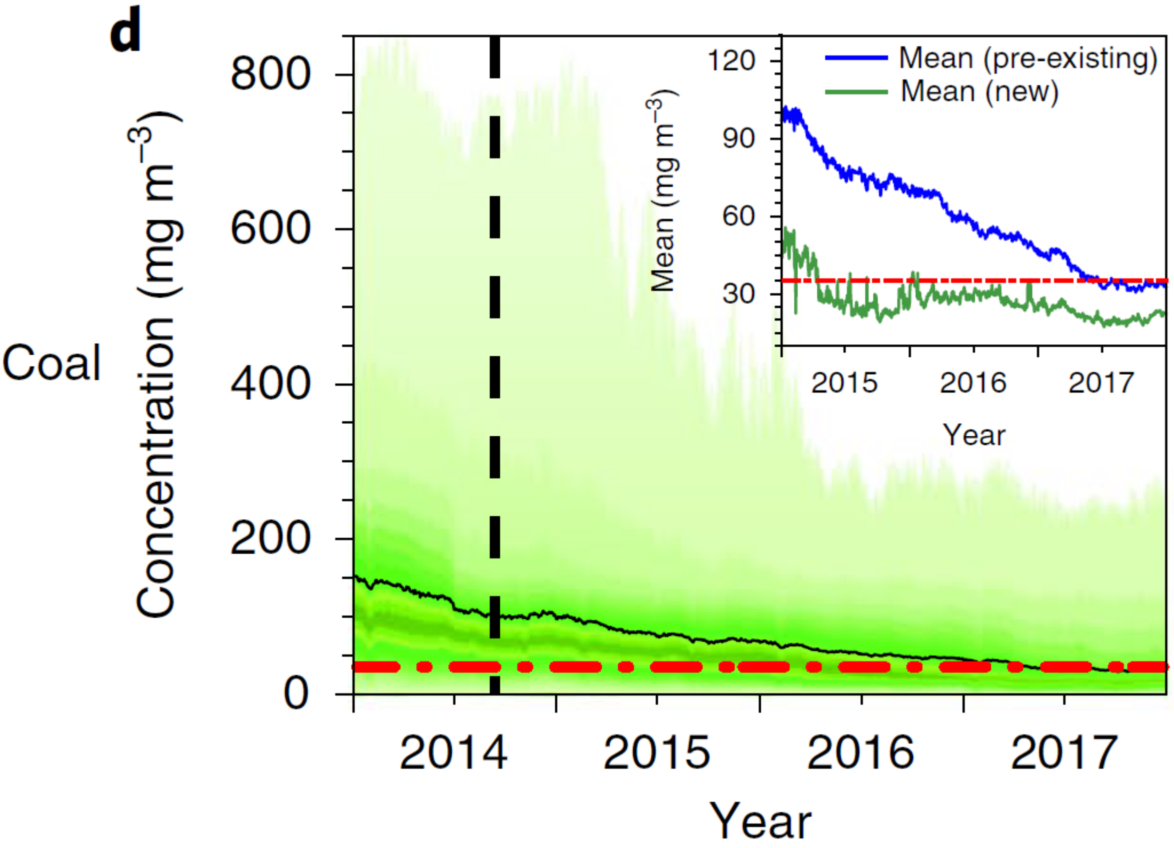


Figure 1: Evolution of the mean SO_2 concentration of the whole Chinese coal power plant capacity between 2014 and 2017 [51]

Among the manufacturers of SO_2 removal techniques, several reference cases reveal that similar or lower emission levels than the BAT AEL are achievable:

- LAB/CNIM dry FGD system with hydrated lime for Solvay Tavaux (France) which has a 134 MWth coal boiler: SO_2 concentration from 500-2,000 to 150 mg/Nm^3 [52];
- LAB/CNIM wet FGD technology with lime slurry preparation for Albioma Le Gol (La Réunion, France) which has a 122 MWth plant burning bagasse and coal: SO_2 concentration from 600-2,000 to 200 mg/Nm^3 [52];

- SOLVAir DSI technology with sodium bicarbonate [53]: for Solvay soda ash plant (Spain) industrial coal boiler, decreased SO_2 concentration from 800 to 190 mg/Nm^3; for coal steam boiler of 50 MWth in France, brought the SO_2 flue-gas concentration from 1,700 to 400 mg/Nm^3.
- SOLVAir dry injection of sodium bicarbonate sorbents technique has also been revealed to have significant removal efficiencies on other installations [54]: a mixed biomass and coal fired plant in France decreased its exhaust concentration from 900 to 200 mg/Nm^3; three coal-fired TPP in Czech Republic achieved SO_2 concentrations of about 320 mg/Nm^3; two US power plants (respectively of 660 and 1,300 MWe) brought down their flue-gas concentrations to 130 and 140 mg/Nm^3, respectively.

According to SOLVAir, their DSI technology with its sorbents can be designed to meet SO_2 flue-gas concentrations as low as 15 mg/Nm^3 with an electrostatic precipitator (ESP) and 3 mg/Nm^3 with a baghouse filter [53][54], at dry conditions and 6% O_2. In addition, their technology is said to have the advantage of being less energy-consuming and the initial investment is five times cheaper compared to wet scrubber, although the sorbent consumption is about 20% higher than for wet scrubber [55].

These examples from the literature survey show that achieving the BAT AEL is possible using the right reduction techniques. The correct dimensioning is essential.

Moreover, in the framework of the development of the LCP BREF [2], a benchmark on EU plants was realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of current ELVs, expressed as daily averages at 6% O_2, are as in the following:

Table 7: Proposal of potential updates in ELVs for SO_2 emissions from combustion of coal-type solid fuels, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential SO_2 ELV – daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	170-220	170-400	159-209	159-378	1	2
100-300 MW	135-200	135-220[1]	105-173	113-209	2	2
> 300 MW	25-110	25-165 if PC*, 50-220 if FBC	17-91	17-146 (PC) 34-198 (FBC)	1	1

[1]: 250 mg/Nm^3 if put into operation no later than Jan. 2014

*: pulverised combustion boilers

The equivalent monthly averages are estimated based on a report [35] which investigate the correspondences between daily, monthly and yearly averages, in particular in the framework of compliance with both IED ELV and LCP BAT AEL. In this report, monthly averages can be estimated according to the following equation:

$$monthly\ BAT\ AEL = 0.45 * daily\ BAT\ AEL + 0.55 * yearly\ BAT\ AEL$$

The equivalent monthly averages given in Table 7 and the following tables are all estimated based on this formula.

3.1.2. Solid biomass and peat

For combustion plants burning solid biomass or peat, the emission limit values for SO_2 from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 8: Emission limit values of SO_2 for solid biomass or peat from the AGP, expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity

	ELV of SO_2 (in mg/Nm^3 at 6% O_2)			
	Solid biomass		Peat	
Thermal input capacity	New plant	Existing plant	New plant	Existing plant
50-100 MW	200	200	300	300
100-300 MW	200	200	300	300
Higher than 300 MW	150	200	150 (200 if FBC*)	200

*: fluidised bed combustion boilers

In the European BAT conclusions for LCP [3], the BAT AEL for LCP burning solid biomass or peat, expressed as daily averages at 6% O_2, are as in the following:

Table 9: BAT AEL of SO_2 for solid biomass or peat from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of SO_2 for biomass or peat (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	30-175	30-215
100-300 MW	20-85	20-175[1]
Higher than 300 MW	20-70	20-85[2]

[1]: 20-215 if average sulphur content higher than 0.1 wt%
[2]: 20-165 if average sulphur content higher than 0.1 wt% and 20-215 if, in addition, put into operation before January 2014 or FBC burning peat

The sulphur content of wood is known to be very low, making SO_2 emissions from its combustion not a great matter of importance. For instance, in France, the sulphur content of natural wood is assumed to be lower than 0.01 % per weight (wt%). However, some solid biomass wastes may have a higher sulphur content, leading to not negligible emission levels.

In foreign regulations, SO_2 emissions from solid biomass are not seemed to be a specific matter of concern and no mention is made about it. Therefore, it can be supposed that solid biomass is included in the solid fuel category and the ELV given in the chapter 3.1.1 can be considered.

These environmental levels can be respected through the application of the same reducing techniques as for coal-type solid fuels [2][3], and their potential applicability is of almost 100% as well.

As for coal fuels, the dimension of the reduction unit, the residence time of the flue-gas in this reduction unit and the reagent consumption can be essential to achieve lower emission levels.

Among the manufacturers of SO_2 removal techniques, several study cases showed that similar or lower emission levels than the BAT AEL are achievable for plants burning biomass:

- LAB/CNIM wet FGD technology with lime slurry preparation for Albioma Le Gol (La Réunion, France) which has a 122 MWth plant burning bagasse and coal: SO_2 concentration from 600-2,000 to 200 mg/Nm^3 [52];
- SOLVAir DSI technology [54] brought down the exhaust concentration of a mixed biomass and coal fired plant in France from 900 to 200 mg/Nm^3.

In addition, in the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the Proposal of potential updates of current ELV, expressed as daily averages at 6% O_2, are as in the following:

Table 10: Proposal of potential updates in ELV for SO_2 emissions from combustion of solid biomass and peat, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential SO_2 ELV - daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	30-175	30-215	22-117	22-152	1	1
100-300 MW	20-85	20-175[1]	15-66	15-117	1	1
> 300 MW	20-70	20-85[2]	15-51	15-66	1	1

[1]: 20-215 if average sulphur content higher than 0.1 wt%
[2]: 20-165 if average sulphur content higher than 0.1 wt% and 20-215 if, in addition, put into operation before January 2014 or FBC burning peat

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

3.1.3. Liquid fuels

For combustion plants burning liquid fuels, the ELV for SO_2 from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 3% O_2 and as monthly averages, are as in the following:

Table 11: Emission limit values of SO_2 for liquid fuels, from the AGP, expressed as monthly averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity

	ELV of SO_2 (in mg/Nm^3 at 3% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	350	350
100-300 MW	200	250
Higher than 300 MW	150	200

In the European BAT conclusions for LCP [3], the BAT AEL for LCP burning liquid fuels, expressed as daily averages at 3% O_2, are as in the following:

Table 12: BAT AEL of SO_2 for liquid fuels from the LCP BAT Conclusions, expressed as daily averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of SO_2 for liquid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	150-200	150-200
100-300 MW	150-200	150-200
Higher than 300 MW	50-120	150-165[1]

[1]: 150-175 mg/Nm^3 if put into operation no later than Jan. 2014

In the US regulation [32], the emission limit values are given per energy input or output but converting them given the approximative yields of the combustion plants and taking the stoichiometric dry flue-gas volumes given in the BREF document on LCP [1], the SO_2 ELV for LCP > 73 MWth burning liquid fuels range from about 164 to 226 mg/Nm^3 at 3% O_2, on a monthly average basis, depending on the date of construction or modification of the plant.

In the Chinese regulation [33], the ELV of SO_2 for all LCP burning liquid fuels are of 100 mg/Nm^3 for new facilities and 200 mg/Nm^3 for existing ones, at 3% O_2. For specific key regions which are more sensitive to atmospheric pollution and its impact, the ELV is set at 50 mg/Nm^3 for new and existing plants. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

In the Indian regulation [34], the SO_2 ELV applied are of 720 mg/Nm^3 for TPP with a rated thermal input power lower than 500 MWth and 240 mg/Nm^3 if > 500 MW, if installed in the period of 2004-2016, and of 120 mg/Nm^3 for all sizes of TPP installed in 2017 and afterwards, at 3% O_2. However, as for Chinese regulation, no mention is made if the ELV are daily, monthly or annual averages.

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: duct sorbent injection (DSI), spray dry absorber (SDA) or wet scrubber or FGD. The potential applicability of these techniques is of almost 100%. As for solid fuels, wet FGD implementation on existing plants (i.e., retrofitting) or installations < 300 MWth may rise some technical and economic limitations.

It needs to be noted that the dimensioning of the flue-gas treatment unit, the residence time of the flue-gas (i.e., the treatment duration) in the unit and the reagent consumption, can be primordial in order to achieve lower emission levels for one specific reduction technique.

From the literature survey carried out, a few reference cases have been found for SO_2 flue-gas concentrations of plants burning liquid fuels. However, the achieved concentrations in these ones show that BAT AEL can be met through the application of SO_2 reduction techniques mentioned above:

- SOLVAir DSI technology applied to a fuel-fired district heating French boiler of 180 MWth enabled to reduce the exhaust gas concentration from 1,100 to 165 mg/Nm^3 [54].

According to SOLVAir, their DSI technology with its sorbents can be designed to meet SO_2 flue-gas concentrations as low as 15 mg/Nm^3 with an electrostatic precipitator (ESP) and 3 mg/Nm^3 with a baghouse filter [54], at dry conditions and 6% O_2, which is equivalent to about 18 and 4 mg/Nm^3 at 3% O_2.

In addition, in the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the Proposal of potential updates of current ELV, expressed as daily averages at 3% O_2, are as in the following:

Table 13: Proposal of potential updates in ELVs for SO_2 emissions from combustion of liquid fuels,
expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and the update indexes

	Potential SO_2 ELV - daily (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	150-200	150-200	95-186	95-186	1	1
100-300 MW	150-200	150-200	95-186	95-186	2	1
> 300 MW	50-120	150-165[1]	42-82	95-135	1	1

[1]: 150-175 mg/Nm^3 if put into operation no later than Jan. 2014

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

3.1.4. Gaseous fuels:

For combustion plants with a rated thermal power higher than 50 MW burning gaseous fuels, the ELV for SO_2 from the AGP [1] are as in the following:

Table 14: Emission limit values of SO_2 for gaseous fuels in the AGP, expressed as monthly averages at 3% O_2 in mg/Nm^3 [1]

	SO_2 emission limit values in AGP (in mg/Nm^3 at 3% O_2)	
Fuel type	New plant	Existing plant
Natural gas	35	35
Liquefied gas	5	5
Coke oven gas	400	400
Blast furnace gas	200	200
Gasified refinery residues	35	800

In the European BAT conclusions for LCP [3], no BAT AEL is given for SO_2 for natural or liquefied gas. For iron and steel process gases (coke oven gas or blast furnace gas) being burned in LCP > 50 MW, the BAT AEL are of 50-200 mg/Nm^3 for new and existing plants, and of 50-300 mg/Nm^3 if a high share of coke oven gas is present in the fuel mix, as daily averages at 3% O_2 [3].

For the process gases from the chemical industry, the BAT AEL for SO_2 are of 90-200 mg/Nm^3 for new and existing facilities [3].

Finally, in the BAT conclusions for Oil Refining [31], the SO_2 BAT AEL for the combustion of refinery gas is of 5-35 mg/Nm^3 as monthly average, at 3% O_2.

In the Chinese regulation [33], the ELV of SO_2 for TPP is of 35 mg/Nm^3 for new and existing facilities burning natural gas and of 100 mg/Nm^3 for new and existing installations burning other gas, at 3% O_2. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

The emission levels for iron and steel process gases can be respected through the application of one or a combination of using low sulphur content auxiliary fuels and flue-gas desulphurisation [2][3].

In the literature, it is hard to find reference cases for SO_2 emission levels for natural gas as its sulphur content is low so SO_2 emissions are not a great matter of concern.

In the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

In short, the SO_2 ELV for natural and liquefied gases in the current version of the AGP do not seem to require updates (i.e., the updates indexes are **3** for these fuels).

For the other gaseous fuels, based on the BAT Conclusions [3], the potential update of current ELV, expressed as daily averages at 3% O_2, are as in the following:

Table 15: Proposal of potential updates in ELVs for SO_2 emssions from combustion of gaseous fuels,

expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential SO_2 ELV (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
Natural gas	35*		Already as monthly average		3	3
Liquefied gas	5*				3	3
Coke oven gas	50-300		36-218		1	1
Blast furnace gas	50-200		36-173		2	2
Gasified refinery residues	5-35*		Already as monthly average		2	1
Chemical process gas	90-200		46-151		1	1

*: these ELV are expressed as monthly averages

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

3.2.Limit values for the sulphur content of gas oil

Table 16: Table 2, Annex IV, Proposal of potential updates in ELVs for the Sulphur content of gas oil

Page	Reference	Potential update	Description	Potential Applicability (%)	Potential ELVs
38	**Annex IV Table 2:** Limit values for the sulphur content of gas oil Sulphur content (per cent by weight) Gas oil **< 0.10%**	**Update Index 1:** Light heating oils with low sulphur content are available (0,005 wt %) [56] however 0.1 wt% is standard sulphur limit for light heating oil	Sulphur reduction in the oil refining process through refinery fuel oil (RFO) desulphurisation by hydro-treatment in addition to selection of low-sulphur crude	Almost 100 %.	**0.005 %** [56]

Sulphur content limits for gas oil in Annex IV of the Gothenburg Protocol are listed in the table 2 of annex IV [1].

"Gas oil" in this context means any petroleum-derived liquid fuel, excluding marine fuel and fuels used for self-propelling vehicles (e.g. EN 590). This refers particularly to CN commodity codes 2710 19 25 (Kerosene excl. jet fuel), 2710 19 29 (medium oils and preparations), 2710 19 45-49 (gas oils of petroleum or bituminous minerals).

Refinery fuel oil (RFO) desulphurisation by hydro-treatment can reduce sulphur content to 0.005 % by weight [56]. This sulphur content level is standard for e.g. light heating oil in many EU member states or the US, while conventional sulphur content of light heating oil is 0.1 % as listed in Annex IV. Heavy heating oils have sulphur contents of 0.5-1% or potentially even more, however, these oils are not included here, as Table 2 in Annex IV refers to "any petroleum-derived liquid fuel of which at least 85% by volume (including losses) distils at 350°C".

3.3. Limit values for SO_x for Sulphur recovery units in oil and gas refineries

Table 17: Table 3, Annex IV, Proposal of potential updates of Sulphur recovery rate in sulphur recovery units for off-gas treatment

Page	Reference	Potential update	Description	Potential Applicability (%)	Potential ELVs
39	**Annex IV Table 3:** Limit value expressed as a minimum sulphur recovery rate of sulphur recovery units New plant: **99.5 %**	**Update Index 3:** According to present BATs, no update necessary	Specific unit that generally consists of a Claus process for sulphur removal of hydrogen sulphide (H_2S)-rich gas streams from amine treating units and sour water strippers. SRU is generally followed by a tail gas treatment unit (TGTU) for remaining H_2S removal [2]	Almost 100 %	**99.5 %** [37] as yearly average
	Existing plant: **98.5 %**	No update necessary		Almost 100 %	**96-99.5 % [37]** as yearly average

As described in the previous chapter, in mineral oil and gas refineries, the sulphur from the fuels is removed. This mainly ends up as H_2S in acid by-product gases from which sulphur is removed and recovered. These sulphur recovery units (SRUs) generally consists of a Claus process for sulphur removal of hydrogen sulphide (H_2S)-rich gas streams from amine treating units and sour water strippers. The multi-step Claus process recovers sulphur from the gaseous hydrogen sulphide found in raw natural gas and from the by-product gases derived from refining crude oil and other industrial processes. Main chemical reactions taking place in the Claus process are as follows:

$$2\ H_2S + 3\ O_2 \rightarrow 2\ SO_2 + 2\ H_2O \text{ (thermal step)}$$

$$4\ H_2S + 2\ SO_2 \rightarrow 3\ S_2 + 4\ H_2O \text{ (catalytic step)}$$

SRU is generally followed by a tail gas treatment unit (TGTU) for remaining H_2S removal. TGTU is family of techniques, additional to the SRU in order to enhance the removal of sulphur compounds. They can be divided into four categories according to the principles applied [37]:

- direct oxidation to sulphur
- continuation of the Claus reaction in multiple reactors (multi stage Claus process)
- oxidation to SO_2 and recovering sulphur from SO_2
- reduction to H_2S and recovery of sulphur from this H_2S (e.g. through an amine process)

Sulphur recovery efficiency is calculated over the whole treatment chain (including SRU and TGTU) as the fraction of sulphur in the feed that is recovered in the sulphur stream routed to the collection pits. When the applied technique does not include a recovery of sulphur (e.g. seawater scrubber), it refers to the sulphur removal efficiency, as the % of sulphur removed by the whole treatment chain.

As described before, sulphur recovery within a multi stage Claus process is common technology. A simplified flow diagram of a SRU consisting or two Claus reactors and a subsequent oxidative reactor for efficient sulphur recovery is shown in Figure 2.

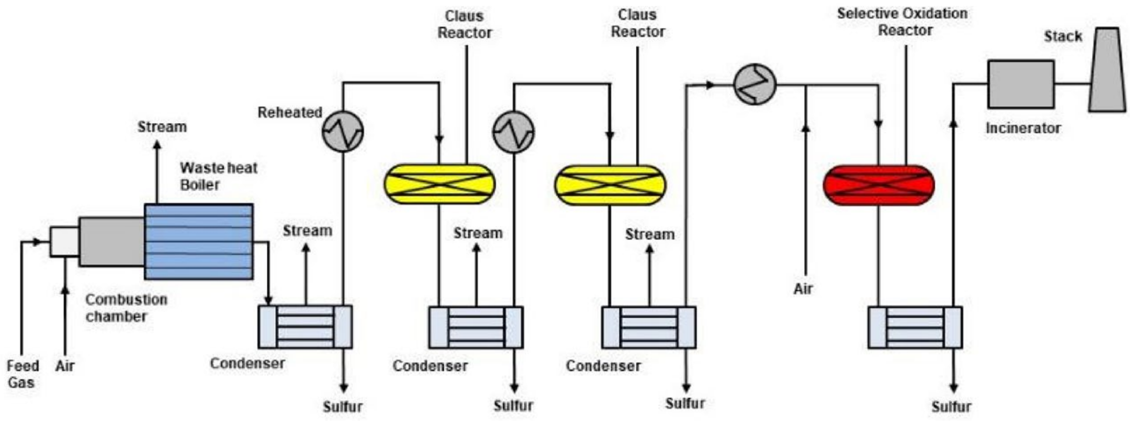


Figure 2: Shematic flow sheet of a sulphur recovery unit (SRU) with multiple claus reactors [57]

Hence, the sulphur recovery rate as listed in Table 17 is the percentage of the imported hydrogen sulphide (H_2S) converted to elemental sulphur as a yearly average.

As shown in Table 17, the recovery rates in Annex IV are within the ELVs of the European BREF document [37] and the related BAT conclusions [31]. Therefore, there seems to be no need for adjustment of ELVs.

3.4. Limit values for SO_x emissions released from titanium dioxide production

Table 18: Table 4, annex IV, Proposal of potential updates in ELVs for SOx emissions from TiO_2 production

Page	Reference	Potential update	Description	Potential Applicability (%)	Potential ELVs
Annex IV Table 4: Limit values for SOx emissions released from titanium dioxide production (annual average)					
39	**Sulphate process:** ELV for SO_x (expressed as SO_2) (kg/t of TiO_2): **total emission: 6 kg/t** as yearly average	**Update Index 2:** GP ELV as the upper value of the range of BAT AELs from the EU BREF, update possible	Multi-stage scrubbing [38]: 1. scrubbed with recycled waste water 2. quenched and then scrubbed with caustic soda solution. 3. quenched, passed through an electrostatic precipitator (removing SO_3 aerosols) 4. Removal of SO_2 via oxidation with aqueous H_2O_2 to produce sulphuric acid which is re-used Removing H_2S by absorption in an aqueous suspension of ZnO	Almost 100 %	As yearly average [38]: **1 – 6 kg/t**
	Chloride process: ELV for SOx (expressed as SO_2) (kg/t of TiO_2): **total emission: 1.7 kg/t** as yearly average	**Update Index 2:** GP ELV as the upper value of the range of BAT AEL from the EU BREF, update possible	Specific configurations of a multistage waste gas treatment unit based on liquid scrubbing with caustic soda or water → sulphur is removed for sale	Almost 100 %	As yearly average [38]: **1.3 – 1.7 kg/t**

Titanium dioxide (TiO_2) is an inorganic compound which is mainly used in pigments for paints and varnishes as well as paper and plastics, printing inks, fibers, rubber, cosmetic products. TiO_2 is currently produced using two distinct processing routes:

1. In the chloride process, the ore is treated with chlorine and carbon to give titanium tetrachloride, a volatile liquid that is further purified by distillation. The $TiCl_4$ is treated with oxygen to regenerate chlorine and produce the titanium dioxide.
2. In the sulphate process, ilmenite concentrate (45-60% TiO_2) is treated with sulphuric acid to extract iron (II) sulphate pentahydrate. The resulting synthetic rutile is further processed according to the specifications of the end user, i.e. pigment grade.

New TiO_2 plants are likely to adopt the chloride process route, as it offers better raw material and energy efficiency, along with a more compact plant layout which typically benefits in reduced scope of plant maintenance. Nonetheless, particularly in China also new sulphate route plants were installed in recent years. This seems to be mainly due to the abundance of ilmenite concentrate.

In both processes, SO_2 emissions to air are a key emission factor and respective abatement technologies are necessary. Especially in the sulphate process due to the use of large quantities of sulphuric acid, multi-stage scrubbing systems as listed in Table 18 are necessary.

In the case of the sulphate process, the multi-stage scrubbing system must cope with a wide range of flows. Typical processing steps are as follows [38]:

1. First, off-gases are scrubbed with recycled waste water (this system is only applicable if the feedstock is solely ilmenite). The wash-water outflow has to be treated in an appropriate way.
2. Secondly, off-gases are quenched and then scrubbed with caustic soda solution. The resulting solution contains Na_2SO_4, $NaHSO_3$, Na_2S, and is decomposed with sulphuric acid to produce SO_2 and S going as a feed to the acid plant; the resulting small amounts of Na_2SO_4 solution is discharged. This system is only applicable if there is the possibility to use the SO_2 and S as a feedstock for other processes on the site.
3. Thirdly, off-gases are quenched and then scrubbed with caustic soda solution. Scrubbed caustic soda solution, after oxidation of $NaHSO_3$, is released to the sewerage system, and then it is sent to the waste water treatment plant located at the site.
4. In a fourth step, off-gases are quenched, then passed through an electrostatic precipitator (removing SO_3 aerosols), followed by the removal of SO_2 via oxidation with aqueous H_2O_2 to produce sulphuric acid which is re-used.
5. Finally, H_2S is removed by absorption in an aqueous suspension of ZnO, which is used as a feedstock for the production of Zn containing pigments at the same site. This is a patented waste free system [38].

The European BREF reports an ELV for SO_2 of 1-6 kg/t of TiO_2 production via the sulphate process depending on site specific conditions and the number of stages in the scrubbing system. The ELV in table 4, Annex IV is 6 kg/t, hence meets the upper value of the range in the EU BREF document [38].

In the case of the chloride process, there are two different abatement techniques based on scrubbing trains. This first technique uses caustic soda as the liquid scrubbing medium and produced hypochlorite as a co-product. The second approach is simply based on water scrubbing and produces hydrochloric acid for re-use or for sale. The choice of which is preferred, depends on the local market for co-products. The EU BREF [38] reports ELVs for SO_2 emissions to air of 1.3-1.7 kg/t of TiO_2 while Annex IV also in the case lists the upper value of the range (1.7 kg/t, cf. Table 18).

4. Annex V: limit values for emissions of NOx from stationary sources

4.1. Limit values for NO_x emissions released from combustion plants

Table 19: Table 1, annex V, Proposal of potential updates in ELVs for emissions of nitrogen oxides from combustion plants

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
42-43	**Annex V Table 1:** Limit values for NO_x emissions released from combustion plants				
	Coal, lignite and other solid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW – New and existing plants:* Coal, lignite and other solid fuels: **300** mg/m^3 at 6 % O_2 **[Update Index 1 for new plants,** **Update Index 2 for existing plants]** Pulverised lignite: **450** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity between 100 and 300 MW – New and existing plants:* **200** mg/m^3 at 6 % O_2 **[Update Index 1 for new plants,** **Update Index 2 for existing plants]** *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: Coal, lignite and other solid fuels: **150** mg/m^3 at 6 % O_2 **[Update Index 1]** Pulverised lignite: **200** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **200** mg/m^3 at 6 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - combustion optimisation - combination of primary techniques for NO_x reduction such as air or fuel staging, flue-gas recirculation, low-NO_x burners (LNB) - selective non-catalytic reduction (SNCR) - selective catalytic reduction (SCR)	Almost 100 %, except for SCR for combustion plant less than 100 MW$_{th}$. Some limitations may exist for SNCR if the plant operates less than 1,500 hours per year with highly variable loads and/or if the cross-sectional area is large enough to prevent homogeneous mixing of NH_3 and NO_x. SCR is not applicable for plants smaller than 300 MW$_{th}$ which operate less than 500 hours per year. Technical and economic barriers can exist for retrofitting on plants operating less than 1,500 hours per year.	**Coal, lignite and other solid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW (as daily average)[2][3]*: New plants: **155-200** mg/m^3 at 6 % O_2 Existing plants: **165-330** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW (as daily average) [2][3]*: New plants: **80-130** mg/m^3 at 6 % O_2 Existing plants: **155-210** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]*: FBC boiler combusting coal and/or lignite and lignite-fired PC boiler: New plants: **80-125** mg/m^3 at 6 % O_2 Existing plants: **140-165** mg/m^3 at 6 % O_2 (upper value of the range is 220 mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014) Coal-fired PC boiler: New plants: **80-125** mg/m^3 at 6 % O_2 Existing plants: **85-165** mg/m^3 at 6 % O_2 (Upper value of the range is 200 mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014)

Pag.	**Reference and update Index**	**Potential update**	**Description**	**Potential Applicability (%)**	**Potential ELVs**
	Solid biomass and peat: *Combustion plant with a thermal input capacity between 50 and 100 MW:* New plants: **250** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **300** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity between 100 and 300 MW – New and existing plants:* New plants: **200** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **250** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: **150** mg/m^3 at 6 % O_2 **[Update Index 2]** Existing plants: **200** mg/m^3 at 6 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - combustion optimisation - low-NO_x burners (LNB) - air staging - fuel staging - flue-gas recirculation - selective non-catalytic reduction (SNCR) - selective catalytic reduction (SCR)	Almost 100 %, except for SCR and SNCR if the plant operates less than 500 hours per year, and for SCR for combustion plant less than 100 MW_{th}. Some limitations may exist for SNCR if the plant operates less than 1,500 hours per year with highly variable loads. There may be technical and economic barriers for retrofitting of SCR on plants smaller than 300 MW_{th}.	**Solid biomass and peat:** *Combustion plant with a thermal input capacity between 50 and 100 MW (as daily average) [2][3]*: New plants: **120-200** mg/m^3 at 6 % O_2 Existing plants: **120-275** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW – New and existing plants (as daily average) [2][3]*: New plants: **100-200** mg/m^3 at 6 % O_2 Existing plants: **100-220** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]*: New plants: **65-150** mg/m^3 at 6 % O_2 Existing plants: **95-165** mg/m^3 at 6 % O_2 (Upper value of the range is 200 mg/m^3 at 6 % O_2 if the plant is put into operation no later than 7 January 2014)

Pag.	**Reference and update Index**	Potential update	Description	Potential Applicability (%)	**Potential ELVs**
	Liquid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW:* New plants: **300** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: **450** mg/m^3 at 3 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - air staging, - fuel staging, - flue-gas recirculation, - low-NO_x burners (LNB), - water/steam	Almost 100 %, except for SCR and SNCR if the plant operates less than 500 hours per year, and for SCR for combustion plant less than 100 MW_{th}. Some limitations may exist for SNCR if the plant operates less than 1,500 hours	**Liquid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW (as daily average) [2][3]*: New plants: **100-215** mg/m^3 at 3 % O_2 Existing plants: **210-330** mg/m^3 at 3 % O_2 (upper value of the range is **450** mg/m^3 at 3 % O_2 if the plant is put into operation no later than 27 November 2003 and operates less than 1,500 hours per year)

Pag.	**Reference and update Index**	Potential update	Description	Potential Applicability (%)	**Potential ELVs**
	Combustion plant with a thermal input capacity between 100 and 300 MW: New plants: **150** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: Liquid fuels in general: **200** mg/m^3 at 3 % O_2 **[Update Index 1]** Plant within refineries and chemical installations: Distillation and conversion residues from crude oil refining: **450** mg/m^3 at 3 % O_2 **[Update Index 1]**		addition, - selective non-catalytic reduction (SNCR), - selective catalytic reduction (SCR), - advanced control system.	per year with highly variable loads. There may be technical and economic barriers for retrofitting SCR on plants operating less than 1,500 hours per year.	*Combustion plant with a thermal input capacity between 100 and 300 MW (as daily average) [2][3]*: New plants: **85-100** mg/m^3 at 3 % O_2 Existing plants: Liquid fuels in general: **85-145** mg/m^3 at 3 % O_2 Mixture of fuels in refineries Existing units *[37]:* **30-300** mg/m^3 at 3 % O_2 as monthly average
	Combustion plant with a thermal input capacity exceeding 300 MW: New plants: **100** mg/m^3 at 3 % O_2 **[Update Index 2]** Existing plants: Liquid fuels in general: **150** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: Distillation and conversion residues from crude oil refining within refineries and chemical installations: **450** mg/m^3 at 3 % O_2 **[Update Index 1]**				*Combustion plant with a thermal input capacity exceeding 300 MW (as daily average) [2][3]*: New plants: **85-100** mg/m^3 at 3 % O_2 Existing plants: Liquid fuels (HFO and gas-oil): **85-110** mg/m^3 at 3 % O_2 (upper value of the range is 145 mg/m^3 at 3 % O_2 if the plant is put into operation no later than 7 January 2014) Existing units *[37]:* Mixture of fuels in refineries **30-300** mg/m^3 at 3 % O_2 as monthly average
	For process fuels in boilers in the chemical industry: No specific ELVs **[Update Index 1]**	Upgraded current abatement techniques are available			*Combustion plant with a thermal input capacity exceeding 50 MW, which operates more than 500 hours per year:* Chemical industry process fuels, mixture of gases and liquids New plants *[2][3]*: **50-110** mg/m^3 at 3 % O_2 as daily average Chemical industry process fuels, mixture of gases and liquids – Existing plants *[2][3]*: **100-330** mg/m^3 at 3 % O_2 as daily average

Pag.	**Reference and update Index**	Potential update	Description	Potential Applicability (%)	**Potential ELVs**
	Gaseous fuels: *Combustion plant with a thermal input capacity exceeding 50 MW:* Natural gas – New and existing plants: **100** mg/m^3 at 3 % O_2 **[Update Index 1 for new, Update Index 2 for existing]** Other gaseous fuels New plants: **200** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: **300** mg/m^3 at 3 % O_2 **[Update Index 1]** Process gas in the iron and steel industry No specific ELVs **[Update Index 1]** Process gas in the chemical industry No specific ELVs **[Update Index 1]** Refineries, gas firing No specific ELVs **[Update Index 1]**	Upgraded current abatement techniques are available Iron and steel process gas, only Chemical industry process gases only	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - combustion optimisation, - air or fuel staging, - flue-gas recirculation, - low-NO_x burners (LNB), - advanced control system, - reduction of combustion temperature, - selective non-catalytic reduction (SNCR), - selective catalytic reduction (SCR).	Almost 100 %, except for SNCR and SCR for plants operating less than 500 hours per year, and for SCR for combustion plant smaller than 100 MW$_{th}$. Advanced control system application may be limited for retrofitting on old combustion plants. Some limitations may exist for SNCR if the plant operates less than 1,500 hours per year with highly variable loads. Technical and economic barriers can exist for retrofitting of SCR on plants operating less than 1,500 hours per year.	**Gaseous fuels:** *Combustion plant with a thermal input capacity exceeding 50 MW (as daily average) [2][3]*: Natural gas – new plants: **30-85** mg/m^3 at 3 % O_2 Natural gas – existing plants: **85-110** mg/m^3 at 3 % O_2 *Other gases:* Iron and steel process gas New plants: **22-100** mg/m^3 at 3 % O_2 Iron and steel process gas –Existing plants: **22-110** mg/m^3 at 3 % O_2 (not applicable when plant operates less than 1,500 hours per year. Upper value of the range is 160 mg/m^3 at 3 % O_2 if plant is put into operation no later than 7 January 2014) Chemical industry process gas only New plants: **30-100** mg/m^3 at 3 % O_2 Chemical industry process gas Existing plants: **85-110** mg/m^3 at 3 % O_2 (higher value of the range is 210 mg/m^3 at 3 % O_2 if plant is put into operation no later than 7 January 2014) Refineries, gas firing – new plants (as monthly average) *[37]:* **30-100** mg/m^3 at 3 % O_2 Refineries, gas firing – existing plants (as monthly average)*[2]*: **30-150** mg/m^3 at 3 % O_2 (upper value of the range is 200 mg/m^3 at 3 % O_2 if high air pre-heat is used or if H_2 fuel content is higher than 50%)

Table 20: Table 2, Annex V, proposal for update of limit values for emissions of nitrogen oxides from gas turbines

Pag.	**Reference and update Index**	Potential update	Description	Potential Applicability (%)	**Potential ELVs**
44	**Table 2:** Limit values for NO$_x$ emissions released from onshore combustion turbines (including Combined Cycle Gas Turbine CCGT) Combustion plant with a thermal input capacity exceeding 50 MW Liquid fuels (light and medium distillates): New plants: **50** mg/m^3 at 15 % O$_2$ **[Update Index 3]** Existing plants: **90** mg/m^3 at 15 % O$_2$ (200 mg/m^3 at 15 % O$_2$ if operating less than 1,500 hours a year) **[Update Index 3]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - low-NO$_x$ burners (LNB), - water/steam addition, - selective catalytic reduction (SCR).	LNB are applicable only for turbine models for which they are available on the market. SCR is not applicable if the plant operates less than 500 hours per year. There may be technical and economic barriers for retrofitting SCR on plants operating less than 1,500 hours per year. Moreover, retrofitting may be constrained by space availability.	
44	**Table 2:** Limit values for NO$_x$ emissions released from onshore combustion turbines (including Combined Cycle Gas Turbine CCGT) Combustion turbines with a thermal input capacity exceeding 50 MW – New: Natural gas: **50** mg/m^3 at 15 % O$_2$ **[Update Index 1]** Other gases: **50** mg/m^3 at 15 % O$_2$ **[Update Index 2]** Combustion turbines with a thermal input capacity exceeding 50 MW – Existing: Natural gas: **50** mg/m^3 at 15 % O$_2$ (150 mg/m^3 at 15 % O$_2$ if operating less than 1,500 hours a year) **[Update Index 2]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques *[2][3]*: - advanced control system, - water/steam addition, - dry low-NO$_x$ burners (DLN) - low-load design concept, - low-NO$_x$ burners (LNB), - selective catalytic reduction (SCR).	Advanced control system application is limited for old combustion plants. DLN application is limited in the presence of water/steam addition systems. LNB are generally applicable to supplementary firing for heat recovery steam generators (HRSGs) in the case of combined-cycle gas turbine (CCGT) combustion plants. SCR is not applicable if the plant	Open-cycle gas turbines within a plant with a thermal input capacity exceeding 50 MW *[2][3]* *(as daily average)*: Natural gas – new turbine: **25-50** mg/m^3 at 15 % O$_2$ Natural gas – existing turbine operating more than 500 hr/year: **25-55** mg/m^3 at 15 % O$_2$ (upper value of the range is 80 mg/m^3 at 15 % O$_2$ if the plant is put into operation no later than 27 November 2003 and operates between 500 and 1,500 hours per year) Combined-cycle gas turbines within a plant with a thermal input capacity between 50 and 600 MW *[2][3](as daily average)*: Natural gas – new turbine: **15-40** mg/m^3 at 15 % O$_2$ Natural gas – existing turbine with a net total fuel utilisation < 75%: **35-55** mg/m^3 at 15 % O$_2$

Pag.	Reference and update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Other gases: **120** mg/m^3 at 15 % O_2 (200 mg/m^3 at 15 % O_2 if operating less than 1,500 hours a year) **[Update Index 1 for existing turbines for iron and steel gases]** **[Update Index 2 for existing turbines for refinery gas]**			operates less than 500 hours per year or for plants smaller than 100 MW$_{th}$. There may be technical and economic barriers for retrofitting SCR on plants operating less than 1,500 hours per year. Finally, SCR retrofits may be constrained by space availability.	Natural gas – existing turbine with a net total fuel utilisation > 75%: **35-55** mg/m^3 at 15 % O_2 (upper value of the range is 80 mg/m^3 at 15 % O_2 if plant is put into operation no later than 7 January 2014) Combined-cycle gas turbines within a plant with a thermal input capacity exceeding 600 MW *[2][3]* *(as daily average)*: Natural gas – new turbine: **15-40** mg/m^3 at 15 % O_2 Natural gas – existing turbine with a net total fuel utilisation < 75%: **18-50** mg/m^3 at 15 % O_2 Natural gas – existing turbine with a net total fuel utilisation > 75%: **18-55** mg/m^3 at 15 % O_2 (higher range is 65 mg/m^3 at 15 % O_2 if plant is put into operation no later than 7 January 2014) Combined-cycle gas turbines with a thermal input capacity exceeding 50 MW: Iron and steel process gas – new turbine (as daily average) *[1][3]*: **30-50** mg/m^3 at 15 % O_2 Iron and steel process gas – existing turbine operating more than 500 hours per year (as daily average) *[2][3]*: **30-55** mg/m^3 at 15 % O_2 (upper value of the range is 70 mg/m^3 at 15 % O_2 if plant is put into operation no later than 7 January 2014) Gas firing in refinery gas turbines – new plant (as monthly average) *[37]:* **20-50** mg/m^3 at 15 % O_2 (upper value of the range is 75 mg/m^3 at 15 % O_2 if H_2 fuel content is higher than 10%) Gas firing in refinery gas turbines – existing plant (as monthly average) *[37]:* **40-120** mg/m^3 at 15 % O_2

4.1.1. Coal, lignite and other solid fuels:

For combustion plants burning coal-type solid fuels, the emission limit values for NO_x from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 21: Emission limit values of NO_x for coal-type solid fuels from the AGP, expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity[1]

	ELV of NO_x for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	300[1]	300[1]
100-300 MW	200	200
Higher than 300 MW	150[2]	200

[1]: 450 mg/Nm^3 if the fuel is pulverised lignite
[2]: 200 mg/Nm^3 if the fuel is pulverised lignite

In the BAT conclusions for LCP [3], the BAT AEL of NO_x for LCP burning coal or lignite, expressed as daily averages at 6% O_2, are as in the following:

Table 22: BAT AEL of NO_x for coal or lignite from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of NO_x for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	155-200	165-330
100-300 MW	80-130	155-210
Higher than 300 MW	80-125	85-165[1] if PC*, 140-165[2] if FBC*

[1]: 85-200 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 140-220 mg/Nm^3 if put into operation no later than Jan. 2014

*: PC “pulverised combustion” and FBC “fluidised bed combustion”

In the US regulation [32], the ELV are given per energy input or output but converting them given the approximative thermal efficiencies of the combustion plants and taking the stoichiometric dry flue-gas volumes given in the BREF document on LCP[2], the NO_x ELV for LCP > 73 MWth burning solid fuels range from about 90 to 143 mg/Nm^3 at 6% O_2, on a monthly average basis, depending on the date of construction or modification of the plant.

In the Chinese regulation [33], the ELV of NO_x for all TPP burning solid fuels are of 100 mg/Nm^3 for new and existing facilities, at 6% O_2. The imposed ELV is not stricter for specific key regions [33]. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

The ultra-low emission Chinese programme has introduced ELV for NO_x at 50 mg/Nm^3 for coal-fired TPP [51], from 2015 for new installations and 80 % of the total coal-fired capacity must comply with it by 2030.

In the Indian regulation [34], the NO_x ELV applied are of 450 mg/Nm^3 for coal TPP installed in the period of 2004-2016, and of 100 mg/Nm^3 for all sizes of TPP installed in 2017 or later, at 6% O_2. However, as for the Chinese regulation, no mention is made if the ELV are daily, monthly or annual averages.

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: combustion optimisation, air or fuel staging, flue-gas recirculation, low-NO_x burners, SNCR or SCR. The potential applicability of these techniques is of almost 100%, except for SCR which is not applicable for plants < 100 MWth [3] and for SNCR and SCR for installations operating less than 500 hours annually. Some technical and economic limitations can exist for SNCR and SCR for plants operating less than 1,500 hours per year.

Larger efficiencies are obtained through combination of primary measures and secondary measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR). With SCR, the size and type of catalysts, the residence time of flue gases, the reagent consumption are among parameters enabling larger NOx removal efficiencies.

In the literature, one study reports that the mean NO_x concentration achieved for the whole Chinese coal-fired TPP capacity was of 52.0 mg/Nm^3 in December 2017 (see Figure 3), following the introduction of the ultra-low emission standard programme [51]. The shutdown of old and small TPP to build new and larger ones helped reducing the overall concentration but also the installation of state-of-the-art pollution control technologies such as SCR. By the end of 2017, more than 98% of the total capacity were equipped with NO_x removal techniques (with 89% being SCR running about 94% of the time) whereas only 13% of the coal-fired TPP capacity was equipped in 2011 [51]. From 2015 to the end of 2017, 96 GW of coal-fired capacity has been built with an average stack concentration of 47.7 mg/Nm^3. Thanks to the ULE programme, the monthly emission factor of Chinese PP declined by more than 76% between 2014 and 2017 [51].

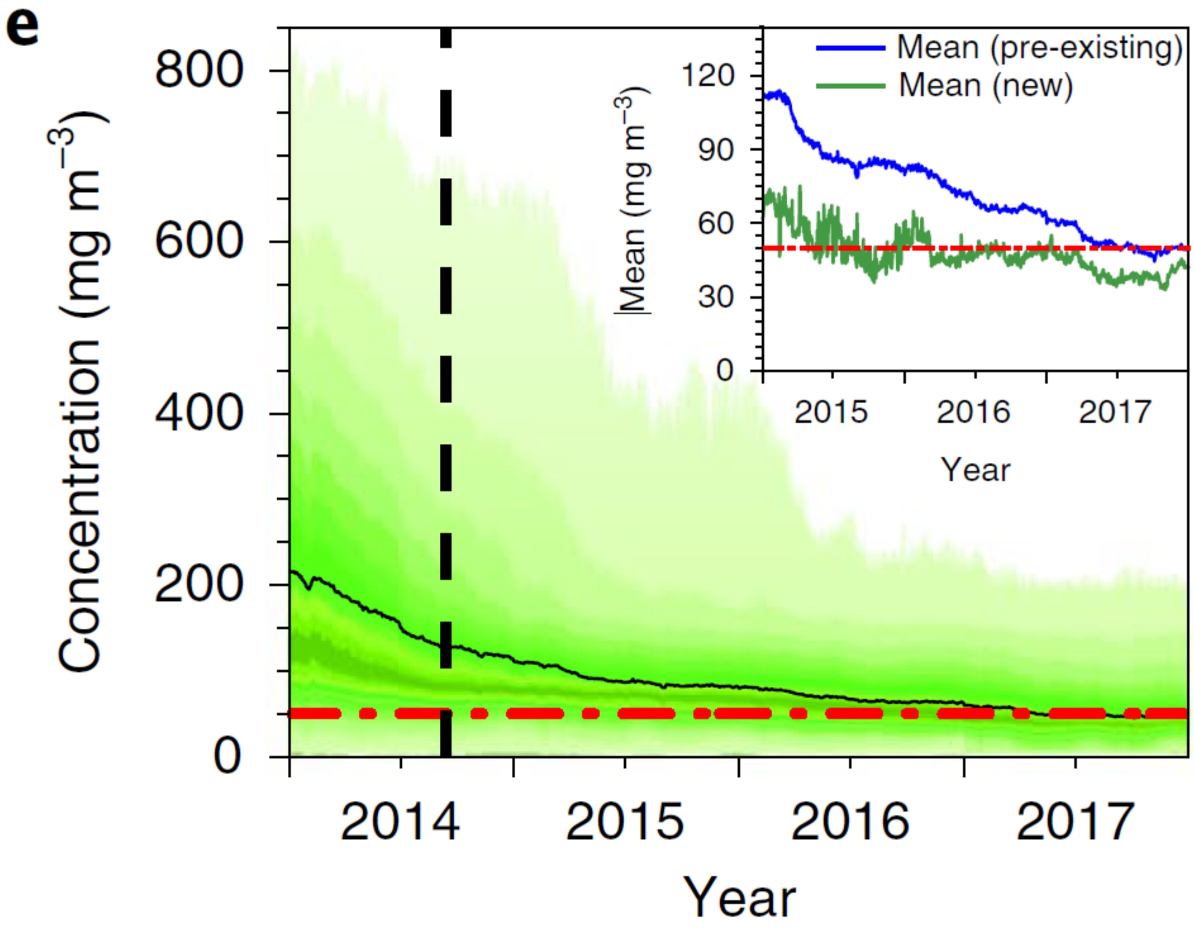


Figure 3: Evolution of the mean NO_x concentration of the whole Chinese coal power plant capacity between 2014 and 2017 [51]

From manufacturers of NO_x removal techniques, several reference cases for coal-fired boilers show that similar or lower emission levels than the BAT AEL are achievable:

- For a 321 MWth hard coal power plant in Poland, the installation of over-fire air system and low-NO_x burners from Fortum has enabled to achieve concentrations below 300 mg/Nm^3 without urea injection and below 190 mg/Nm^3 with SNCR [10], without affecting the boiler steam performance;
- For an Indian coal power plant > 100 MWe, the combustion modification by Fortum enabled to significantly reduce NOx emissions: a target concentration of 290 mg/Nm^3 was for all load conditions and concentrations as low as 200 mg/Nm^3 were achieved [12];
- EES Corp review of SNCR performances revealed some references cases for coal boilers between 40 and 165 MWth with achieved NOx concentrations below 180-190 mg/Nm^3, with only SNCR or a combination of SNCR with over-fire air (OFA) system [13].

Moreover, in the framework of the development of the BREF report on LCP, a benchmark on EU plants was realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of current ELVs, expressed as daily averages at 6% O_2, are as in the following:

Table 23: Proposal of potential updates in ELVs for NO_x from combustion of coal-type solid fuels, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and the update indexes

	Potential NO_x ELV – daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	155-200	165-330	125-173	129-297	1	2[3]
100-300 MW	80-130	155-210	64-114	125-194	1	2
> 300 MW	80-125	85-165[1] if PC*, 140-165[2] if FBC*	64-103	74-157 (PC) 110-157 (FBC)	1	1

[1]: 85-200 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 140-220 mg/Nm^3 if put into operation no later than Jan. 2014
[3]: the update index is 1 for pulverised lignite
*: PC "pulverised combustion" and FBC "fluidised bed combustion"

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

4.1.2. Solid biomass and peat:

For combustion plants burning solid biomass or peat, the ELV for NO_x from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 24: Emission limit values of NO_x for solid biomass and peat from the AGP, expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [1]

	ELV of NO_x (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	250	300
100-300 MW	200	250
Higher than 300 MW	150	200

In the European BAT conclusions for LCP [3], the BAT AEL for LCP burning solid biomass or peat, expressed as daily averages at 6% O_2, are as in the following:

Table 25: BAT AEL of NO_x for solid biomass or peat from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity[3]

	BAT AEL of NO_x for biomass or peat (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	120-200	120-275
100-300 MW	100-200	100-220
Higher than 300 MW	65-150	95-165[1]

[1]: 95-200 mg/Nm^3 if put into operation no later than Jan. 2014

In most of foreign regulations assessed, solid biomass is not treated on its own. Therefore, it can be supposed that solid biomass is included in the solid fuel category and the ELV given in the chapter 4.1.1 can be considered.

The same reducing techniques as for coal-type solid fuels [2][3] can be applied to achieve the imposed emission levels, and their potential applicability is of almost 100% as well except for the conditions given in chapter 4.1.1.

Larger efficiencies are obtained through combination of primary measures and secondary measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR). With SCR, the size and type of catalysts, the residence time of flue gases, the reagent consumption are among parameters enabling larger NOx removal efficiencies.

In the literature, no reference value of achieved concentration following the implementation of NO_x removal technology was found for recent applications on LCP burning biomass.

In the framework of the development of the LCP BREF, a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of current ELVs expressed as daily averages at 6% O_2, are as in the following:

Table 26: Proposal of potential updates in ELVs for NO_x emissions from combustion of solid biomass and peat, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential NO_x ELV - daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	120-200	120-275	93-173	93-248	1	1
100-300 MW	100-200	100-220	73-167	73-198	1	1
> 300 MW	65-150	95-165[1]	51-145	65-157	2	1

[1]: 95-200 mg/Nm^3 if put into operation no later than Jan. 2014

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

4.1.3. Liquid fuels - boilers:

For combustion plants burning liquid fuels, the ELV for NO_x from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 3% O_2 and as monthly averages, are as in the following:

Table 27: Emission limit values of NO_x for liquid fuels, from the AGP, expressed as monthly averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity

	ELV of NO_x (in mg/Nm^3 at 3% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	300	450
100-300 MW	150	200[1]
Higher than 300 MW	100	150[1]

[1]: 450 mg/Nm3 if fuel is distillation and conversion residues from crude oil refining within refineries and chemical installations

In the European BAT conclusions for LCP [3], the BAT AEL for LCP burning liquid fuels, expressed as daily averages at 3% O_2, are as in the following:

Table 28: BAT AEL of NO_x for liquid fuels from the LCP BAT Conclusions, expressed as daily averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity[3]

	BAT AEL of NO_x for liquid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	100-215	210-330[1]
100-300 MW	85-100	85-145[2]
Higher than 300 MW	85-100	85-110[2,3]

[1]: 210-450 mg/Nm^3 if put into operation no later than Jan. 2014 and operate less than 1,500 hours annually

[2]: 30-300 mg/Nm^3 if mixture of fuels in refineries

[3]: 85-145 mg/Nm^3 if put into operation no later than Jan. 2014

In the US regulation [32], the converted ELV, the NO_x ELV for LCP burning liquid fuels range from about 111 to 176 mg/Nm^3 at 3% O_2, on a monthly average basis, depending on the date of construction or modification of the plant.

In the Chinese regulation [33], the ELV of NO_x for all LCP burning liquid fuels are of 100 mg/Nm^3 for new facilities and 200 mg/Nm^3 for existing ones, at 3% O_2. For specific key regions which are more sensitive to atmospheric pollution and its impact, the ELV is set at 100 mg/Nm^3 for new and existing plants. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

In the Indian regulation [34], the NO_x ELV applied are of 540 mg/Nm^3 for TPP burning liquid fuels and installed in the period of 2004-2016, and of 120 mg/Nm^3 for all sizes of TPP installed in 2017 or later, converted at 3% O_2. However, as for Chinese regulation, no mention is made if the ELV are daily, monthly or annual averages.

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: combustion optimisation, air or fuel staging, flue-gas recirculation, low-NO_x burners, SNCR or SCR. The potential applicability of these techniques is of almost 100%, except for SCR which is not applicable for plants < 100 MWth according to the LCP BREF [2] and for SNCR and SCR for installations operating less than 500 hours annually. Some technical and economic limitations can exist for SNCR and SCR for plants operating less than 1,500 hours per year.

Larger efficiencies are obtained through combination of primary measures and secondary measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR). New generation low NO_x burners are more efficient. With SCR, the size and type of catalysts, the residence time of flue gases, the reagent consumption are among parameters enabling larger NO_x removal efficiencies.

In the literature, only a few references were found for the NO_x concentrations achieved following removal technology application for liquid fuel used in LCP, which reveal that similar or lower emission levels than the BAT AEL are possible to meet:

- EES Corp review of SNCR performances revealed some references cases for gas/oil boilers: NO_x concentrations about 120 mg/Nm^3 were achieved for a 50 MWth boiler, and concentrations around 60 mg/Nm^3 were observed for a 20 MWth and a 420 MWth boilers [12];
- For an Estonian combustion plant of a total 1,600 MWe capacity burning oil shale, the Fortum installation of low-NO_x combustion control and over-fire air systems, plus one out of eight boilers delivered with SNCR, made the daily exhaust gas concentration drop below 180 mg/Nm^3 with almost only primary techniques [11];
- FIVES Pillard implementation of 8 low-NO_x burners (LNB) of 15.5 MW each, making a total capacity of 124 MW, on the conversion of a French district heating plant burning biofuel enabled them to decrease the concentration from 580 (while burning heavy fuel oil) to 141 mg/Nm^3 [14]. For the backup fuel of a 82 MW boiler burning diesel oil, concentrations of 96 mg/Nm^3 were achieved with the application of LNB with 20% EGR [14].

In the framework of the development of the LCP BREF [2] , a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of ELVs, expressed as daily averages at 3% O_2, are as il the following:

Table 29: Proposal of potential updates in ELVs for NO_x emissions from combustion of liquid fuels, expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential NO_x ELV - daily (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	100-215	210-330[1]	86-207	177-297	1	1
100-300 MW	85-100	85-145[2]	63-86	63-120	1	1
> 300 MW	85-100	85-110[2,3]	63-86	63-105	2	1

[1]: 210-450 mg/Nm^3 if put into operation no later than Jan. 2014 and operate less than 1,500 hours annually
[2]: 30-300 mg/Nm^3 if mixture of fuels in refineries
[3]: 85-145 mg/Nm^3 if put into operation no later than Jan. 2014

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

4.1.4. Gaseous fuels - boilers:

For combustion plants with a rated thermal power higher than 50 MW burning gaseous fuels, the ELV for NO_x for boilers from the AGP [1] are as in the following:

Table 30: Emission limit values of NO_x for gaseous fuels used in boilers in the AGP [1] (in mg/Nm^3 at 3% O_2)

	NO_x ELV for boilers in AGP (in mg/Nm^3 at 3% O_2)	
Fuel type	New plant	Existing plant
Natural gas	100	100
Other gaseous fuels	200	300

In the BAT conclusions for LCP [3] and for refining of mineral oil [31], the BAT AEL for NO_x emissions for LCP boilers burning gaseous fuels, expressed as daily averages at 3% O_2, are as in the following:

Table 31: BAT AEL of NO_x for gaseous fuels from the LCP [3] and refining of mineral oil [31] BAT Conclusions, expressed as daily averages at 3% O_2, in mg/Nm^3

	BAT AEL of NO_x for gaseous fuels (in mg/Nm^3 at 3% O_2)	
Fuel type	New plant	Existing plant
Natural gas	30-85	85-110
Iron and steel gases	22-100	22-110[1]
Chemical industry process gases	30-100	85-110[2]

	BAT AEL of NO_x for gaseous fuels (in mg/Nm^3 at 3% O_2)	
Fuel type	New plant	Existing plant
Refinery gas	30-100*	30-150*,3

[1]: 22-160 mg/Nm^3 if put into operation no later than Jan. 2014 and no ELV imposed if operate less than 1,500 hours annually
[2]: 85-210 mg/Nm^3 if put into operation no later than Jan. 2014
[3]: 30-200 mg/Nm^3 if high air pre-heat is used or if H_2 fuel content is higher than 50%
*: expressed as monthly average

In the Chinese regulation [33], the ELV of NO_x for new and existing TPP burning gaseous fuels is of 100 mg/Nm^3 for natural gas and 200 mg/Nm^3 for other gases, at 3% O_2. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

In the US and Indian regulations [32][34], the NO_x ELV for natural gas are not so stringent with approximately 114-181 mg/Nm^3 (converted from g/GJ gross output) for the US depending on the date of modification or construction of the plant, and 120 mg/Nm^3 for Indian TPP installed from 2017 onwards. Moreover, no mention of ELV for other gases is made.

The BAT AEL emission levels can be respected through the application of one or a combination of the following techniques [2][3]: combustion optimisation, air or fuel staging, flue-gas recirculation, low-NO_x burners, advanced control system, reduction of combustion temperature, SNCR or SCR. The potential applicability of these techniques is of almost 100%, except for SCR which is not applicable for plants < 100 MWth [3] and for both SNCR and SCR for installations operating less than 500 hours annually. For plants operating less than 1,500 hours per year, some technical and economic limitations can exist for SNCR if there are highly variable loads and retrofitting for SCR.

Larger efficiencies are obtained through combination of primary measures and secondary measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR). New generation low NOx burners are more efficient. With SCR, the size and type of catalysts, the residence time of flue gases, the reagent consumption are among parameters enabling larger NOx removal efficiencies.

In the literature, some references were found for NO_x concentrations achieved following the application of reduction techniques for gas fired LCP, which reveal that similar or lower emission levels than the BAT AEL are possible to meet:

- EES Corp review of SNCR performances revealed some reference cases for gas and oil boilers: NO_x concentrations of about 120 mg/Nm^3 were achieved for a 50 MWth boiler, and concentrations around 60 mg/Nm^3 were observed for a 20 MWth and a 420 MWth boilers [12];
- EES Corp also showed that the application of SNCR on a refinery gas boiler of 20 MWth made it meet a flue gas concentration of 60 mg/Nm^3 [12];
- FIVES Pillard implementation of 6 burners of 20.6 MW each on a French district heating plant burning natural gas achieved concentration of 98 mg/Nm^3 [14].

- FIVES Pillard also enabled to achieve NO_x concentrations between 38 and 48 mg/Nm^3 for several projects with medium installations (about 10-15 MW), following the application of natural gas low-NO_x burners (LNB), without the use of exhaust gas recirculation (EGR) [14]. Concentrations around 20 mg/Nm^3 are expected with the addition of EGR. This was demonstrated with the implementation of 5 new LNB of 32 MW each on Samsung boilers which reached NO_x concentrations of 16 mg/Nm^3, but also with the LNB application with 20% EGR on ERZ plant (Zurich) of 82 MW where NO_x exhaust-gas concentrations of 14 mg/Nm^3 were achieved [14];

In the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

For the other gaseous fuels, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of ELVs, expressed as daily averages at 3% O_2, are as in the following:

Table 32: Proposal of potential updates in ELVs for NO_x emissions from combustion of gaseous fuels, expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential NO_x ELV (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
Natural gas	30-85	85-110	19-71	66-105	1	2
Iron and steel gases	22-100	22-110[1]	18-81	21-105	1	1
Chemical industry process gases	30-100	85-110[2]	25-89	77-105	1	1
Refinery gas	30-100*	30-150*,[3]	Already as monthly average		2	2

[1]: 22-160 mg/Nm^3 if put into operation no later than Jan. 2014 and no ELV imposed if operate less than 1,500 hours annually

[2]: 85-210 mg/Nm^3 if put into operation no later than Jan. 2014

[3]: 30-200 mg/Nm^3 if high air pre-heat is used or if H_2 fuel content is higher than 50%

*: expressed as monthly average

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

4.1.5. Gaseous and liquid fuels - turbines:

For combustion plants with a rated thermal power higher than 50 MW burning gaseous fuels, the ELV for NO_x for onshore turbines (including combined cycle gas turbines (CCGT)) from the AGP [1] are as in the following:

Table 33: Emission limit values of NOx emissions released from onshore combustion turbines (including Combined Cycle Gas Turbine CCGT) in the AGP (in mg/Nm3 at 15% O_2) [1]

NO_x ELV for turbines in AGP (in mg/Nm^3 at 15% O_2)[a]		
Fuel type	New plant	Existing plant
Light and medium distillate fuel oils	50	90[1]
Natural gas[b]	50	50[2, c,d]
Other gaseous fuels	50	120[3]

[1]: 200 mg/Nm^3 if the plant operates less than 1,500 hours per year
[2]: 150 mg/Nm^3 if the plant operates less than 1,500 hours per year
[3]: 200 mg/Nm^3 if the plant operates less than 1,500 hours per year

[a] Gas turbines for emergency use that operate less than 500 hours per year are not covered.

[b] Natural gas is naturally occurring methane with not more than 20% (by volume) of inert gases and other constituents.

[c] 75 mg/m^3 in the following cases, where the efficiency of the gas turbine is determined at ISO base load conditions:

- Gas turbines, used in combined heat and power systems having an overall efficiency greater than 75%.
- Gas turbines used in combined cycle plants having an annual average overall electrical efficiency greater than 55%.
- Gas turbines for mechanical drives.

[d] For single gas turbines not falling into any of the categories mentioned under footnote c, but having an efficiency greater than 35% — determined at ISO base load conditions — the ELV for NO_x shall be 50 x η / 35 where η is the gas-turbine efficiency at ISO base load conditions expressed as a percentage.

In the BAT conclusions for LCP [3] and for refining of mineral oil [31], there is no BAT AEL for turbines burning liquid fuels. However, the BAT AEL for NO_x emissions for turbines burning gaseous fuels, expressed as daily averages at 15% O_2, are available and are as in the following:

Table 34: BAT AEL of NO_x for gaseous fuels for turbines according to the LCP [3] and refining of mineral oil [31] BAT Conclusions, expressed as daily averages at 15% O_2 in mg/Nm^3

		ELV of NO_x for gaseous fuels (in mg/Nm^3 at 15% O_2)	
Installation	Fuel type	New plant	Existing plant
Open-cycle gas turbine	Natural gas	25-50	25-55[1]
Combined-cycle gas turbine 50-600 MW		15-40	35-55[2]
Combined-cycle gas turbine > 600 MW		15-40	18-50[*] 18-55[**,3]

		ELV of NO_x for gaseous fuels (in mg/Nm^3 at 15% O_2)	
Installation	Fuel type	New plant	Existing plant
Open- or combined-cycle gas turbine	Iron and steel gases	30-50	30-55^4
Open- or combined-cycle gas turbine in refineries	Gaseous fuel	20-50^{5,***}	40-120***

^{1}: 25-80 mg/Nm^3 if put into operation no later than 27 Nov. 2003 and operates between 500 and 1,500 hours per year
^{2}: 35-80 mg/Nm^3 if put into operation no later than Jan. 2014 and net total fuel utilisation > 75%
^{3}: 18-65 mg/Nm^3 if put into operation no later than 7 Jan. 2014
^{4}: 30-70 mg/Nm^3 if put into operation no later than 7 Jan. 2014
^{5}: 20-75 mg/Nm^3 if H_2 fuel content is higher than 10%
*: net total fuel utilisation < 75%
**: net total fuel utilisation > 75%
***: expressed as monthly averages

In the Chinese regulation [33], the ELV of NO_x for new and existing turbines, burning gaseous fuels is of 50 mg/Nm^3 for natural gas and 120 mg/Nm^3 for other gases or liquid fuels, at 15% O_2. However, in the available documents in English language, it is not stated if the ELV are daily, monthly or annual averages.

The BAT AEL emission levels can be respected through the application of one or a combination of the following techniques [2][3]: advanced control system, water or steam addition, low-NO_x burners (LNB) or SCR. The potential applicability of these techniques varies:

- Advanced control system implementation is limited for old plants,
- Dry LNB application in the presence of water or steam addition may be constrained,
- LNB are mostly applicable to supplementary firing for heat recovery steam generation in the case of CCGT,
- SCR is not applicable for plants < 100 MWth and for installations operating less than 500 hours annually [3]. For plants operating less than 1,500 hours per year and retrofits, some technical and economic limitations can exist.

It is not easy to find references of recent performances of low-NO_x technologies on turbines in the literature. However, a report from General Electric [15] revealed that NO_x concentrations as low as 4 mg/Nm^3 (starting from 47 mg/Nm^3) were already achieved in 1999 with the application of their post-combustion catalytic system without ammonia injection on a Canadian facility, although the operating and measurement conditions are not reported. More recently, one article stated that GE completed the first installation of a new gas-fired turbine which can achieve NO_x concentrations around 9 mg/Nm^3 with the application of dry low-NO_x burners (DLN) [16]. For its application on nine existing gas turbines at five power generation in China, NO_x concentrations of 15 mg/Nm^3 were reported [16].

In the framework of the development of the LCP BREF, a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

For gaseous fuel combustion in turbines, based on the assessment carried out in the EU for the development of the BAT Conclusions, the proposal of potential updates of ELVs, expressed as daily averages at 15% O_2, are as in the following:

Table 35: Proposal of potential updates in ELVs for NO_x from gas turbines burning gaseous fuel, expressed as daily averages at 15% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and the update indexes

		Potential NO_x ELV (in mg/Nm^3 at 15% O_2)		Est. equivalent monthly averages (mg/Nm^3 15% O_2)		Update Index	
Installation	Fuel type	New	Existing	New	Existing	New	Existing
OCGT	Natural gas	25-50	25-55[1]	20-42	20-52	2	2
CCGT 50-600 MW		15-40	35-55[2]	12-35	21-50* 30-52**	1	2
CCGT > 600 MW		15-40	18-50* 18-55**,[3]	12-35	14-45* 14-52**	1	2
OCGT or CCGT	Iron and steel gases	30-50	30-55[4]	25-42	25-52	2	1
OCGT or CCGT	Gaseous fuel	20-50[5]***	40-120***	Already as monthly average		2	2

[1]: 25-80 mg/Nm^3 if put into operation no later than 27 Nov. 2003 and operates between 500 and 1,500 hours per year
[2]: 35-80 mg/Nm^3 if put into operation no later than Jan. 2014 and net total fuel utilisation > 75%
[3]: 18-65 mg/Nm^3 if put into operation no later than 7 Jan. 2014
[4]: 30-70 mg/Nm^3 if put into operation no later than 7 Jan. 2014
[5]: 20-75 mg/Nm^3 if H_2 fuel content is higher than 10%
*: net total fuel utilisation < 75%
**: net total fuel utilisation > 75%
***: expressed as monthly averages

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

4.2. Limit values for NOx emissions released from cement clinker production

In cement production, NOx emissions are influenced by different parameters such as the type of fuel, the type of combustion, the combustion air-ratio and the flame temperature [39]. Thus, to reduce NOx emissions, several primary measures can be implemented as a first step, while additional secondary end-of-pipe measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR) are necessary to meet the emission levels summarized in Table 36. Both primary and secondary measures and related ELVs are described below.

Table 36: Table 3, annex V, Proposal of potential updates in ELVs for NOx emissions from cement cement clinker production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
44	**Annex V Table 3:** Limit values for NOx emissions released from cement clinker production General (existing and new plants): **500 mg/m^3 at 10 % O_2**	**Update Index 1** Upgraded current abatement techniques are available	The techniques are advanced primary measures (e.g. low NOx burners) associated with SNCR and/or SCR [39]	Almost 100 %. Some limitations may exist if the primary measures are not able to reach concentrations below 1000 mg/m^3.	**200 to 450 mg/m^3** as daily average [40] (at 10% O_2)
	Existing Lepol and Long Rotary Kilns in which no waste is co in-incinerated **800 mg/m^3 at 10 % O_2**	**Update Index 2** GP ELV in the upper range of EU BAT, however, ELV adjustment possible	The technique are advanced primary measures (low NOx burners, mid-kiln firing) associated with SNCR and/or SCR 39]	Almost 100 %	**400 to 800 mg/m^3** as daily average [40] (at 10% O_2)

Primary measures:

Among primary measures, flame cooling, low NO_x burners, staged combustion, mid kiln firing and addition of mineralizers to the raw material are the main techniques used in cement plants [39]:

(a) *Flame cooling* can be achieved by an addition of water to the fuel or directly to the flame. It lowers the temperature and so limits NO_x formation;

(b) *The addition of mineralizers*, such as fluorine, to the raw material also enables the reduction of the sintering zone temperature and thus NO_x formation;

(c) *Low NO_x burners* enable to reduce NO_x emissions during combustion processes. Combustion with low NO_x burner consists in a cold combustion with an internal or external flue gas recirculation. NO_x reductions up to 30% are achievable in successful installations and emission levels of 600–1000 mg/Nm^3 have been reported with the use of this technology;

(d) In *staged combustion*, the first combustion stage takes place in the rotary kiln. The second combustion stage is a burner at the kiln inlet; it decomposes nitrogen oxides generated in the first stage. In the third combustion stage the fuel is fed into the calciner with an amount of tertiary air. This system reduces the generation of NO_x from the fuel, and also decreases the NO_x coming out of the kiln. In the fourth and final combustion stage, the remaining tertiary air is fed into the system as 'top air' for residual combustion. Staged firing technology can in general only be used with kilns equipped with a precalciner;

(e) *Mid-kiln firing* is applied in long wet or dry kilns. It creates a reducing zone by injecting fuel at an intermediate point in the kiln system. In some installations using this technique, NO_x reductions of 20–40% have been achieved.

The optimum conditions for NO_x prevention are frequently in conflict with the best setting for the kiln operations. There are also limits to this approach mainly due to the formation of CO and SO_2 emissions.

It is important to point out that primary measures cannot guarantee the achievement of emission limits as low as 500 mg/Nm^3 at 10% O_2, daily average. Even though primary measures contribute to NOx reduction, secondary measures such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR) need to be used to achieve larger NO_x emission reductions.

SNCR

Selective non-catalytic reduction (SNCR for short) is a secondary process for flue gas denitrification. Thermolysis converts ammonia (NH_3) or urea with the gaseous nitrogen oxides (NO_x) to water vapor and nitrogen. Among the secondary measures, SNCR is the main technique considered in cement plants [61]. The efficiency is highly dependent on temperature window and injection of ammonia or urea must be done in the optimal temperature zone. Outside the range of optimal temperatures, ammonia slip increases or NO emissions increase. Experience has shown that for NO_x values <350 mg / m^3, the NH_3 emissions from unconsumed reducing agent increase significantly (even if the optimum temperature window is hit). For low NO_x values (<200 mg / m^3) [58], the SNCR process is only partly suitable, possibly in furnaces with a calciner and at the same time low NOx raw-gas emissions. The NH_3 slip is also responsible for the fact that lower NO_x emission levels, e.g. 200 mg/m^3, cannot be achieved with the SNCR process. The NH_3 slip increases significantly in these cases and breaks the positive nitrogen balance.

SCR

High NO_x emission reduction (> 90 %) can be expected with selective catalytic reduction (SCR) with a range of NO_x emissions of 100–200 mg/Nm^3 and a lower stochiometric ratio (around 1) as compared to the SNCR case [59]. The European BREF document and the BAT conclusions for cement production [39][40]describe SCR as a future technology that still needs additional process development. However, there are currently several plants equipped with SCR, especially in Germany or Switzerland, where the national ELV implemented is 200 mg/Nm^3 at 10 % O_2 [58]. TiO_2 and V_2O_5 catalysts are most often used at temperature of ~300°C in which ammonia solution has been evaporated. Two or more layers of catalyst bricks are located after the pre-heater outlet (high-dust) or as a tail-end system after the process filter (low-dust). The catalyst lifetime ranges within 5 to 6 years, depending on local situations (high-dust catalysts are likely to be replaced faster than low-dust catalysts, which work up to 10 years). The type of catalyst used in an SCR process must always be adapted to the exhaust gas-specific situation in individual cases. To prevent catalyst deactivation, SO_2 concentrations must be kept as low as possible [59].

Achievable emission reduction levels through the respective technologies are summarized in Figure 4. As indicated in Table 36, there is clear potential for decreasing the ELVs both in Annex V of the Gothenburg Protocol and in the EU BREF document and conclusions [39][40].

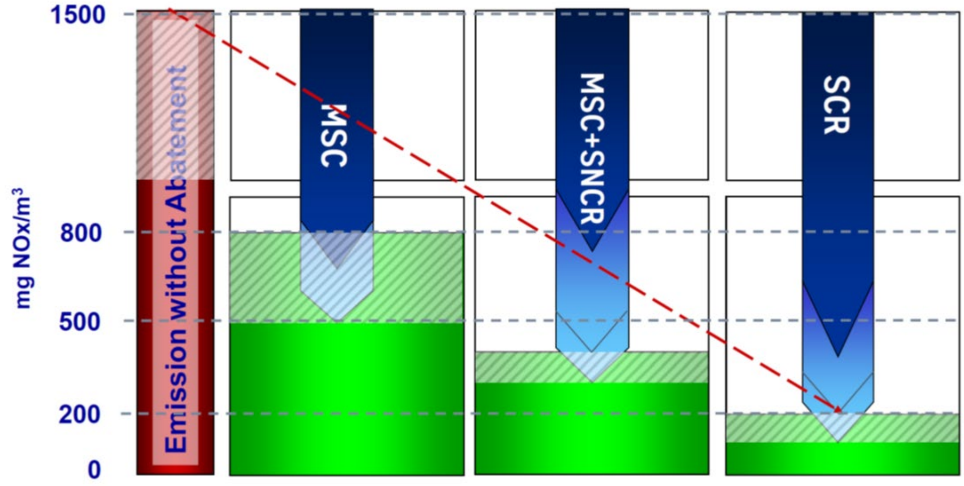


Figure 4: capabilities of techniques to reduce NOx emissions in cement plants [58]

4.3. Limit values for NOx emissions released from new stationary engines

The classical end-of-pipe technique for NOx reduction from stationary engines, particularly from diesel engines, is selective catalytic reduction (SCR). This is a selective reduction of nitrogen oxides with ammonia or urea in the presence of a catalyst. The technique is based on the reduction of NO_x to nitrogen in a catalytic bed by reaction with ammonia (in general aqueous solution) at an optimum operating temperature of around 300–450 °C. Several layers of catalyst may be applied to achieve higher NO_x reduction. A further concept to reduce NO_x in diesel engines is the "Low-NO_x combustion concept" This technique consists of a combination of internal engine modifications, e.g. combustion and fuel injection optimisation (the very late fuel injection timing in combination with early inlet air valve closing), turbocharging or the so called "Miller cycle". In the Miller case, the engine leaves the intake valve open during part of the compression stroke, so that the engine is compressing against the pressure of the supercharger rather than the pressure of the cylinder walls. This reduces NO_x formation in diesel engines. Further measures to reduce NO_x are exhaust gas recirculation or water/steam addition [2]. Water or steam is used as a diluent for reducing the combustion temperature in gas turbines, engines or boilers and thus the thermal NO_x formation. It is either premixed with the fuel prior to its combustion (fuel emulsion, humidification or saturation) or directly injected in the combustion chamber (water/steam injection).

For spark ignited Otto engines fuelled by natural gas, propane or gasoline, three-way catalytic converters are effective in preventing air pollution. In this case, the oxidation of carbon monoxide (CO) and hydrocarbons (HC) as well as the reduction of nitrogen oxides (NO_x) occur simultaneously to form the harmless products; carbon dioxide (CO_2), water (H_2O) and nitrogen (N_2).

Table 37 summarizes the ELVs for NO_x from large stationary engines, related abatement techniques and potential emission levels. Depending on the type of motor and the fuels, there are some potentials for adjustment of ELVs, particularly for new installations. However, it has to be taken into account that some fuels types (such as gaseous fuels) include a broad range of gases such as biogas, landfill gas or sewage gas. Hence, case specific ELVs might sometimes be necessary.

Table 37: Table 4, annex V, Proposal of potential updates in ELVs for NOx emissions from stationary engines

45	**Annex V Table 4:** Limit values for NOx emissions released from new stationary engines				
	Gas engines > 1 MWth Spark ignited (= Otto) engines all gaseous fuels: ELV (mg/m^3)				
	Spark ignited (= Otto) engines: **95** mg/m^3 (enhanced lean burn)	**Update Index 3** ELVs are in the range of limits described in different references (TA Luft, 44th BImSchV, EU BREF, US EPA) [73][2][3]	The usual abatement technique for CO is through three-way catalysts which also remove NOx, further techniques for lean-burn engines are selective catalytic reduction (SCR) processes [73]	100%	**95** mg/m^3 [73]
	All gaseous fuels: **190** mg/m^3 (Standard lean burn or rich burn with catalyst)	**Update Index 2** Upper range of ELVs from EU BAT conclusions	Three-way catalysts, SCR. All gaseous fuels is a broad range that might need further specification. This includes biogas, sewage gas etc. where ELVs are usually higher.	100%	**115-190** mg/m^3 [2]
	Dual fuel engines > 1 MWth: ELV (mg/m^3)				
	In gas mode (all gaseous fuels): **190** mg/m^3	**Update Index 2**	Three-way catalysts, SCR.	100%	**115-190** mg/m^3 [2]
	In liquid mode (all liquid fuels): **225** mg/m^3	**Update Index 1** Update possible	Exhaust-gas recirculation, water/steam addition, SCR	100%	**100** mg/m^3 [73]
	Diesel engines > 5 MWth (compression ignition) Slow (< 300 rpm)/medium (300 rpm–1,200 rpm)/ speed, ELV (mg/m^3)				
	5 MWth–20 MWth: Heavy fuel oil and bio oils: **225** mg/m^3; Light fuel oil and natural gas: **190** mg/m^3	**Update Index 1** Update possible	Selective catalytic reduction (SCR)	100%	**100** mg/m^3 [73]
	20 MWth and high speed (> 1200 rpm): **190** mg/m^3 for all fuels	**Update Index 1** Update possible	Selective catalytic reduction (SCR)	100%	**100** mg/m^3 [73]

4.4. Limit values for NOx emissions released from iron ore sinter plants

Table 38 summarizes the ELVs for NOx in Annex V of the Gothenburg Protocol and the proposal for update of ELVs through secondary reduction measures described in the EU BREF [42]. Beside primary measures such as low NOx burners and waste gas recirculation, NOx reduction is achieved through a Regenerated Activated Carbon Process with additional NH_3 injection or through Selective Catalytic Reduction (SCR) [43]. As the SCR process in principle has been described before, the following explanation focusses on the RAC process as a secondary reduction measure which is mainly applied for desulphurisation but which may additionally reduce NO_x through ammonia injection. As shown in Table 38, there is a clear potential for stricter ELVs considering RAC or SCR as secondary reduction measures. The potential ELVs are derived from EU BAT Conclusions [43].

Table 38: Table 5, annex V, Proposal of potential updates in ELVs for NOx emissions from iron ore sinter plants

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
46	**Annex V Table 5:** Limit values for NOx emissions released from iron ore sinter plants **New installations, ELV for NOx (mg/m^3): 400** measured as average values over a longer period of time	**Update Index 1** Update possible	Primary measures such as waste gas recirculation and low NOx burners in combination with regenerated activated carbon process **(RAC)** or selective catalytic reduction **(SCR)** [42]	Almost 100%	**RAC < 250 mg/m^3** **SCR < 120 mg/m^3** daily average [43]

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Existing installations, ELV for NOx (mg/m^3): 400 measured as average values over a longer period of time	**Update Index 1** Update possible depending on process specification	Primary measures such as waste gas recirculation and low NOx burners in combination with regenerated activated carbon process **(RAC)** or selective catalytic reduction **(SCR)** [42]	Depending on process specification and space → site specific	**RAC < 250 mg/m^3** **SCR < 120 mg/m^3** daily average[43]

Regenerated activated carbon (RAC) is a dry desulphurisation technique based on an adsorption of SO_2 by activated carbon. When the SO_2-laden activated carbon is regenerated, the process is called regenerated activated carbon (RAC). In this case, a high quality, expensive activated carbon type may be used, and sulphuric acid (H_2SO_4) is yielded as a by-product. The bed is regenerated either with water or thermally. The RAC system can be developed as a single-stage or a two-stage process. In the single-stage process, the waste gases are led through a bed of activated carbon and pollutants are adsorbed by the activated carbon. Additionally, NO_X removal occurs when ammonia (NH_3) is injected into the gas stream before the catalyst bed. In the two-stage process, the waste gases are led through two beds of activated carbon. Ammonia can be injected before each bed to reduce NO_x emissions. This technique can jointly reduce SO_x and NO_x emissions. The EU BREF conclusions report NO_x emissions of < 250 mg/m^3 for the RAC process while additional reductions to < 120 mg/m^3 can be achieved when applying selective catalytic reduction (SCR) for NO_x abatement.

4.5. Limit values for NOx emissions released from the production of nitric acid

Nitric acid is a key industrial chemical for the production of fertilizers. The current production route of nitric acid is known as “the Ostwald process” in which nitric acid is produced by oxidation of ammonia. This highly exothermic reaction is carried out over a highly selective platinum–rhodium catalyst. The temperature ranges between 800 and 930 °C [61]. The liquid ammonia is evaporated, superheated and sent to a converter containing the catalyst. In the converter, ammonia is converted into nitric oxide which is then converted into nitrogen dioxide in the oxidation vessel with the help of secondary air. The process water absorbs nitrogen dioxide to form nitric acid in the absorption column. The tail gas of the absorption column containing high levels of NO_x is treated in a DeNOx unit before being discharged [61]. The DeNOx unit is normally based on selective catalytic reduction process (SCR) with an additional H_2O_2 absorption in the last stage. An established DeNOx process that outperforms the emission levels summarized in Table 39 is the so called EnviNOx® process which is shortly described in the following. As shown in Table 39, the ELVs in Annex V are in the upper range of the emission values reported in the EU BREF document for inorganic chemicals production [38] However, this document is from 2007 and there is potential for reducing emission by applying e.g. the EnviNOx® process.

Table 39: Table 6, Annex V, Proposal of potential updates in ELVs for NO_x emissions from nitric acid production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
46	**Annex V Table 6:** Limit values for NOx emissions released from nitric acid production **New installations, ELV for NOx (mg/m^3): 160**	**Update Index 1** Emission limits in the range of EU BREF, no pressing update necessary	Different primary measures and combined NO_x and N_2O abatement in tail gases, selective catalytic reduction (SCR), addition of H_2O_2 to the last absorption stage (EnviNOx) [44]	Almost 100%	**5-75 ppmv which is around 10 to155 mg/m^3** yearly average according to the EU BREF document [38] **5-25 ppmv based on current DeNOx units**

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Existing installations, ELV for NOx (mg/m^3): 190	**Update Index 2** Emission limits in the range of EU BREF, no pressing update necessary	Different primary measures and combined NOx and N_2O abatement in tail gases, selective catalytic reduction SCR, addition of H_2O_2 to the last absorption stage (EnviNOx) [44]	Almost 100%	**5-90 ppmv which is around 10 to 185 mg/m^3** yearly average [38]

ThyssenKrupp Industrial Solutions for example provides a DeNOx unit for nitric acid production called EnviNOx® [44]. The Process is currently suitable for tail gas temperatures between 425°C and 520°C. High rates of N_2O removal are possible with 98% typically achieved in commercial installations and NO_X emissions can be reduced to low levels depending on the amount of ammonia supplied, with **5 – 25 ppmv** being usual.

With the EnviNOx® process, ammonia consumption is similar to that of classical SRC/DeNOx processes [44] and the process is explicitly mentioned in the EU BREF as BAT [38] In this process, specific iron zeolites are used as catalyst for the selective reduction of NO_X (NO and NO_2) with ammonia and the decomposition of N_2O. The EnviNOx® reactor is typically located in the tail gas stream on the inlet side of the tail gas turbine where the tail gas temperature is at its highest. Figure 5 illustrates a possible configuration of the EnviNOx® process, which is normally realized in one single reactor. As indicated before, this BAT or comparable DeNOx units could explicitly reduce NOx emissions beyond current ELVs both in the EU BREF document and in Annex V of the Gothenburg protocol.

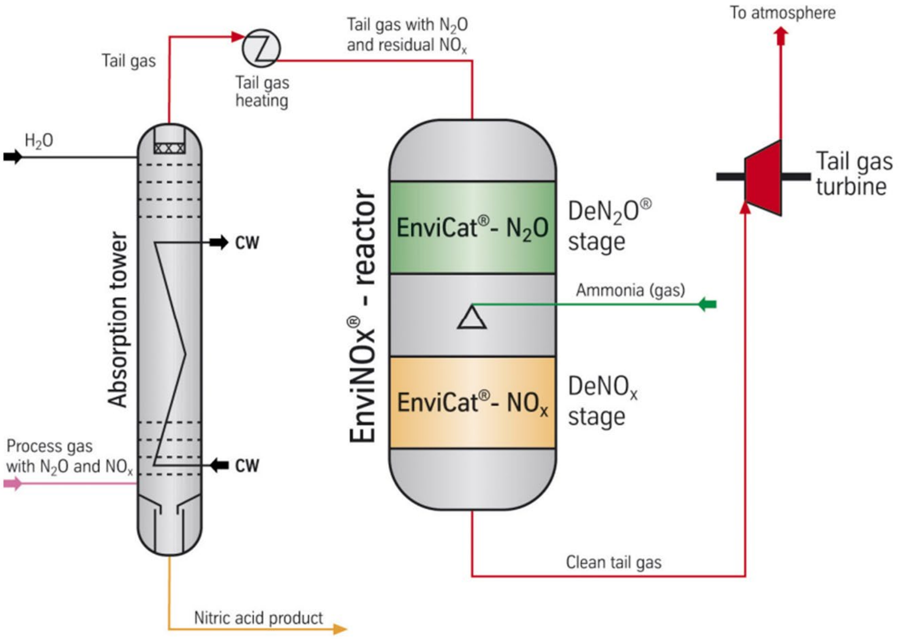


Figure 5: EnviNOx® process for combined N2O and NO_x abatement for nitric acid plants using N2O decomposition and NO_x reduction with ammonia [44].

5. Annex VI: limit values for emissions of VOC from stationary sources

Most of the potential emission limit values (ELV) identified for VOCs emissions from the use of solvents come from the recently published "*Best Available Techniques (BAT) Reference Document on Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals" or* STS BREF [4] and the associated decision [5]. The scope of this reference document covers the largest industrial solvent consumers with a solvent consumption higher than 200 tons. However, the following BREFs and decisions have also been used:

- Best Available Techniques (BAT) Reference document for the Tanning of Hides and Skins of 2013 [6],
- Commission implementing Decision of 11 February 2013 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the tanning of hides and skins of 2013 [7],
- Best Available Techniques (BAT) Reference Document for Organic fine chemicals of 2006 [26],
- Best Available Techniques (BAT) Reference Document for the Food, Drink and Milk Industries of 2019 [72],
- Commission implementing Decision (EU) 2019/2031 of 12 November 2019 establishing best available techniques (BAT) conclusions for the food, drink and milk industries, under Directive 2010/75/EU of the European Parliament and of the Council of 2019 [27],
- Best available techniques (BAT) reference document for Common waste gas management and treatment systems in the chemical sector, Final draft of March 2022 [28].

5.1. Limit values for VOCs classified as CMR

Article 5 in annex VI of the current GP is as in the following:

> *5. The following ELVs apply for waste gases containing substances harmful to human health:*
>
> *(a) 20 mg/m^3 (expressed as the mass sum of individual compounds) for discharges of halogenated VOCs, which are assigned the following risk phrases: "suspected of causing cancer" and/or "suspected of causing genetic defects", where the mass flow of the sum of the considered compounds is greater than or equal to 100 g/h; and*
>
> *(b) 2 mg/m^3 (expressed as the mass sum of individual compounds) for discharges of VOCs, which are assigned the following risk phrases: "may cause cancer", "may cause genetic defects", "may cause cancer by inhalation", "may damage fertility", "may damage the unborn child", where the mass flow of the sum of the considered compounds is greater than or equal to 10 g/h.*

Chemical substances can have various harmful effects on human health. They can be characterised as "CMR", for carcinogenic, mutagenic or toxic for reproduction. The Classification, Labelling and Packaging regulation (CLP) [92] introduces hazard categories that define the level of evidence of the observed CMR effects. Two categories are defined:

- Category 1 which is divided into 2 sub-categories:

    - 1A which includes the substances that are known of being CMR to humans and carrying the hazard statements H340, H350, H360.
    - 1B which includes the substances that are presumed of being CMR to humans and carrying the hazard statements H340, H350, H360.
- Category 2 which covers the substances that are suspected of being CMR to humans and the hazard statements H341, H351, H361.

According to the final draft of the BREF for common waste gas management and treatment systems in the chemical sector [28] (BREF WGC), VOCs containing substances classified as CMR 1A, 1B or 2 can be treated with waste gas treatment technique listed in a previous chapter of this document. When a CMR substance is identified, it must be eliminated or replaced whenever technically possible [69]. Moreover, a chemical management system that includes an inventory of all the hazardous substances and substances of very high concern used in the process(es) is a method for managing this type of products [28]. The potential for substitution of the substances that are listed in this inventory, focusing on those substances other than raw materials, can be analysed periodically (e.g. annually) in order to identify possible new available and safer alternatives, with no or lower environmental impacts [28].

According to the final version of the European BREF WGC [28] (chapter 4), the Best Available Technique Associated Emission Levels are as in the following:

Table 40: Best Available Technique Associated Emission Levels for channelled emissions of CMR VOCs [28]

Substance	BAT AELs (mg eq C/Nm^3) – Daily average
Sum of VOCs classified as CMR 1A or 1B	< 1-5 The BAT-AEL does not apply to minor emissions (i.e. when the mass flow of the sum of the VOCs classified as CMR 1A and 1B is below e.g. 1 g/h)
Sum of VOCs classified as CMR 2	< 1-10 The BAT-AEL does not apply to minor emissions (i.e. when the mass flow of the substance concerned is below e.g. 50 g/h).

The limit values of the current annex VI of the Gothenburg Protocol, could be reinforced as well as the emission thresholds from which these ELVs would be mandatory, based on what is proposed for the chemical processes by the BREF WGC [28].

The proposals characterised as update index 1, are as in the following:

Table 41: Proposal of potential updates in ELVs for CMR substance emissions

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
52	**Article 5:** The following ELVs apply for waste gases containing substances harmful to human health: a) 20 mg/m3 (expressed as the mass sum of individual compounds) for discharges of halogenated VOCs, which are assigned the following risk phrases: "suspected of causing cancer" and/or "suspected of causing genetic defects", where the mass flow of the sum of the	**Update Index 1**	A chemical management system that includes an inventory of the hazardous substances and substances of very high concern used in the process(es) can be developed for managing this type of products. The potential for substitution of the substances that are listed in this inventory, focusing on those substances other than raw materials, is analysed periodically (e.g. annually) in order to identify possible new		Based on the BREF WGC [28] a) < 1-10 mg/m^3 (expressed as the mass sum of all individual compounds which are classified CMR (carcinogenic, mutagenic and reprotoxic) of category 2 as: "suspected of causing cancer" and/or "suspected of causing genetic defects", where the mass flow of the sum of the considered compounds is greater than or equal to 50 g C/h.

Pag.	**Reference and Update Index**	**Potential update**	**Description**	**Potential Applicability (%)**	**Potential ELVs**
	considered compounds is greater than or equal to 100 g/h; b) 2 mg/m3 (expressed as the mass sum of individual compounds) for discharges of VOCs, which are assigned the following risk phrases: “may cause cancer”, “may cause genetic defects”, “may cause cancer by inhalation”, “may damage fertility”, “may damage the unborn child”, where the mass flow of the sum of the considered compounds is greater than or equal to 10 g/h.		available and safer alternatives, with no or lower environmental impacts [28]. Common VOC emission reduction techniques are also used.		b) < 1-5 mg/m^3 (expressed as the mass sum of all individual compounds which are classified CMR (carcinogenic, mutagenic and reprotoxic) of category 1A and 1B: “may cause cancer”, “may cause genetic defects”, “may cause cancer by inhalation”, “may damage fertility”, “may damage the unborn child”, where the mass flow of the sum of the considered compounds is greater than or equal to 1 g C/h.

5.2. Limit values for VOC emissions released from storage and distribution of petrol, excluding the loading of seagoing ships

The current limit values are as in the following in table 1, annex VI of the GP:

Limit values for VOC emissions from the storage and distribution of petrol, excluding the loading of seagoing ships (stage I)

Activity	*Threshold value*	*ELV or reduction efficiency*
Loading and unloading of mobile container at terminals	*5,000 m^3 petrol throughput annually*	*10g VOC/m^3 including methane*[a]
Storage installations at terminals	*Existing terminals or tank farms with a petrol throughput of 10,000 Mg/year or more* *New terminals (without thresholds except for terminals located in small remote islands with a throughput less than 5,000 Mg/year)*	*95 wt-%*[b]
Service stations	*Petrol throughput larger than 100 m^3/year*	*0.01wt-% of the throughput*

[a] *The vapour displaced by the filling of petrol storage tanks shall be displaced either into other storage tanks or into abatement equipment meeting the limit values in the table above.*

[b] *Reduction efficiency expressed in % compared to a comparable fixed-roof tank with no vapour-containment controls, i.e., with only a vacuum/pressure relief valve.*

[c] *Vapours displaced by the delivery of petrol into storage installations at service stations and in fixed-roof tanks used for the intermediate storage of vapours must be returned through a vapour-tight connection line to the mobile container delivering the petrol. Loading operations may not take place unless the arrangements are in place and properly functioning. Under these conditions, no additional monitoring of the compliance with the limit value is required.*

No update has been identified.

5.3. Limit values for VOC emissions released from car refuelling at service stations

The current limit values are as in the following in table 2, annex VI of the GP:

Limit values for VOC emissions for car refuelling at service station (stage II)

Threshold values	*Minimum vapour capture efficiency wt-%* [a]
New service station if its actual or intended throughput is greater than 500 m^3 per annum *Existing service station if its actual or intended throughput is greater than 3,000 m^3 per annum as of 2019* *Existing service station if its actual or intended throughput is greater than 500 m^3 per annum and which undergoes a major refurbishment*	*Equal to or greater than 85 wt-% with a vapour/petrol ratio equal to or greater than 0.95 but less than or equal to 1.05 (v/v)*

[a] *The capture efficiency of the systems has to be certified by the manufacturer in accordance with relevant technical standards or type approval procedures.*

The Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations [70] consolidated by the Commission Directive 2014/99/EU of 21 October 2014 amending, for the purposes of its adaptation to technical progress, Directive 2009/126/EC on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations [71] is well represented in the table 2 of the annex VI of the GP. A possible update could be the decrease of the threshold for existing installations from throughput of 3,000 m^3 per annum to a throughput of 500 m^3 per annum.

The proposal is characterised as update index 2, is as in the following:

Table 42: Annex VI, table 2, Proposal of potential updates in ELVs for VOC emissions from car refuelling at service stations (stage II)

Pag.	**Reference and Update Index**	**Potential update**	**Description**	**Potential Applicability (%)**	**Potential ELVs**
52	**Table 2:** Limit values for VOC emissions for car refuelling at service station (stage II) New service station if its actual or intended throughput is greater than 500 m^3 per annum Existing service station if its actual or intended throughput is greater than 3,000 m^3 per annum as of 2019 Existing service station if its actual or intended throughput is greater than 500 m^3 per annum and which undergoes a major refurbishment *Minimum vapour capture efficiency wt-%* Equal to or greater than 85 wt-% with a vapour/petrol ratio equal to or greater than 0.95 but less than or equal to 1.05 (v/v)	**Update Index 2** Potential update by decreasing the threshold for existing plants		Applicability subject to cost impacts	Possible lower threshold for existing service stations to implement ELVs (from a throughput of 3000 m^3 per annum to a throughput of 500 m^3 per annum)

5.4.Limit values for VOC emissions released from adhesive coating

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 43: Annex VI, table 3, Proposal of potential updates in ELVs for VOC emissions from adhesive coating

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
54	**Table 3:** Limit values for adhesive coating Footwear manufacture (solvent consumption > 5 Mg/year) 25 g VOC / pair of shoes Other adhesive coating (solvent consumption 5 Mg/year–15 Mg/year) ELVc = 50 mg C/m^3 (150 mg C/m^3 if techniques enabling solvent recovery) ELVf = 25 wt-% or less of the solvent input. Or total ELV of 1.2 kg or less of VOC/kg of solid input Other adhesive coating (solvent consumption 15 Mg/year–200 Mg/year) ELVc = 50 mg C/m^3 (150 mg C/m3 if techniques enabling solvent recovery) ELVf = 20 wt-% or less of the solvent input. Or total ELV of 1 kg or less of VOC/kg of solid input Other adhesive coating (solvent consumption > 200 Mg/year) ELVc = 50 mg C/m^3 (100 mg C/m^3 if techniques enabling solvent recovery) ELVf = 15 wt-% or less of the solvent input. Or total ELV of 0.8 kg or less of VOC/kg of solid input	Upgraded current abatement techniques are available [4][5] **Update index 3** for plants with a solvent consumption ≤ 200 t/year **Update Index 1** for plants with solvent consumption > 200 tons.	Reduction of VOC emissions is based on a series of BAT related to raw materials (such as high solids coatings, varnishes…) and their optimal uses (reduced consumption through adequate application techniques…), minimising the use of solvent-based cleaning agents, the reduction of fugitive emissions by applying principles of good housekeeping, use of secondary flue gas reduction techniques [4][5] The associated monitoring for total VOC emissions and fugitive emissions is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant, [5] . For VOC emissions in waste gases BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality) [5] In order to reduce the energy consumption of the VOC abatement system, BAT is to use one or a combination of the following techniques: (a) maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans; (b) internal concentration of solvents in the waste gases; (c) external concentration of solvents in the waste gases through adsorption; (d) plenum technique to reduce waste gas volume [4] [5].	.	Total emissions of VOCs from the manufacturing of adhesive tapes with a solvent consumption > 200 Mg/year [5] < 1-3 % of the solvent input. VOC emissions in waste gases from the manufacturing of adhesive tapes: 2-20 mg C/Nm^3. The upper value of the range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.

Using the STS BREF and the STS decision, new limit values can be proposed for adhesive tape manufacturing.

According to information provided by the STS BREF [4], total VOCs emissions from the manufacturing of adhesive tapes (in % of the solvent input) can be low. Elevated total emissions may occur in the two following cases:

- When products which require coating with highly volatile components and/or high coating weights can have a considerable residual solvent content are used.
- Ancillary activities (e.g., cleaning, transferring) which are characterised by erratic intervals and often by short peaks with high concentrations, so exhaust air treatment may have an unfavourable cost-benefit ratio.

BAT to reduce emissions are multiple, both primary measures and secondary measures. The BAT have been described in the summary table above. In terms of primary techniques, the following products can be used: hot melt adhesives, water based adhesives, UV cured adhesives.

The proposed limit values for plants consuming more than 200 t solvents per year are based on the BAT AELs provided by the decision establishing BAT for surface treatment using organic solvents (STS decision) [5] which are as in the following:

Table 44: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the manufacturing of adhesive tapes [5]

Parameter	Unit	BAT AEL – Yearly average
Total VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1-3(1) (1) This BAT-AEL may not apply to the manufacturing of plastic films used in temporary surface protection.

Monitoring is caried out by a solvent management plan.

Table 45: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the manufacturing of adhesive tapes [5]

Parameter	Unit	BAT AEL – Daily average	
		if techniques not allowing reuse/recycling of the recovered solvents	With techniques allowing the reuse/recycling of the recovered solvent
TVOC	mg C/Nm^3	2-20	2-50

BAT is to monitor emissions in waste gases with a frequency depending on the emission level and in accordance with EN standards: continuous in case of emissions larger the 10 kg C/h and once a year for smaller emissions.

5.5. Limit values for VOC emissions released from coating activities in the vehicle industry

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 46: Table 5, Annex VI, Proposal of potential updates in ELVs of VOC emissions from coating activites in the vehicle industry

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
54/55	**Table 5:** Limit values for coating activities in the vehicle industry 1/ Manufacture of cars (M1, M2) Solvent consumption > 15 Mg/year and ≤ 5,000 coated items a year or > 3,500 chassis built: 90 g VOC/m^2 or 1.5 kg/body + 70 g/m^2 (yearly) Solvent consumption 15 Mg/year –200 Mg/year and > 5,000 coated items a year: *Existing installations:* 60 g VOC/m^2 or 1.9 kg/body + 41 g/m^2 (yearly) *New installations:* 45 g VOC/m^2 or 1.3 kg/body + 33 g/m^2 (yearly) Solvent consumption > 200 Mg/year and > 5,000 coated items a year): 35 g VOC/m^2 or 1 kg/body + 26 g/m^2 (yearly) 2/ Manufacture of truck cabins (N1, N2, N3) Solvent consumption > 15 Mg/year and ≤ 5,000 coated items/year *Existing installations*: 85 g VOC/m^2 *New installations*: 65 g VOC/m^2 Solvent consumption 15 to 200 Mg/year and > 5,000 coated items/year *Existing installations*: 75 g VOC/m^2 *New installations*: 55 g VOC/m^2 Solvent consumption > 200 Mg/year and > 5,000 coated items a year: 55 g VOC/m^2 (yearly) 3/ Manufacture of trucks and vans	Upgraded current abatement techniques are available **Update index 3** for plants with solvent consumption ≤ 200 tons. **Update Index 1** Update of limit values for plants with solvent consumption > 200 tons.	VOCs are reduced through use of one or a combination of the coating systems given in below in order to reduce the consumption of solvents, other raw materials and energy, as well as to reduce VOC emissions: (a) mixed (SB-mix) coating; (b) water-based (WB) coating; (c) integrated coating process; (d) three-wet process [4][5] BAT is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant, as defined in Part 7(2) of Annex VII to Directive 2010/75/EU and to minimise the uncertainty of the solvent mass balance data by using all of the techniques [5]	For (a) mixed (SB-mix) coating; (b) water-based (WB) coating; (c) integrated coating process; (d) three-wet process: only applicable to new plants or major plant upgrades of existing ones.	Manufacture of cars (M1, M2) with solvent consumption > 200 Mg/year [5] 1/ Passenger cars *New plant*: 8-15 g VOC/ m^2 of surface area, as yearly average *Existing plant*: 8-30 g VOC/ m^2 of surface area, as yearly average Manufacture of truck cabins (N1, N2, N3) 2/ Truck cabins Solvent consumption > 200 Mg/year. From [5]: *New plant:* 8-20 g VOC/ m^2 of surface area, as yearly average *Existing plant:* 8-40 g VOC/ m^2 of surface area, as yearly average 3/ Manufacture of Vans Solvent consumption > 200 Mg/year. From [5]: *New plant:* 10-20 g VOC/ m^2 of surface area, as yearly average *Existing plant*: 10-40 g VOC/ m^2 of surface area, as yearly average 4/ Manufacture of Trucks Solvent consumption > 200 Mg/year. From [5]: *New plant*: 10-40 g VOC/ m^2 of surface area, as yearly average *Existing plant*: 10-50 g VOC/ m^2 of surface area, as yearly average 5/ Manufacture of Buses Solvent consumption > 200 Mg/year. From [5]:

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Solvent consumption > 15 Mg/year and ≤ 2,500 coated items/year *Existing installations*: 120 g VOC/m² *New installations*: 90 g VOC/m² Solvent consumption 15 to 200 Mg/year and > 2,500 coated items/year *Existing installations*: 90 g VOC/m² *New installations*: 70 g VOC/m² Solvent consumption > 200 Mg/year and > 2,500 coated items a year: 50 g VOC/m² (yearly) 4/ <u>Manufacture of buses</u> Solvent consumption > 15 Mg/year and ≤ 2,000 coated items/year *Existing installations*: 290 g VOC/m² *New installations*: 210 g VOC/m² Solvent consumption 15 to 200 Mg/year and > 2,000 coated items/year *Existing installations*: 225 g VOC/m² *New installations*: 150 g VOC/m² Solvent consumption > 200 Mg/year and > 2,000 coated items a year): 150 g VOC/m² (yearly)				*New plant:* < 100 g VOC/ m² of surface area, as yearly average *Existing plant:* 90-150 g VOC/ m² of surface area, as yearly average

According to information provided by the STS BREF [4], solvent-based paints have been replaced with solvent-free or water-based equivalents or more efficient solvent-based technologies and, additional off-gas treatment units have been installed. These new or upgraded technologies implemented in this sector have reduced VOCs emissions per car by 21 % and total VOCs emissions of the sector by 16% from 2008 to 2017 in the EU. Mixed (SB-mix) coating, water-based (WB) coatings, integrated coating process and three-wet process and their combination are among the BATs available for this sector [5].

The proposed limit values for plants consuming more than 200 t solvents per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 47: BAT-associated emission levels (BAT-AELs) for total emissions of VOCs from the coating of vehicles [5]

Parameter	Vehicle type	Unit	BAT AELs – Yearly average	
			New plant	Existing plant
Total VOC emissions as calculated by the solvent mass balance	Passenger cars	g VOCs per m^2 of surface area	8–15	8–30
	Vans		10-20	10-40
	Truck cabins		8-20	8-40
	Trucks		10-40	10-50
	Buses		< 100	90-150

The BAT-AELs refer to emissions from all process stages, carried out at the same installation from the electrophoretic coating or any other kind of coating process up to and including the final wax and polish of the topcoat, as well as solvents used in cleaning of production equipment, both during and outside the production period.

5.6. Limit values for VOC emissions released from coating activities in various industrial sectors

5.6.1. Coating of wooden surfaces, metal and plastic surfaces

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 48: Table 6, annex VI, Proposal of potential updates in ELVs of VOC emissions from coating activities in various industrial sectors

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs

56	**Table 6:** Limit values for coating activities in various industrial sectors
	1/ Wood coating
	Solvent consumption 15 to 25 Mg/year: ELVc = 100 mg C/m^3 (daily); ELVf = 25 wt-% or less of the solvent input (yearly). Or total ELV of 1.6 kg or less of VOC/kg of solid input (yearly)
	Solvent consumption 25 to 200 Mg/year: ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating; ELVf = 20 wt-% or less of the solvent input (yearly). Or total ELV of 1 kg or less of VOC/kg of solid input (yearly)
	Solvent consumption > 200 Mg/year: ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating; ELVf = 15 wt-% or less of the solvent input (yearly). Or total ELV of 0.75 kg or less of VOC/kg of solid input (yearly)
	2/ Coating of metal and plastics
	Solvent consumption 5 Mg/year–15 Mg/year: ELVc = 100 mg C/m^3 (daily); ELVf = 25 wt-% or less of the solvent input (yearly). Or total ELV of
		Upgraded current abatement techniques are available [4][5]
		Update index 3 for plants with solvent consumption ≤ 200 tons.
		Update Index 1
		Update of limit values for plants with solvent consumption > 200 tons.
			Reduction of VOC emissions is based on a series of BAT related to raw materials (such as high solids coatings, varnishes…) and their optimal uses (reduced consumption through adequate application techniques…), minimising the use of solvent based cleaning agents, the reduction of fugitive emissions by applying principles of good housekeeping, use of secondary flue gas reduction techniques [4][5]
			The associated monitoring for total VOC emissions and fugitive emissions is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant, [5].
			For VOC emissions in waste gases BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to
				For (a) maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans: only applicable to central thermal off-gas treatment systems in batch processes such as printing.
				For (b) internal concentration of solvents in the waste gases: the applicability may be limited by health and safety factors such as the LEL, and product quality requirements.
				For (c) external concentration of solvents in the waste gases through
					1/ Coating of wooden surfaces (solvent consumption >200 Mg/year) [5]
					Total VOC emissions for flat substrates < 0.1 kg VOCs per kg of solid mass input (yearly average);
					Total VOC emissions for other than flat substrates < 0.25 kg VOCs per kg of solid mass input (yearly average)
					Or fugitive VOC emissions < 10% of the solvent input (yearly average), and VOC emissions in waste gases = 5-20 mg C/Nm^3 (daily average or average over the sampling period). For plants using adsorption techniques in combination with a waste gas treatment technique, an additional ELV of less than 50 mg C/Nm^3 applies to the waste

	0.60 kg or less of VOC/kg of solid input (yearly) 3/ Other coating, including textile, fabric film and paper (excluding web screen printing for textiles, see printing) *Solvent consumption 5 Mg/year–15 Mg/year*: ELVc = 100 mg C/m^3 (daily); ELVf = 25 wt-% or less of the solvent input (yearly). Or total ELV of 1.6 kg or less of VOC/kg of solid input (yearly) *Solvent consumption > 15 Mg/year:* ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating; ELVf = 20 wt-% or less of the solvent input (yearly). Or total ELV of 1.0 kg or less of VOC/kg of solid input (yearly) 4/ Coating of plastic workpieces *Solvent consumption 15 to 200 Mg/year:* ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating; ELVf = 20b wt-% or less of the solvent input (yearly). Or total ELV of 0.375 kg or less of VOC/kg of solid input (yearly) *Solvent consumption > 200 Mg/year):* ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating; ELVf = 20b wt-% or less of the solvent input (yearly). Or total ELV of 0.35 kg or less of VOC/kg of solid input (yearly) 5/ Coating of metal surfaces *Solvent consumption 15-200 Mg/year*: ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating ELVf = 20 wt-% or less of the solvent input (yearly). Or total ELV of 0.375 kg or less of VOC/kg of solid input (yearly). Exception for coatings in contact with food: Total ELV of 0.5825 kg or less of VOC/kg of solid input (yearly) *Solvent consumption >200 Mg/year*: ELVc = 50 mg C/m^3 (daily) for drying and 75 mg C/m^3 (daily) for coating ELVf = 20 wt-% or less of the solvent input (yearly). Or total ELV of 0.33 kg or less of VOC/kg of solid input (yearly). Exception for coatings in contact with food: Total ELV of 0.5825 kg or less of VOC/kg of solid input (yearly)		use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality) [5] In order to reduce the energy consumption of the VOC abatement system, BAT is to use one or a combination of the following techniques: (a) maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans; (b) internal concentration of solvents in the waste gases; (c) external concentration of solvents in the waste gases through adsorption; (d) plenum technique to reduce waste gas volume [4][5].	adsorption: the applicability may be restricted where the energy demand is excessive due to the low VOC content. For (d) plenum technique to reduce waste gas volume: generally applicable.	gas of the concentrator. 4/ Coating of other metal and plastic surfaces (solvent consumption >200 Mg/year) [5] Coating of plastic surfaces Total VOC emissions < 0.05-0.3 kg VOCs per kg of solid mass input (yearly average). Or fugitive VOC emissions < 1-10 % of the solvent input (yearly average) and VOC emissions in waste gases = 1-20 mg C/Nm^3 (daily average or average over the sampling period). The upper value of the range is 35 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent. 5/ Coating of metal surfaces Total VOC emissions < 0.05-0.2 kg VOCs per kg of solid mass input. Or fugitive VOC emissions < 1-10 % of the solvent input and VOC emissions in waste gases = 1-20 mg C/Nm^3. The upper value of the range is 35 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 49: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating of wooden surfaces [5]

Parameter	Coated substrates	Unit	BAT AELs – Yearly average
Total VOC emissions as calculated by the solvent mass balance	Flat substrates	kg VOCs per kg of solid mass input	< 0.1
	Other than flat substrates		< 0.25

Or,

Table 50: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating of wooden surfaces [5]

Parameter	Unit	BAT AELs – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 10

And

Table 51: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating of wooden surfaces [5]

Parameter	Unit	BAT AELs – Daily average
TVOC	mg C/Nm^3	5-20*

*For plants using techniques allowing the reuse/recycling of the recovered solvent, BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

Table 52: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating of plastic and metal surfaces [5]

Parameter	Coated substrates	Unit	BAT AELs – Yearly average
Total VOC emissions as calculated by the solvent mass balance	Coating of metal surfaces	kg VOCs per kg of solid mass input	< 0.05–0.2
	Coating of plastic surfaces		< 0.05–0.3

Or

Table 53: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating of plastic and metal surfaces [5]

Parameter	Unit	BAT AEL – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 10

And

Table 54: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating of plastic and metal surfaces [5]

Parameter	Unit	BAT AELs – Daily average	
		With no reuse/recycling	With techniques allowing the reuse/recycling of the recovered solvent
TVOC	mg C/Nm^3	1-20*	1-35*

*For plants using techniques allowing the reuse/recycling of the recovered solvent, BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

5.6.2. Leather coating

The proposals for update of limit values are as in the following. They are characterised as update index 1:

Table 55: Table 7, annex VI, Proposal of potential updates in ELVs for VOC emissions from leather coating

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
57	**Table 7:** Limit values for leather and winding wire coating 1/ Leather coating in furnishing and particular leather goods used as small consumer goods like bags, belts, wallets, etc. (solvent consumption > 10 Mg/year): Total ELV of 150 g/m² (yearly) 2/ Other leather coating (solvent consumption 10 Mg/year–25 Mg/year): Total ELV of 85 g/m² (yearly) 3/ Other leather coating (solvent consumption > 25 Mg/year): Total ELV of 75 g/m² (yearly)	Upgraded current abatement techniques are available [6][7] **Update Index 1**	In order to reduce the airborne emissions of halogenated volatile organic compounds, BAT is to replace halogenated volatile organic compounds used in the process with substances that are not halogenated [6][7] In order to reduce airborne emissions of volatile organic compounds (VOC) from finishing, BAT is to use one or a combination of the techniques given below, priority being given to the first one: (a) The use of water-borne coatings in combination with an efficient application system; (b) The use of extraction ventilation and an abatement system [6][7]	Applicability: does not apply to the dry degreasing of sheepskins carried out in closed cycle machines	Leather coating [7] Where water-borne coatings are used in combination with an efficient application system: Upholstery and automotive leather: VOC emissions = 10-25 g C/m². Footwear, garment, and leather goods leathers: VOC emissions = 40-85 g C/m². Coated leathers (coating thickness > 0,15 mm): VOC emissions = 115-150 g C/m². Where an extraction ventilation and abatement system is used as an alternative to the use of water-borne finishing materials whatever the consumption is VOC emissions = 9-23 g C/m².

According to the BREF tanning of hides and skins [6], the main source of organic solvent emissions in tanneries is the coating process with the use of solvent-based lacquers. The consumption of organic solvents can be reduced by the introduction of water-borne coating materials, as well as modern methods of application, such as improved spraying techniques and roller coating. Tanneries employing solvent-based degreasing processes for sheepskins also have organic solvent emissions requiring special abatement.

Organic solvents are also used in the following steps: degreasing in the tanyard operations, dyeing in the splitting and post tanning step.

Chlorinated organic compounds may be released in the following processes: soaking, degreasing, dyeing, fat liquoring and finishing. Tetrachloroethene, chlorobenzene and hexachlorobenzene are examples of halogenated organic solvents used in degreasing sheepskins and pigskins [6].

Furthermore, abatement techniques such as activated carbon filters are feasible, but their use is not standard practise in tanneries. Fugitive emissions may be a major part of the total VOC emissions.

The proposed limit values for plants are based on the BAT AELs provided by Decision tanning of hides and skins [7] which are as in the following:

Table 56: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the leather coating [7]

Type of process	Type of products	BAT AEL in g VOC/m² (annual average values per unit of finished leather)
Where water-borne coatings are used in combination with an efficient application	Upholstery and automotive leather	10-25
	Footwear, garment, and leather goods	40-85
	Coated leathers (coating thickness > 0,15 mm)	115-150
Where an extraction ventilation and abatement system are used as an alternative to the use of water-borne finishing materials	All	9-23 (g eq. C/m²)

5.6.3. Winding wire coating

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 57: Table 7, annex VI, proposal ofupdate of limit values for VOC emissions from winding wire coating

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
57	**Table 7:** Limit values for leather and winding wire coating Winding wire coating (solvent consumption > 5 Mg/year): Total ELV of 10 g/kg (yearly) applies for installations where average diameter of wire ≤ 0.1 mm Total ELV of 5 g/kg (yearly) applies for all other installations	Upgraded current abatement techniques are available [4][5] **Update index 3** for plants with solvent consumption ≤ 200 tons. **Update Index 1** Update of limit values for plants with solvent consumption > 200 tons.	Reduction of VOC emissions is based on a series of BAT related to raw materials (such as high solids coatings, varnishes…) and their optimal uses (reduced consumption through adequate application techniques…), minimising the use of solvent based cleaning agents, the reduction of fugitive emissions by applying principles of good housekeeping, use of secondary flue gas reduction techniques [4][5] The associated monitoring for total VOC emissions and fugitive emissions is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant [5]. For VOC emissions in waste gases BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality) [5].		Manufacture of winding wire (solvent consumption >200 Mg/year) [5]. Total emissions of VOCs for coating of winding wire with an average diameter greater than 0.1 mm, total ELV = 1-3.3 g VOCs per kg of coated wire. VOC emissions in waste gases from the manufacture of winding wire = 5-40 mg C/Nm^3

According to the STS decision [5], BAT are one of the following techniques or a combination of them: process-integrated VOC oxidation, solvent free lubricants, self-lubricant coatings and high solid enamels.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 58: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from winding wire coating [5]

Parameter	Product type	Unit	BAT AELs – yearly average
Total VOC emissions as calculated by the solvent mass balance	Coating of winding wire with an average diameter greater than 0,1 mm	g VOCs per kg of coated wire	1-3.3

And

Table 59: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the manufacture of winding wire [5]

Parameter	Unit	BAT AEL – Daily average
TVOC	mg C/Nm^3	5-40

5.7. Limit values for VOC emissions released from coil coating

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 60: Table 8, annex VI, Proposal of potential updates in ELVs for VOC emisisons from coil coating

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs

57/58	**Table 8:** Limit values for coil coating
	Existing installations
	Solvent consumption > 25 Mg/year: ELVc = 50 mg C/m^3 ELVf = 10 wt-% or less of the solvent input. Or total ELV of 0.45 kg or less of VOC/kg of solid input. If techniques are used which allow reuse of recovered solvent, the limit value shall be 150 mg C/m^3.
	New installations
	Solvent consumption > 25 Mg/year:
	ELVc = 50 mg C/m^3 (daily); If techniques are used which allow reuse of recovered solvent, the limit value shall be 150 mg C/m^3. ELVf = 5 wt-% or less of the solvent input (yearly). Or total ELV of 0.3 kg or less of VOC/kg of solid input (yearly).
		Upgraded current abatement techniques are available [4][5]
		Update index 3 for plants with solvent consumption ≤ 200 tons.
		Update Index 1
		Update of limit values for plants with solvent consumption > 200 tons
			Reduction of VOC emissions is based on a series of BAT related to raw materials (such as high solids coatings, varnishes…) and their optimal uses (reduced consumption through adequate application techniques…), minimising the use of solvent based cleaning agents, the reduction of fugitive emissions by applying principles of good housekeeping, use of secondary flue gas reduction techniques [4][5].
			The associated monitoring for total VOC emissions and fugitive emissions is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant, [5]
			For VOC emissions in waste gases BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality) [5].
			In order to reduce the energy consumption of the VOC abatement system, BAT is to use one or a combination of the following techniques: (a) maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans; (b) internal concentration of solvents in
				For (a) maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans: only applicable to central thermal off-gas treatment systems in batch processes such as printing.
				For (b) internal concentration of solvents in the waste gases: the applicability may be limited by health and safety factors such as the LEL, and product quality requirements.
				For (c) external concentration of solvents in the waste gases through adsorption: the applicability may be restricted where the energy demand is excessive due to the low VOC content.
				For (d) plenum technique to reduce waste gas volume: generally applicable.
					Coil coating
					Solvent consumption >200 Mg/year [5]:
					Fugitive emissions of VOCs < 1-3% of the solvent input (yearly average).
					VOC emissions in waste gases = 1-20 mg C/Nm^3 (daily) (The upper end is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.

Pag.	**Reference and Update Index**	**Potential update**	**Description**	**Potential Applicability (%)**	**Potential ELVs**
			the waste gases; (c) external concentration of solvents in the waste gases through adsorption; (d) plenum technique to reduce waste gas volume [5]		

According to the STS BREF, solvent-based coatings are the dominant systems used throughout the industry and the TVOC levels from unabated release points can vary and at times may be > 50 mg/m^3 due to intermittent localised activities within the coater house such as line cleaning and tray cleaning. Industry-wide clean gas TVOC concentrations are in general below 20 mg C/Nm^3.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 61: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from coil coating [5]

Parameter	Unit	BAT AEL – yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1-3

And

Table 62: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from coil coating [5]

Parameter	Unit	BAT AEL – Daily average	
		With no reuse/recycling	With techniques allowing the reuse/recycling of the recovered solvent
TVOC	mg C/Nm^3	1-20*	1-50*

*For plants using an off-gas treatment technique, an additional ELV of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

5.8. Limit values for VOC emissions released from dry cleaning

The proposals for update of limit values are as in the following. They are characterised as update index 1:

Table 63: Table 9, annex VI, Proposal of potential updates in emission limit values for VOC emisisons from dry cleaning

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
58	**Table 9:** Limit value for dry cleaning Total ELV of 20 g VOC/kg (yearly)	**Update Index 1**	Perchloroethylene is the most common solvent used for dry cleaning. It is “suspected of causing cancer” There are alternatives to the use of this solvent but the potential for these alternatives to harm human health and the environment is not well-understood yet [29]	Almost 100% for the ELV. Many of the alternative solvents are relatively new products with no established occupational exposure limits.	Dry cleaning Total ELV < 10 g VOC/kg cleaned garment (yearly) Possible phase out of perchloroethylene

Perchloroethylene (PER) was one of the most used solvents in dry cleaning machines. It is a halogenated solvent which is classified as a CMR substance (C2: suspected of being a CMR substance) according to [68]. Dry cleaning is covered by chapter V and annex VII of the European IED [64], as well as several national regulations.

In many countries, the use of PER is declining and even more, forbidden in dry cleaning applications. As examples, in Norway, the sales of new machines using perchloroethylene is forbidden since 2005 and for the existing ones, a tax on the use of the product has been implemented [65].

In the USA, California proceeds to removal of machines using perchloroethylene. Since 2008, new installations using perchloroethylene are forbidden. California is committed to remove the existing installations by 2023 [65]. Furthermore, the city of Minneapolis banned the use of PER and became the first PER-free city in the USA in January 2018 [29].

France implemented a specific national regulation [66] that entered into force on 1st March 2013 and intends to progressively phase out machines using PER in residential areas by 2022. All machines located in workplaces adjacent to inhabited buildings must be phased out by the 1st of January 2022.

Wet-based cleaning is one of the alternatives to perchloroethylene. The other alternatives are based on the use of other solvents [29]:

- n-Propyl Bromide which is a brominated hydrocarbon, and considered by reference [29], as a regrettable substitution,
- Solvon K4 or dibutoxymethane, or Butylal, which is an oxygenated hydrocarbon,
- Decamethylcylclopentasiloxane (called D5),
- Glycol ethers: dipropylene glycol tert-butyl ethers (DPTB), dipropylene glycol, n-butyl ether (DPNB), and propylene glycol t-butyl ether (PGtBE),
- High-flashpoint hydrocarbons which are petroleum-based solvents and have relatively high flammability and volatility,
- Liquid carbon dioxide which is a technology that combines carbon dioxide with specialised detergents under high pressure.

Other alternative solvents are identified:

- Hi-Glo, which is a solvent mixture based on an oxygenated hydrocarbon,
- KTEX, which is a combination of hydrocarbons associated with a glycol ether.

According to reference [29], some of these alternatives have been promoted as safe and environmentally friendly, although their effects on human health and the environment may have not been well characterized. Many of the alternative solvents are relatively new products with no established occupational exposure limits (e.g., glycol ethers and Solvon K4). Unfortunately, the search for dry cleaning solvents has resulted in regrettable substitutions, such as the use of n-PB.

According to reference [29], dry cleaning machines have evolved through several "generations" to minimize PER release. The 1st generation machines were "transfer machines," where cleaned fabrics were manually transferred from the washer to a dryer. Since then, various pollution prevention controls have been implemented through the subsequent generations, culminating in the latest 5th generation machines, which are closed-loop and equipped with refrigerated condensers, carbon absorbers, inductive fans, and sensor-actuated lockout devices.

According to the current situation and efficiency of newest machines (5th generation) [29], the potential limit value could be as in the following:

Table 64: Proposal for update of ELV for emissions VOC from dry cleaning

Total potential ELV - yearly average (in g VOC/kg cleaned garment) from [29]
< 10

This value is reached by newest generation machines with activated carbon purifier still using perchloroethylene, according to the French VOC emission inventory [113].

Moreover, the complete phase out of perchloroethylene in dry cleaning application could be envisaged in the future.

5.9. Limit values for VOC emissions released from manufacturing of coatings, varnishes and adhesives

The proposals for update of limit values are as in the following. They are characterised as update index 2. The proposal of potential updates of limit values is based on the BAT AELs defined by the draft final Best Available Techniques (BAT) Reference Document for Common Waste Gas Management and Treatment Systems in the Chemical Sector [28]:

Table 65: Table 10, annex VI, Proposal of potential updates in limit values for VOC emissions from manufacturing of coatings, varnishes and adhesives

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
58	**Table 10:** Limit values from manufacturing of coatings, varnishes, inks and adhesives *New and existing installations* with solvent consumption between 100 Mg/year–1,000 Mg/year: ELVc = 150 mg C/m^3, ELVf = 5 wt% or less of the solvent input. Or total ELV of 5 wt% or less of the solvent input. *New and existing installations* with solvent consumption > 1,000 Mg/year: ELVc = 150 mg C/m^3, ELVf = 3 wt % or less of the solvent input. Or total ELV of 3 wt % or less of the solvent input.	**Update Index 2** Possibly ELVs could be updated based of the BREF WGC [28].			Stack emissions from [28]: <1 to 20 mg C/m^3 and to 30 when using techniques to recover solvents. Diffuse emissions from [28]: 3% to 5% as percentage of the solvent inputs (yearly average) for existing and new plants with solvent consumption larger than 100 Mg/year

5.10. Limit values for VOC emissions released from printing activities

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 66: Table 11, annex VI, prposal of update of ELV for VOC emissions from printing activities

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
58/59/60	1/ Heat-set offset Solvent consumption 15 – 25 Mg/year: *New and existing presses*: ELVc = 150 mg C/m^3, ELVf = 30 wt % or less of the solvent input. Solvent consumption 25 – 200 Mg/year: *New and existing presses*: ELVc = 20 mg C/m^3, ELVf = 30 wt % or less of the solvent input. Solvent consumption > 200 Mg/year): *New and upgraded presses*: Total ELV = 10 wt-% or less of the ink consumption (yearly). *Existing presses:* Total ELV = 15 wt-% or less of the ink consumption (yearly). 2/ Publication gravure Solvent consumption 25-200 Mg/year: *New installations*: ELVc = 75 mg C/m^3 ELVf = 10 wt-% or less of the solvent input *Or* total ELV of 0.6 kg or less of VOC/kg of solid input *(yearly)* *Existing installations:* ELVc = 75 mg C/m^3 ELVf = 15 wt-% or less of the solvent input *Or* total ELV of 0.8 kg or less of VOC/kg of solid input *(yearly)* Solvent consumption > 200 Mg/year: *New installations*: Total ELV = 5 wt-% or less of the solvent input (yearly). *Existing installations:* Total ELV = 7 wt-% or less of the solvent input (yearly)		VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant [5]. For VOC emissions in waste gases BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality) [5]. In order to reduce the energy consumption of the VOC abatement system, BAT is to use one or a combination of the following techniques: (a) maintaining the VOC concentration sent to the waste gas treatment system by using variable-frequency drive fans; (b) internal concentration of solvents in the waste gases; (c) external concentration of solvents in the waste gases through adsorption; (d) plenum technique to reduce waste gas volume [5].		1/Heatset web offset printing Solvent consumption >200 Mg/year [5]: Total VOCs emissions from < 0.01-0.04 kg VOCs per kg of ink input (yearly average). Or fugitive emissions of VOCs < 1-10% of the solvent input (yearly average) and, VOC emissions in waste gases = 1-15 mg C/Nm^3 (daily average or average over the sampling period) 2/ Publication rotogravure printing Solvent consumption >200 Mg/year [5]: Fugitive emissions of VOCs from < 2.5% of the solvent input (yearly average). VOC emissions in waste gases between 10-20 mg C/Nm^3 (daily average or average over the sampling period). 3/ Non-publication rotogravure printing Solvent consumption >200 Mg/year [5]: Total emissions of VOCs < 0.1-0.3 kg VOCs per kg of solid mass input (yearly average). Or fugitive emissions of VOCs from flexography and non-publication rotogravure printing < 1-12% of the solvent input (yearly average) and, VOC emissions in waste gases 1-20 mg C/Nm^3 (daily average or average over the sampling period). The upper value of the range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	3/ Packaging rotogravure and flexography Solvent consumption 15-25 Mg/year: *New and existing installations*: ELVc = 100 mg C/m^3 ELVf = 25 wt-% or less of the solvent input *Or* total ELV of 1.2 kg or less of VOC/kg of solid input *(yearly)* Solvent consumption 25-200 Mg/year: *New and existing installations*: ELVc = 100 mg C/m^3 ELVf = 20 wt-% or less of the solvent input *Or* total ELV of 1.0 kg or less of VOC/kg of solid input *(yearly)* Solvent consumption > 200 Mg/year: *For plants with all machines connected to oxidation*: Total ELV = 0.5 kg VOC/kg of solid input (yearly) - *For plants with all machines connected to carbon adsorption*: Total ELV = 0.6 kg VOC/kg of solid input (yearly) - *For existing mixed plants where some existing machines may not be attached to an incinerator or solvent recovery*: Emissions from the machines connected to oxidizers or carbon adsorption are below the emission limits of 0.5 or 0.6 kg VOC/kg of solid input respectively. - *For machines not connected to gas treatment*: use of low solvent or solvent free products, connection to waste gas treatment when there is spare capacity and preferentially run high solvent content work on machines connected to waste gas treatment. Total emissions below 1.0 kg VOC/kg of solid input (yearly).				

5.10.1. Heatset web offset printing

According to the STS BREF [4], all installations use thermal off-gas treatment techniques which is the general rule in the sector due to the offensive smell of waste gases. Most installations in this sector apply integrated dryer-oxidisers at each press specifically designed for heatset web offset printing.

Techniques specifically used in heatset web offset to reduce VOC emissions are [4]:

- low-IPA (isopropanol) or IPA-free additives for dampening solutions.
- use of waterless offset plates.
- automatic cleaning systems for blanket cylinders, capture and routing of solvent emissions from cleaning to the off-gas treatment system.
- web offset dryer integrated with thermal off-gas treatment.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 67: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from heatset web offset printing [5]

Parameter	Unit	BAT-AEL – yearly average
Total VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of ink input	$< 0.01\text{-}0.04^{(1)}$ (1) The upper end of the BAT-AEL range is related to the production of high-quality products.

Or

Table 68: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from heatset web offset printing [5]

Parameter	Unit	BAT AEL – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	$< 1\text{-}10^{(1)}$ (1) The upper end of the BAT-AEL range is related to the production of high-quality products.

And

Table 69: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from heatset web offset printing [5]

Parameter	Unit	Potential ELV – Daily average
TVOC	mg C/Nm^3	1-15

5.10.2. Publication rotogravure printing

According to the STS BREF [4], all publication rotogravure printing plants nowadays have toluene recovery installations. In spite of the toluene recovery, part of the toluene input is still emitted. The main sources of VOC emissions are:

- the printing process and its cleaning operations,
- the solvent recovery system,
- the printed product.

In order to minimise toluene emissions to air, various techniques have been identified:

- direct piping of inks,

- closed-loop distiller system at the toluene recovery for recovering the toluene residue from decanted water,
- use of retention inks,
- connection to the toluene recovery system of all potential toluene-emitting activities/processes: print units, toluene washing machines, dryers, press room air at units.

According to the STS BREF [4], total emissions of VOCs as a percentage of the solvent input are below 3 % in all cases and close to or lower than 1 % when non-solvent-based cleaning agents are used.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 70: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from publication rotogravure printing [5]

Parameter	Unit	BAT AEL – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 2.5

And

Table 71: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from publication rotogravure printing [5]

Parameter	Unit	Potential ELV – Daily average
TVOC	mg C/Nm^3	10-20

5.10.3. Flexography and non-publication rotogravure printing

According to the STS BREF [4], almost all of the reported values for fugitive emissions of VOCs are below the IED limit value of 20 % of the solvent input and more than the half of reported values are below 10 % of the solvent input.

The main reported techniques for the minimisation of fugitive emissions are:

- safe storage of hazardous substances and measures to prevent unplanned releases.
- handling and use of hazardous materials.
- air extraction from drying processes.
- enclosed application zones with air extraction.
- hall ventilation partly used as dryer input, treated in RTO.
- air recirculation in dryers.
- overpressure management with installed waste air pipes to minimise leakages caused by overpressure.
- ink management techniques that include an automatic ink mixing system and management of ink residues.
- automatic hardener dosing using enclosed piping system (two-component systems).
- air extraction from washing machines, adhesive mixing and ink mixing area.

- automatic parts cleaning machine (solvent-based, connected to ‘smoothener’ and common waste gas extraction for treatment in a RTO).
- solvent-free adhesives (hot melts).
- ultrasonic cleaning machine for anilox rollers.

The proposed limit values for plants consuming more than 200 t solvent per year are based on the BAT AELs provided by STS decision [5] which are as in the following:

Table 72: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from flexography and non-publication rotogravure printing [5]

Parameter	Unit	BAT AEL – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of solid mass input	< 0.1-0.3

Or

Table 73: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from flexography and non-publication rotogravure printing [5]

Parameter	Unit	BAT AEL – Yearly average
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1-12

And

Table 74: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from flexography and non- publication rotogravure printing [5]

Parameter	Unit	BAT AEL – Daily average	
		With no reuse/recycling	With techniques allowing the reuse/recycling of the recovered solvent
TVOC	mg C/Nm^3	1-20*	1-50*

*For plants using an off-gas treatment technique, an additional ELV of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator

5.11. Limit values for VOC emissions released from manufacturing of pharmaceutical products

The proposals for update of limit values are as in the following. They are characterised as update index 1:

Table 75: Table 12, annex VI, Proposal of potential updates in ELVs for VOC emissions from manufacturing of pharmaceutical products

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
60	**Table 12:** Limit values for manufacturing of pharmaceutical products *New installations* Solvent consumption > 50 Mg/year: ELVc = 20 mg C/m^3 (a,b) and ELVf = 5 wt-% or less of the solvent input (b) *Existing installations* Solvent consumption > 50 Mg/year): ELVc = 20 mg C/m^3 (a,c) and ELVf = 15 wt-% or less of the solvent input (c). (a) If techniques are used which allow reuse of recovered solvents, the limit value shall be 150 mg C/m^3 (b) A total limit value of 5% of solvent input may be applied instead of applying ELVc and ELVf (c) A total limit value of 15% of solvent input may be applied instead of applying ELVc and ELVf.	**Update Index 1** Update of limit values	One or a combination of techniques can be applied as a recovery/abatement system for a whole site, an individual production building, or an individual process. This depends on the particular situation and affects the number of point sources. BAT is to select VOC recovery and abatement techniques according to an in depth assessment of possible use of techniques [28]. According to Reference [28], BAT is to incorporate the following features: - Implementation of an inventory of channelled and diffuse emissions to air, maintenance of such an inventory and regular review, as part of the environmental system, - Reduce the frequency of other than normal operating conditions (OTNO), development of a management plan for emissions to air - An integrated waste gas management and treatment strategy for channelled emissions based on the combination of waste gas streams with similar characteristics, limit thus optimise minimising the number of emission points and the correct design and maintenance of abatement systems (considering the maximum flow rate and concentrations) to ensure optimal availability, effectiveness and efficiency of the equipment.	Almost 100%	Stack emissions from [28]: <1 to 20 mg C/m^3 and to 30 when using techniques to recover solvents. The limit ranges only apply to the extent that they lead to lower emission levels than the current emission VOC limit values and limit values for VOC classified as CMR 1A, 2A and 2 Diffuse emissions from [28]: ≤ 5% as percentage of the solvent inputs (yearly average) if the solvent consumption is larger than 50 t/year

The proposed limit values for plants consuming more than 50 t solvent per year are based on the BAT AELs provided by draft BREF WGC [28], which are as in the following:

Table 76: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from manufacturing of pharmaceutical products [28]

BAT AEL (in mg C/m^3) – Daily average or average over the sampling method
< 1 to 20 The upper end of the BAT-AEL range may be higher and up to 30 mg C/Nm^3 when using techniques to recover solvents

As mentioned above the limit ranges only apply to the extent that they lead to lower emission levels than the current emission VOC limit values and limit values for VOC classified as CMR 1A, 2A and 2.

The new draft of BREF WGC [28] provides BAT AELs for fugitive emissions as in the following for plants whose total annual solvent consumption is larger than 50t/year:

Table 77: BAT-associated emission level (BAT-AEL) for diffuse VOC emissions to air from the use of solvents or the reuse of recovered solvents [28]

BAT AEL as percentage of the solvent inputs (yearly average)
≤ 5%

5.12. Limit values for VOC emissions released from conversion of natural or synthetic rubber

The proposals for update of limit values are as in the following. They are characterised as update index 3 for plants as no relevant pieces of information has been found.

Table 78: Table 13, annex VI, Proposal of potential updates in limit values for VOC emissions from conversion of natural or synthetic rubber

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
61	**Table 13:** Limit value for conversion of natural or synthetic rubber New and existing installations: conversion of natural or synthetic rubber (solvent consumption > 15 Mg/year): ELVc = 20 mg C/m^3 and ELVF = 25wt-% of the solvent input. Or total ELV = 25 wt-% of solvent input. If techniques are used which allow reuse of recovered solvent, the limit value shall be 150 mg C/m^3. The fugitive limit does not include solvents sold as part of a preparation in a sealed container.	**Update Index 3** No identified literature results identified.			

5.13. Limit values for VOC emissions released from surface cleaning

The proposals for update of limit values are as in the following. They are characterised as update index 3 for plants as not enough relevant pieces of information has been found:

Table 79: Table 14, annex VI, Proposal of potential updates in limit values for VOC emissions from surface cleaning

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
61	**Table 14:** Limit values for surface cleaning Surface cleaning using substances mentioned in paragraph 3 (z) (i) of annex VII: - Solvent consumption between 1-5 Mg/year: ELVc = 20 mg expressed as the mass sum of individual compounds/m^3. ELVf = 15 wt-% of solvent input. - Solvent consumption > 5 Mg/year: ELVc = 20 mg	**Update Index 3** No update identified	In order to reduce VOC emissions from cleaning processes, BAT is to minimise the use of solvent-based cleaning agents and to use a combination of the techniques given below [4]: (a) Protection of spraying areas and equipment: Application areas and equipment (e.g. spray booth walls and robots) susceptible to overspray and drips, etc. are covered with fabric covers or disposable foils	The selection of cleaning techniques may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.	

Pa g.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	expressed as the mass sum of individual compounds/m^3. ELVf = 10 wt-% of solvent input Other surface cleaning: - Solvent consumption between 2-10 Mg/year: ELVc = 75 mg C/m^3. ELVf = 20 wt-% of solvent input. - Solvent consumption > 10 Mg/year: ELVc = 75 mg C/m^3. ELVf = 15 wt-% of solvent input.		where foils are not subject to tearing or wear. (b) Solids removal prior to complete cleaning: Solids are removed in a (dry) concentrated form, usually by hand, with or without the aid of small amounts of cleaning solvent. This reduces the amount of material to be removed by solvent and/or water in subsequent cleaning stages, and therefore the amount of solvent and/or water used. (c) Manual cleaning with pre-impregnated wipes: Wipes pre-impregnated with cleaning agents are used for manual cleaning. Cleaning agents may be solvent-based, low-volatility solvents or solvent- free. (d) Use of low-volatility cleaning agents: Application of low-volatility solvents as cleaning agents, for manual or automated cleaning, with high cleaning power. (e) Water-based cleaning: Water-based detergents or water-miscible solvents such as alcohols or glycols are used for cleaning. (f) Enclosed washing machines: Automatic batch cleaning/degreasing of press/machine parts in enclosed washing machines. This can be done using either: (a) organic solvents (with air extraction followed by VOC abatement and/or recovery of the used solvents); or (b) VOC-free solvents; or (c) alkaline cleaners (with external or internal waste water treatment). (g) Purging with solvent recovery: Collection, storage and, if possible, reuse of the solvents used to purge the guns/applicators and lines between colour changes.		

5.14. Limit values for VOC emissions released from extraction of vegetable and animal fat and refining of vegetable oils

The proposals for update of limit values are as in the following. They are characterised as update index 1:

Table 80: Table 15, annex VI, Proposal of potential updates in ELVs for VOC emissions from extraction of vegetable and animal fat and refining of vegetable oil

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
61/62	**Table 15:** Limit values for extraction of vegetable and animal fat and refining of vegetable oil New and existing installations (solvent consumption > 10 Mg/year): - Animal fat: ELV = 1.5 kg VOC/Mg product - Castor: ELV = 3 kg VOC/Mg product - Rape seed: ELV = 1 kg VOC/Mg product - Sunflower seed: ELV = 1 kg VOC/Mg product - Soya beans (normal crush): ELV = 0.8 kg VOC/Mg product - Soya beans (white flakes): ELV = 1.2 kg VOC/Mg product - Other seeds and vegetable material: ELV = 3 kg VOC/Mg product - All fractionation processes, excluding degumming: ELV = 1.5 kg VOC/Mg product - Degumming: ELV = 4 kg VOC/Mg product	**Update Index 1** for Soya beans, rape seeds and sunflower seeds (no size threshold is provided in [27]) **Update Index 3** for other products	BAT are as in the following [72] - Counter current flow of meal and steam in the desolventiser-toaster - Vaporization from the oil/hexane mixture - Condensation in combination with a mineral oil wet scrubber - Gravitational phase separation in combination with distillation	Almost 100%	According to [72] as yearly average values: Soybeans: 0.3 to 0.55 kg VOC (hexane)/t seeds processed Rape seeds and sunflower seeds: 0.2 to 0.7 kg VOC (hexane)/t seeds processed

According to the BREF Food, Drink, Milk [72], the majority (typically > 90 %) of TVOC emissions to air consist of hexane. Hexane emissions are typically reduced by hexane recovery techniques. biofilters, bio scrubbers and wet scrubbers followed by condensation are typically used with the intention of reducing odour emissions. BAT [27] are the use of all the following techniques: counter current flow of meal and steam in the desolventiser-toaster, evaporation from the oil/ hexane mixture, condensation in combination with a mineral oil wet scrubber, gravitational phase separation in combination with distillation.

The proposed limit values for plants with the current solvent consumption levels per year are based on the BAT AELs provided by the decision food, drink and milk [27], which are as in the following:

Table 81: BAT-associated emission levels (BAT-AELs) for hexane losses from oilseed processing and refining [27]

Parameter	Type of seeds or beans processed	Unit	BAT AEL – Yearly average
Hexane losses	Soybeans	kg/tonne of seeds or beans processed	0.3-0.55
	Rapeseeds and sunflower seeds		0.2-0.7

5.15. Limit values for VOC emissions released from impregnation of wood

The proposals for update of limit values are as in the following. They are characterised as update index 1 for plants consuming more than 200 t of solvent per year:

Table 82: Table 16, annex VI, Proposal of potential updates in ELVs for VOC emissions from impregnation of wood

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
62	**Table 16:** limit values for impregnation of wood Wood impregnation Solvent consumption 25 to 200 Mg/year: ELVc = 100 mg C/m^3 (not applicable to impregnation with creosote). ELVf = 45 wt-% or less of solvent input or 11 kg or less of VOC/ m^3 Wood impregnation (solvent consumption > 200 Mg/year) ELVc = 100 mg C/m^3 (not applicable to impregnation with creosote). ELVf = 35 wt-% or less of solvent input or 9 kg or less of VOC/ m^3	**Update Index 1** Update of limit values in plants with solvent consumption > 200 tons.	In order to reduce emissions of VOCs to air from wood and wood products preservation using solvent-based treatment chemicals, BAT is to enclose the emitting equipment or processes, extract the off-gases and send them to a treatment system (thermal oxidation, waste gases sent to a combustion plant, adsorption unit, absorption unit, condensation. For creosote: In order to reduce emissions of organic compounds and odour to air from wood and wood products preservation using creosote, BAT is to use low-volatility impregnating oils, i.e. Grade C creosote instead of Grade B.	Almost 100%	According to [5] Creosote and solvent based treatment: ELVc = 4 – 20 mg C/m^3

According to the STS BREF[4], the main VOC emission source in this sector is from the solvent content of the applied substances. Solvents that remain in the wood after complete drying evaporate over longer periods of time. Fugitive emissions occur during handling, application and drying stages. However, the majority of the emissions occur during the drying process.

The proposed limit values for plants with the current solvent consumption levels per year are based on the BAT AELs provided by the STS decision [5], which are as in the following:

Table 83: BAT-associated emission levels (BAT-AELs) for TVOC emissions in waste gases from wood and wood products preservation using creosote and/or solvent-based treatment chemicals [5]

Parameter	Unit	Process	BAT AEL
TVOC	mg C/Nm^3	Creosote and solventbased treatment	< 4-20

6. Annex X: limit values for emissions of PM from stationary sources

6.1. Limit values for dust emissions released from combustion plants

Table 84: Table 1, annex IV, Proposal of potential updates in ELVs for emissions of dust from combustion plants

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
83-84	**Table 1**: Limit values for dust emissions released from combustion plants				
	Coal, lignite and other solid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW:* New plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **30** mg/m^3 at 6 % O_2 [**Update Index** 1] *Combustion plant with a thermal input capacity between 100 and 300 MW:* New plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **25** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: **10** mg/m^3 at 6 % O_2 **[Update Index 2]** Existing plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - electrostatic precipitator (ESP), - baghouse filter, - boiler sorbent injection - wet flue-gas, desulphurisation (FGD), - dry or semi-dry FGD system.	Almost 100 %. Some limitations may exist for FGD if: - the plant operates less than 500 hours per year, - it is for retrofitting on existing combustion plant operating less than 1,500 hours per year, - the combustion plant is less than 300 MW$_{th}$, there may be technical and economic restrictions	**Coal, lignite and other solid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW* (as daily average) *[2][3]*: New plants: **4-16** mg/m^3 at 6 % O_2 Existing plants: **4-22** mg/m^3 at 6 % O_2 (Upper value of the range is 28 mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014) *Combustion plant with a thermal input capacity between 100 and 300 MW* (as daily average) *[2][3]*: New plants: **3-15** mg/m^3 at 6 % O_2 Existing plants: **4-22** mg/m^3 at 6 % O_2 (Upper value of the range is 25 mg/m^3 at 6 % O_2 if plant put into operation no later than 7 January 2014) *Combustion plant with a thermal input capacity exceeding 300 MW* (as daily average) *[2][3]*: New plants: **3-10** mg/m^3 at 6 % O_2 Existing plants: **3-11** mg/m^3 at 6 % O_2 (Upper value of the range is 20 or 14

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
					mg/m^3 at 6 % O_2 if plant is put into operation no later than 7 January 2014 and if it is between 300-1,000 MW or if bigger than 1,000 MW, respectively)
	Solid biomass and peat: *Combustion plant with a thermal input capacity between 50 and 100 MW:* New plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **30** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity between 100 and 300 MW:* New plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** *Combustion plant with a thermal input capacity exceeding 300 MW:* New plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]** Existing plants: **20** mg/m^3 at 6 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - electrostatic precipitator (ESP), - baghouse filter, - wet flue-gas desulphurisation (FGD), - dry or semi-dry FGD system.	Almost 100 %, except wet-FGD for plants operating less than 500 hours per year. If wet FGD is meant for retrofitting on existing combustion plant operating less than 1,500 hours per year, there may be technical and economic restrictions.	**Solid biomass and peat:** *Combustion plant with a thermal input capacity between 50 and 100 MW (*as daily average*)* *[2][3]*: New plants: **2-10** mg/m^3 at 6 % O_2 Existing plants: **2-22** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity between 100 and 300 MW (*as daily average*)* *[2][3]*: New plants: **2-10** mg/m^3 at 6 % O_2 Existing plants: **2-18** mg/m^3 at 6 % O_2 *Combustion plant with a thermal input capacity exceeding 300 MW (*as daily average*)* *[2][3]*: New plants: **2-10** mg/m^3 at 6 % O_2 Existing plants: **2-16** mg/m^3 at 6 % O_2
	Liquid fuels: *Combustion plant with a thermal input capacity between 50 and 100 MW:* New plants: **20** mg/m^3 at 3 % O_2 **[Update Index 1]** Existing plants: Liquid fuels in general: **30** mg/m^3 at 3 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - electrostatic precipitator (ESP), - baghouse filter, - multicyclones, - wet flue-gas desulphurisation (FGD), - dry or semi-dry FGD system.	Almost 100 %, except wet-FGD for plants operating less than 500 hours per year. Some limitations may exist for wet FGD if: - it is for retrofitting on existing combustion plant operating less than 1,500	**Liquid fuels:** *Combustion plant with a thermal input capacity between 50 and 100 MW (*as daily average*)* *[2][3]*: New plants: **7-18** mg/m^3 at 3 % O_2 Existing plants: Liquid fuels in general: **7-22** mg/m^3 at 3 % O_2 (Upper value of the

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
				hours per year, - the combustion plant is less than 300 MW$_{th}$, there may be technical and economic restrictions.	range is 25 mg/m^3 at 6 % O$_2$ if plant is put into operation no later than 7 January 2014)
	Combustion plant with a thermal input capacity between 100 and 300 MW: New plants: **20** mg/m^3 at 3 % O$_2$ **[Update Index 1]** Existing plants: Liquid fuels in general: **25** mg/m^3 at 3 % O$_2$ **[Update Index 1]**				*Combustion plant with a thermal input capacity between 100 and 300 MW (*as daily average*) [2][3]:* New plants: **7-18** mg/m^3 at 3 % O$_2$ Existing plants: Liquid fuels in general: **7-22** mg/m^3 at 3 % O$_2$ (Upper value of the range is 25 mg/m^3 at 6 % O$_2$ if plant is put into operation no later than 7 January 2014)
	Combustion plant with a thermal input capacity exceeding 300 MW: New plant: **10** mg/m^3 at 3 % O$_2$ **[Update Index 2]** Existing plants: Liquid fuels in general: **20** mg/m^3 at 3 % O$_2$ **[Update Index 1]**				*Combustion plant with a thermal input capacity exceeding 300 MW (*as daily average*) [2][3]:* New plant: **7-10** mg/m^3 at 3 % O$_2$ Existing plants: Liquid fuels in general: **7-11** mg/m^3 at 3 % O$_2$ (Upper value of the range is 15 mg/m^3 at 6 % O$_2$ if plant is put into operation no later than 7 January 2014)
	Combustion plant with a thermal input capacity larger than 50 MW: existing plants Distillation and conversion residues from crude oil refining within refineries and chemical installations: **50** mg/m^3 at 3 % O$_2$ **[Update Index 2]**				*Combustion plant in refineries –existing plants (*as monthly average*) [37]:* Multi-fuel firing in refineries – existing plants: **5-50** mg/m^3 at 3 % O$_2$ (the upper value of the range corresponding to a high share of oil burning where only primary techniques can be applied)

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Gaseous fuels: *Combustion plant with a thermal input capacity exceeding 50 MW – New and existing plants:* Natural gas: **5** mg/m^3 at 3 % O_2 **[Update Index 3]** Other gases other than steel industry gases: **10** mg/m^3 at 3 % O_2 **[Update Index 2]** Steel industry gases: **30** mg/m^3 at 3 % O_2 **[Update Index 1]**	Upgraded current abatement techniques are available	For iron and steel process gases only *[2][3]*: The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - fuel choice/management, - electrostatic precipitator (ESP), - baghouse filter, - gas pre-treatment at the iron- and steel-works For chemical industry process gases *[2][3]*: The means to achieve the associated environmental levels is the application of one or a combination of the following techniques: - electrostatic precipitator (ESP), - baghouse filter, - wet flue-gas desulphurisation (FGD), - dry or semi-dry FGD system.	For chemical industry process gases: Wet-FGD not applicable for plants operating less than 500 hours per year. Some limitations may exist for wet FGD if: - it is for retrofitting on existing combustion plant operating less than 1,500 hours per year, - the combustion plant is less than 300 MWth, there may be technical and economic restrictions. For iron and steel process gases only: ESP and baghouse filters are only applicable if a significant amount of auxiliary fuels with a high ash content is burned together with iron steel gases.	**Gaseous fuels:** *Combustion plant with a thermal input capacity exceeding 50 MW – New and existing plants operating more than 500 hours per year [2][3] (as daily average):* Chemical industry process gases – new and existing plants: **2-10** mg/m^3 at 3 % O_2 Iron and steel industry gases: **2-10** mg/m^3 at 3 % O_2

6.1.1. Coal, lignite and other solid fuels:

For combustion plants burning coal-type solid fuels, the ELV for dust from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 85: Emission limit values of dust for coal-type solid fuels from the AGP [1], expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity

	ELV of dust for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	20	30
100-300 MW	20	25
Higher than 300 MW	10	20

In the European BAT conclusions for LCP [3], the dust BAT AEL for LCP burning coal or lignite, expressed as daily averages at 6% O_2, are as in the following:

Table 86: BAT AEL of dust for coal or lignite from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of dust for coal-type solid fuels (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	4-16	4-22[1]
100-300 MW	3-15	4-22[2]
Higher than 300 MW	3-10	3-11[3]

[1]: 4-28 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 4-25 mg/Nm^3 if put into operation no later than Jan. 2014
[3]: if put into operation no later than Jan. 2014, 3-20 mg/Nm^3 if between 300-1,000 MW and 3-14 mg/Nm^3 if > 1,000 MW

In the US regulation [32], the ELV are given per energy input or output but converting them given the approximative thermal efficiencies of the combustion plants and taking the stoichiometric dry flue-gas volumes given in the BREF document on LCP [2], the dust ELV for LCP > 73 MWth burning solid fuels range from about 11 to 18 mg/Nm^3 at 6% O_2, depending on the date of construction or modification of the plant.

In the Chinese regulation [33], the ELV of dust for all TPP burning solid fuels are of 30 mg/Nm^3 for new and existing facilities, at 6% O_2. For specific key regions which are more sensitive to atmospheric pollution and its impact, the ELV is set at 20 mg/Nm^3 for both existing and new plants [33].

One specific Chinese programme has introduced ultra-low emission standards for coal-fired TPP and the ELV for PM is of 10 mg/Nm^3 [51]. New installations must comply with it by 2015 and 80 % of the total coal-fired capacity must also comply with it by 2030.

In the Indian regulation [34], the dust ELV applied are of 50 mg/Nm^3 for coal TPP installed in the period of 2004-2016, and of 30 mg/Nm^3 for all sizes of TPP installed in 2017 or later, at 6% O_2.

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: electrostatic precipitator (ESP), baghouse filter, boiler sorbent injection, dry, semi-dry or wet FGD when there are SO_2 emission reduction technique.

Abatement efficiency of dust abatement systems can be increased. With ESP, the abatement efficiency can be increased depending on the number of fields (4 to 5 field ESPs, residence time (size). With bag filters, dimensioning, residence time, ceramic filters or sintered metal filters are among parameters used to increase efficiency.

In the literature, one study reports that the mean PM concentration achieved for the whole Chinese coal-fired TPP capacity was of 5.7 mg/Nm^3 in December 2017 (see Figure 6), following the introduction of the ultra-low emission standard programme [51]. Shutting down old and small TPP to build new and larger ones enabled to tackle PM emissions with the use of pollution control techniques such as very efficient ESP or baghouse filters. Most of the TPP was already equipped with PM removal techniques but the efficiency of such techniques has been globally upgraded and, in 2017, 66% of the coal-fired capacity operated with ESP, 9%

with baghouse filters and 25% with a combination of both technologies [51]. The substitution of technologies for more-efficient ones enabled to decrease the monthly emission factor of Chinese PP by more than 83% between 2014 and 2017 [51].

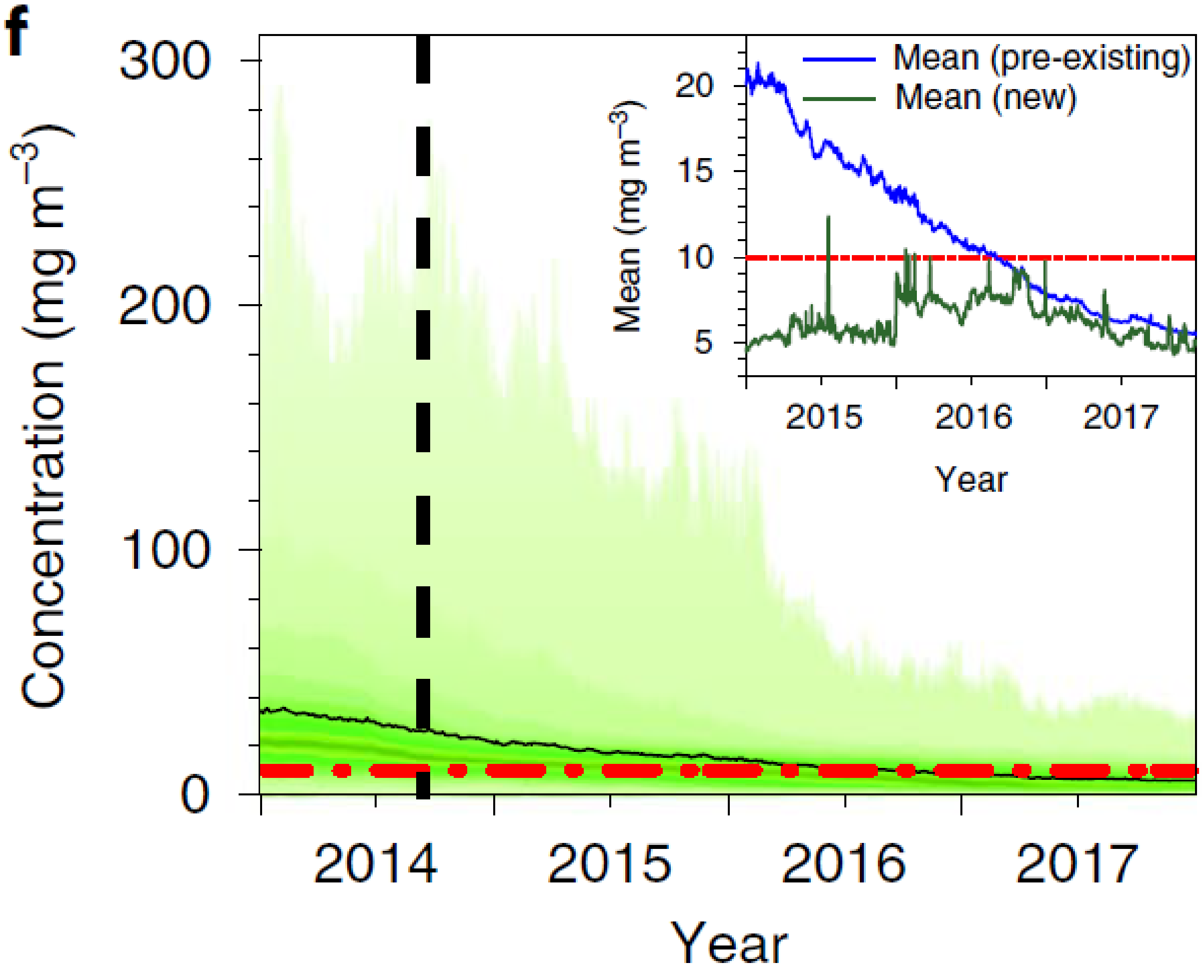


Figure 6: Evolution of the mean PM concentration of the whole Chinese coal power plan capacity between 2014 and 2017 [51]

Several reference cases from manufacturers of dust removal techniques, for coal-fired boilers show that similar or lower emission levels than the BAT AEL are achievable:

- LAB/CNIM dry FGD system, which includes a baghouse filter, enables to reduce dust concentration from 200 to 10 mg/Nm^3 for a 134 MWth coal boiler from Solvay Tavaux (France) [52];
- SOLVAir DSI technology implementation for a pulverized coal boiler of 229 MWth in Czech Republic achieves concentration of 15-17 mg/Nm^3 [53]; for Solvay soda ash plant (Spain) industrial coal boiler, the DSI technique with a baghouse filter decreased dust concentration in the exhaust gas from 70 to under 5 mg/Nm^3 [53].

In the framework of the development of the LCP BREF [2], a benchmark on EU plants was realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions [3], the proposal of potential updates of current ELVs, expressed as daily averages at 6% O_2, are as in the following:

Table 87: Proposal of potential updates in dust ELVs from combustion of coal-type solid fuels, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential dust ELV – daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	4-16	4-22[1]	3-10	3-20	1	1
100-300 MW	3-15	4-22[2]	2-10	3-18	1	1
> 300 MW	3-10	3-11[3]	2-7	2-10	2	1

[1]: 4-28 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 4-25 mg/Nm^3 if put into operation no later than Jan. 2014
[3]: if put into operation no later than Jan. 2014, 3-20 mg/Nm^3 if between 300-1,000 MW and 3-14 mg/Nm^3 if > 1,000 MW

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

6.1.2. Solid biomass and peat:

For combustion plants burning solid biomass or peat, the emission limit values for dust from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 6% O_2 and as monthly averages, are as in the following:

Table 88: Emission limit values of dust for solid biomass or peat from the AGP, expressed as monthly averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity

	Dust ELV (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	20	30
100-300 MW	20	20
Higher than 300 MW	20	20

In the European BAT conclusions for LCP [3], the dust BAT AEL for LCP burning solid biomass or peat, expressed as daily averages at 6% O_2, are as in the following:

Table 89: BAT AEL of dust for solid biomass or peat from the LCP BAT Conclusions, expressed as daily averages at 6% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of dust for biomass or peat (in mg/Nm^3 at 6% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	2-10	2-22
100-300 MW	2-10	2-18
Higher than 300 MW	2-10	2-16

In most of foreign regulations assessed, solid biomass is not treated as a own. Therefore, it can be supposed that solid biomass is included in the solid fuel category and the ELV given in the chapter 6.1.1 can be considered.

The same reducing techniques as for coal-type solid fuels [2][3] can be applied to achieve the imposed emission levels, and their potential applicability is of almost 100% as well except for the conditions given in chapter 6.1.1.

Abatement efficiency of dust abatement systems may be increased. With ESP, the abatement efficiency can be increased depending on the number of fields (4 to 5 field ESPs, residence time (size). With bag filters, dimensioning, residence time, ceramic filters or sintered metal filters are among parameters used to increase efficiency.

Nothing has been found in the literature about recent PM removal technology implementation on biomass LCP and the relative exhaust gas concentrations achieved.

In the framework of the development of the LCP BREF[2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions, the proposal of potential updates of ELVs, expressed as daily averages at 6% O_2, are as in the following:

Table 90: Proposal of potential updates in ELVs for dust emissions from combustion of solid biomass and peat, expressed as daily averages at 6% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential dust ELV - daily (in mg/Nm^3 at 6% O_2)		Est. equivalent monthly averages (mg/Nm^3 6% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	2-10	2-22	2-7	2-18	1	1
100-300 MW	2-10	2-18	2-7	2-15	1	1
> 300 MW	2-10	2-16	2-7	2-13	1	1

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

6.1.3. Liquid fuels:

For combustion plants burning liquid fuels, the ELV for dust from the AGP [1] depending on the plant status (new or existing) and the rated thermal power range, expressed at 3% O_2 and as monthly averages, are as in the following:

Table 91: Emission limit values of dust for liquid fuels, from the AGP [1], expressed as monthly averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity

	ELV of dust (in mg/Nm^3 at 3% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	20	30
100-300 MW	20	25
Higher than 300 MW	10	20

In the European BAT conclusions for LCP [3], the dust BAT AEL for LCP burning liquid fuels, expressed as daily averages at 3% O_2, are as in the following:

Table 92: BAT AEL of dust for liquid fuels from the LCP BAT Conclusions, expressed as daily averages at 3% O_2 in mg/Nm^3, depending on the thermal input capacity [3]

	BAT AEL of dust for liquid fuels (in mg/Nm^3 at 3% O_2)	
Thermal input capacity	New plant	Existing plant
50-100 MW	7-18	7-22[1]
100-300 MW	7-18	7-22[1]
Higher than 300 MW	7-10	7-11[2]

[1]: 7-25 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 7-15 mg/Nm^3 if put into operation no later than Jan. 2014

In addition, from the BAT conclusions for the refining of mineral oil [31], the PM BAT AEL for multi-fuel firing from combustion plants in refineries is of 5-50 mg/Nm^3, as monthly average at 3% O_2, the upper value corresponding to a high share of oil burning with only primary technique applicable.

In the US regulation [32], the converted ELV of dust for LCP > 73 MWth burning liquid fuels range from about 14 to 22 mg/Nm^3 at 3% O_2, depending on the date of construction or modification of the plant.

In the Chinese regulation [33], the ELV of dust for all TPP burning liquid fuels are of 30 mg/Nm^3 for new and existing facilities, at 3% O_2, except for key regions where it is imposed at 20 mg/Nm^3 for both existing and new plants [33].

The aforementioned emission levels can be respected through the application of one or a combination of the following techniques [2][3]: electrostatic precipitator (ESP), baghouse filter, multicyclones, dry, semi-dry or wet FGD when they are associated SO_2 emissions. The potential applicability of these techniques is of almost 100%. The application of wet FGD for plants operating less than 500 hours annually is impossible, whereas its implementation for retrofit or for installations < 300 MWth may rise some technical and economic limitations.

Abatement efficiency of dust abatement systems may be increased. With ESP, the abatement efficiency can be increased depending on the number of fields (4 to 5 field ESPs, residence time (size). With bag filters, dimensioning, residence time, ceramic filters or sintered metal filters are among parameters used to increase efficiency.

In the literature review carried out, no reference case of achieved concentrations was found for PM removal technology for liquid fuels in LCP. For light and medium distillate oils, it is not so surprising as their ash content is quite low and therefore PM emissions are not a great matter of concern.

In the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

Therefore, based on the assessment carried out in the EU for the development of the BAT Conclusions, the proposal of potential updates of ELVs, expressed as daily averages at 3% O_2, are as in the following:

Table 93: Proposal of potential updates in ELVs for dust emissions from combustion of liquid fuels,
expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and update indexes

	Potential dust ELV - daily (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
50-100 MW	7-18	7-22[1]	4-14	4-21	1	1
100-300 MW	7-18	7-22[1]	4-14	4-21	1	1
> 300 MW	7-10	7-11[2]	4-7	4-10	2	1

[1]: 7-25 mg/Nm^3 if put into operation no later than Jan. 2014
[2]: 7-15 mg/Nm^3 if put into operation no later than Jan. 2014

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

For multi-fuel firing from combustion plants in refineries, the BAT AEL of 5-50 mg/Nm^3 as monthly average at 3% O_2 could be considered for the update ELV of the "distillation and conversion residues from crude oil refining withing refineries and chemical installations" from the AGP [1], which was set at 50 mg/Nm^3. The update index for this ELV is estimated to be 2.

6.1.4. Gaseous fuels:

For combustion plants with a rated thermal power higher than 50 MW burning gaseous fuels, the ELV for dust from the AGP [1] are as in the following:

Table 94: Emission limit values of dust for gaseous fuels in the AGP (in mg/Nm^3 at 3% O_2) [1]

	Dust emission limit values in AGP (in mg/Nm^3 at 3% O_2)	
Fuel type	New plant	Existing plant
Natural gas	5	5
Steel industry gas	30	30
Other gases	10	10

In the European BAT conclusions for LCP [3], no BAT AEL is given for dust for natural gas. For iron and steel process gases (coke oven or blast furnace gas) being burned in LCP > 50 MW, the BAT AEL are of 2-10 mg/Nm^3 for new and existing plants, as daily averages at 3% O_2 [3].

For the process gases from the chemical industry, the BAT AEL for dust are of 2-10 mg/Nm^3 for new facilities [3]. For existing plants, the dust BAT AEL are of 2-22 mg/Nm^3 if < 300 MW and 2-11 mg/Nm^3 if > 300 MW.

In the Chinese regulation [33], the dust ELV for TPP burning natural gas is of 5 mg/Nm^3 for new and existing facilities, at 3% O_2.

For iron and steel process gases, the emission levels can be respected through the application of one or a combination of using auxiliary fuel choice, ESP, baghouse filter or flue gas pre-treatment [2][3]. ESP or baghouse filter is only applicable if an important amount of auxiliary fuel with a high ash content is used together with the iron and steel process gases [3]. Abatement efficiency of dust abatement systems may be increased. With ESP, the abatement efficiency can be increased depending on the number of fields (4 to 5 field ESPs, residence time (size). With bag filters, dimensioning, residence time, ceramic filters or sintered metal filters are among parameters used to increase efficiency.

For the chemical industry process gases, ESP, baghouse filter, dry or wet FGD or a combination of these can be used to achieve the BAT AEL [2][3]. The application of wet FGD for plants operating less than 500 hours annually is impossible, whereas its implementation for retrofit or for installations < 300 MWth may rise some technical and economic limitations.

In the literature survey carried out, no reference case was found about PM removal technology for gaseous fuels as their emission level is usually relatively low.

In the framework of the development of the LCP BREF [2], a benchmark on EU plants has been realized and the proposed BAT AEL are in accordance with the observed emission levels.

In short, the dust ELV for natural gas in the current version of the AGP do not seem to require updates (i.e., the updates indexes are **3** for these fuels).

For the other gaseous fuels, based on the assessment carried out in the EU for the development of the BAT Conclusions, the proposal of potential updates of ELVs, expressed as daily averages at 3% O_2, are as in the following:

Table 95: Proposal of potential updates in ELVs for dust from combustion of gaseous fuels, expressed as daily averages at 3% O_2 in mg/Nm^3, as well as estimated corresponding monthly averages and the update indexes

	Potential dust ELV (in mg/Nm^3 at 3% O_2)		Est. equivalent monthly averages (mg/Nm^3 3% O_2)		Update Index	
Thermal input capacity	New	Existing	New	Existing	New	Existing
Natural gas	5*		Already as monthly average		3	3
Iron and steel gas	2-10		2-8		1	1
Chemical process gas	2-10	2-10**	2-7	2-18 if < 300 2-10 if > 300	2	2

*: the ELV is expressed as monthly average

**: we keep the ELV from the AGP for “other gases” which is of 10 mg/Nm^3 as the upper value of the range

The estimation of equivalent monthly averages, from daily and yearly averages, is based on [35] and is explained at the end of the Chapter 3.1.1.

6.2. Limit values for dust emissions released from mineral oil and gas refineries

In oil refineries, dust emissions particularly occur during fluid catalytic cracking (FCC). FCC is a conversion process for upgrading heavy hydrocarbons, using heat and a catalyst to break larger hydrocarbon molecules into lighter molecules. The EU BREF document [37] reports ESPs in combination with multistage cyclone separators and centrifugal washers with third stage ceramic or metal filters to be the most efficient technique for PM emission abatement:

- Electrostatic precipitators operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), catalyst properties and upstream particles removal devices. At FCC units, 3-field ESPs and 4-field ESPs are commonly used. ESPs may be used on a dry mode or with ammonia injection to improve the particle collection.
- Common configuration of cyclonic collection devices consist of a single vessel containing many conventional cyclones or improved swirl-tube technology. For FCC, performance mainly depends on the particle concentration and size distribution of the catalyst fines downstream of the regenerator internal cyclones.
- Centrifugal washers combine the cyclone principle and an intensive contact with water e.g. within a venturi washer. This entails separating the dust by intensively mixing the incoming gas with water, usually combined with the removal of the coarse particles through the use of centrifugal force. The removed dust is collected at the bottom of the scrubber. Also, substances such as SO_2, NH_3 and some VOC and heavy metals may be removed.
- Third stage blowback filters are reverse flow (blowback) ceramic or sintered metal filters where, after retention at the surface as a cake, the solids are dislodged by initiating a reverse flow. The dislodged solids are then purged from the filter system.

The proposal for potentially updated ELVs according to the BAT conclusions [31] are listed in Table 96. The update indexes suggested are 1:

Table 96 Table 2, annex X, proposal of potential updates in ELVs for dust emissions from FCC regenerators in mineral oil and gas refineris

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
84	**Table 2:** Limit values for dust emissions released from mineral oil and gas refineries ELV for dust (mg/m³) from FCC regenerators **50 mg/m^3**	**Update Index 1** Upgraded current abatement techniques are available, especially for new plants a reduction is possible	The techniques are electrostatic precipitators (ESP), multistage cyclone separators, centrifugal washers (venture washers, wet scrubbing), third stage blowback filter (ceramic or sintered metal filters)	Almost 100 % for ESPs and multistage cyclone separators, some limitations exist for wet scrubbers	**10-25 mg/m^3** as monthly average for new plants, **10-50 mg/m^3** for existing plants, according to EU BAT conclusions [31]

6.3. Limit values for dust emissions released from cement clinker and lime production

As the BATs for dust emission reduction from cement clinker production are similar to those of lime production and both processes are also included in the same BREF document [39], both processes are jointly discussed here. The BATs for dust emission abatement are classical fabric bag filters or ESPs. Fabric filters usually reduce emissions to less than 10 mg/m^3 but state-of-the-art ESPs are also reported to achieve emissions of 10 mg/m^3. As summarized in Table 97, there is slight potential for reducing the ELVs. The proposed updates in the limit values are as in Table 97 and the update indexes suggested are 2:

Table 97: Tables 3 and 4, annex X, proposal of potential updates in ELVs for dust emissions from cement clinker and lime production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
85	**Table 3:** Limit values for PM emissions released from cement clinker production General (existing and new plants): **20 mg/m^3 at 10 % O_2**	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESP), fabric filters, hybrid filters	100% applicable to all types of kilns	**10-20 mg/m^3** as daily average [40] when applying fabric filters or new / upgraded ESPs the lower range (10 mg/m^3) is achieved
85	**Table 4:** Limit values for dust emissions released from lime production General (existing and new plants): **20 mg/m^3**	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESP), fabric filters, hybrid filters	100% applicable	**10-20 mg/m^3** as daily average [40] when applying fabric filters or new / upgraded ESPs the lower range (10 mg/m^3) is achieved

6.4. Limit values for dust emissions released from iron and steel production

In the different processing steps of iron and steel production, typical abatement techniques for dust reduction including both dry (e.g. ESP or bag filter) and wet dedusting (e.g. wet ESP or scrubber) are applied [42]. The applied technologies depend on the processing step and the associated emissions. The proposals for update of limit values are as **Erreur ! Référence non valide pour un signet.**. They are characterised as update index 1, 2 or 3:

Table 98 summarizes the abatement techniques and related emission levels for the respective step in steel and iron production. Particularly in the case of sinter plant emissions, an adjustment of the ELVs in Annex X of the Gothenburg Protocol seem reasonable.

The proposals for update of limit values are as **Erreur ! Référence non valide pour un signet.**. They are characterised as update index 1, 2 or 3:

Table 98: Table 5, annex X, proposal of potential updates in ELVs of dust from iron and steel production facilities

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
85	**Table 5:** Limit values for dust emissions released from primary iron and steel production Sinter plant: **50 mg/m^3**	**Update Index 1** Adjustment of ELV possible	The techniques are electrostatic precipitators (ESP), fabric filters, hybrid filters [42][43]	Almost 100 %	**10-15 mg/m^3** if a bag filter is used, with an ESP **20-40 mg/m^3** measured as daily average [43]
	Pelletization plant: **20 mg/m^3 for crushing and grinding, 15 mg/m^3 for the rest**	**Update Index 3** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESP), fabric filters, hybrid filters [42][43]	Almost 100 %	**20 mg/m^3** for crushing, **10-15 mg/m^3 for the rest** (daily average) [43]
	Blast furnace: Hot stoves (>2.5 t/hour) **10 mg/m^3**	**Update Index 3**	Dry dedusting (ESP or Filters) [42][43]	Almost 100 %	**< 20 mg/m^3 according to EU BREF conclusions** (daily average) [43]
	Basic oxygen steelmaking and casting (>2.5 t/hour) **30 mg/m^3**	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	Dry dedusting (ESP or Filters), wet dedusting (wet ESPs or scrubbers) [42][43]	Almost 100 %	**10-30 mg/m^3 according to EU BREF conclusions** (daily average) [43]
	Electric steelmaking and casting (>2.5 t/hour) **15 mg/m^3 for existing, 5 mg/m^3 for new**	**Update Index 2** Adjustment of ELV possible for existing installations	Direct off-gas extraction and hood system / doghouse system [42][43]	Almost 100 %, adjustment for existing plants could be difficult	**5 mg/m^3** (daily average) for new and existing plants [43]

6.5. Limit values for dust emissions released from iron foundries

The BATs for dust emission abatement are classical bag filters or ESPs or even wet scrubbing systems. Wet scrubbing entails separating the dust by intensively mixing the incoming gas with water, usually combined with the removal of the coarse particles through the use of centrifugal force [42]. The removed dust is collected at the bottom of the scrubber. In case of an ESP, higher emission values are reported as compared to a bag filter or a wet scrubbing system.

The proposals for update of limit values are as in the following. They are characterised as update index 2:

Table 99: Table 6, annex X, proposal of potential updates in ELVs of dust from iron foundaries

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
85	**Table 6:** Limit values for PM emissions released iron foundries Iron foundries (>20 t/day): **20 mg/m^3** For all furnaces (cupola, induction, rotary) and all mouldings (lost, permanent)	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESP), fabric filters, or wet scrubbing [42][43]	Almost 100 %.	**5 to 20 mg/m^3** with bag filters or wet scrubbing systems measured as daily average [43]
	Hot and cold rolling **20 mg/m^3, 50 in case bag filters cannot be applied**	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESP) or fabric filters [42][43]	Almost 100 %	**5 to 20 mg/m^3 with bag filters,** **>40 mg/ mg/m^3 with ESPs** (daily average) [43]

6.6. Limit values for dust emissions released from non-ferrous metal production

Annex X (Table 7) of the Gothenburg Protocol only provides one overall ELV for overall non-ferrous metals production. Even though the abatement techniques for dust emissions are relatively similar consisting of bag filters, ESPs or wet scrubbers, the processes and processing steps for primary and secondary metal production are different for each metal and so are the abatement techniques and ELVs. It therefore does not seem reasonable to compare the ELV of 20 mg/m^3 to existing literature values of current BATs. In 2017, the European Joint Research Centre (JRC) released a BREF document for nonferrous metals [45]. Comparison of emission levels to the European BAT conclusions showed that the BREF document is up-to-date and provides vast information on respective abatement technologies. This was also confirmed by industry staff and experts from environmental agencies in earlier TFTEI activities regarding air emissions from aluminium production. It would therefore be possible to provide differentiated ELVs for various processing steps for respective non-ferrous metals (copper, aluminium, nickel, lead, etc.) comparable to the more detailed ELVs of iron and steel production listed in The proposals for update of limit values are as **Erreur ! Référence non valide pour un signet.**. They are characterised as update index 1, 2 or 3:

Table 98.

The proposals for update of limit values are as in the following. They are characterised as update index 1:

Table 100: Table 7, annex X, proposal of potential updates in ELVs for dust emissions from non ferrous metals production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
85	**Table 7**: Limit values for dust emissions released from non-ferrous metals production and processing	**Update Index 1** Update with more details regarding main metals such as aluminium, copper,	The techniques are electrostatic precipitators (ESP), fabric filters, hybrid filters, partly	Almost 100 %	**Overall ELV not useful, higher differentiation necessary, see iron and steel production**

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	ELV for dust (mg/m³): **20 mg/m³**	nickel. lead etc. is necessary	wet scrubbers for some furnaces [15], very detailed information from the EU BREF available		

6.7. Limit values for dust emissions released from glass production

Beside primary measures regarding the handling and properties of raw material input, the BATs for dust emission abatement from glass production are classical bag filters or ESPs. As summarized in Table 101, the emission values in Annex X of the Gothenburg Protocol are in the range of emission levels reported in the European BREF document and BAT conclusions [46][47] except for existing plants.

The proposals for update of limit values are as in Table 101. They are characterised as update index 1 or 2:

Table 101: Table 8, annex X, proposal of potential updates in ELVs for dust emissions from glass production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
86	**Table 8**: Limit values for dust emissions released from glass production ELV for dust (mg/m³) for new installations: **20 mg/m³**	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	Beside primary measures (raw material modification) the techniques are electrostatic precipitators (ESP) and fabric filters [46]	Almost 100 %. Some limitations may exist if the primary measures are not able to reach concentrations below 1000 mg/m³.	**10 to 20 mg/m³** with bag filters (daily average) [47]
	ELV for dust (mg/m³) for existing installations: **30 mg/m³**	**Update Index 1** Update possible according to reference values in the EU BAT conclusions	The techniques are electrostatic precipitators (ESP) and fabric filters [[46]	Almost 100 %	**10 to 20 mg/m³** with bag filters (daily average) [[47]

6.8. Limit values for dust emissions released from pulp production

The separation of dust during pulp production is carried out in an electrostatic precipitator or multistage cyclone. The sulphite process produces wood pulp that is almost pure cellulose fibers by treating wood chips with solutions of sulphite and bisulphite ions. There are different variations of this process depending on the sulphite salt used (mainly magnesium or ammonium).

For the magnesium sulphite process, the dust retained in the ESP consists mainly of MgO but also to a minor extent, K, Na or Ca compounds. The recovered MgO ash is suspended with water and cleaned by washing and slaking to form $Mg(OH)_2$ which is then used as an alkaline scrubbing solution in the multistage scrubbers in order to recover the sulphur component of the cooking chemicals.

For the ammonium sulphite process, the ammonia base (NH_3) is not recovered, as it is decomposed in the combustion process in nitrogen. After the removal of dust, the flue-gas is cooled down by passing through a cooling scrubber operated with water and it then enters a three or more staged scrubber of the flue-gas where the SO_2 emissions are scrubbed with the $Mg(OH)_2$ alkaline solution in the case of the magnesium sulphite process, and with a 100 % fresh NH_3 solution in the case of the ammonium sulphite process [48].

The proposals for potentially updated ELVs achievable with these abatement techniques are summarized in Table 102. Particularly in the recovery boiler and lime kiln and adjustment of the ELVs from Annex X of the Gothenburg protocol seems realistic. The proposals are characterised as update index 1 or 2:

Table 102: Table 9, annex X, proposal of potential updates in ELVs for dust emissions released from pulp production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
86	**Table 9**: Limit values for dust emissions released from pulp production Auxiliary boiler ELV for dust (mg/m^3): **40 mg/m^3** when firing liquid fuels (at 3% oxygen content) **30 mg/m^3** when firing solid fuels (at 6% oxygen content)	**Update Index 2** GP ELV is in the upper level of the range of current abatement technique emissions	The techniques are electrostatic precipitators (ESPs) [48] or a combination of a ESP and a wet scrubber	Almost 100 %, some limitations for wet scrubbers possible	**20 to 40 mg/m^3** as yearly average [49]
	Recovery boiler and lime kiln: **50 mg/m^3**	**Update Index 1** Separation of boiler and lime kiln possible	The techniques are electrostatic precipitators (ESPs) or wet alkaline scrubbers [48]	Almost 100 %, some limitations for wet scrubbers possible	**10-20 mg/m^3** for recovery boilers and **10-30 mg/m^3** for the lime kiln (yearly average) [49]

6.9.Limit values for dust emissions released from waste incineration

Flue gas treatment of waste incineration is a complex multi-stage process including different filtering and scrubbing processes to remove SO_2, NO_x, HF, HCl and further pollutants. Usually, there is a pre-dedusting stage before other flue-gas treatments. This pre-dedusting may include:

- cyclones and multi-cyclones (generally in combination with other FGC components for the efficient capture of the finer dust fractions);
- electrostatic precipitators (ESPs);
- bag filters (BFs).

Subsequently, flue gas polishing is performed for efficient reduction of PM emissions. This may include the following techniques, depending on local conditions and process specifics:

- bag filters;
- wet ESPs;
- electrodynamic Venturi scrubbers;
- agglo-filtering modules;
- ionising wet scrubbers.

The proposals of update of ELV are listed in Table 103. As illustrated here, particularly with the subsequent use of wet scrubbers and bag filters for flue gas polishing, there is potential to update PM ELVs listed in Annex X, table 10 of the Gothenburg Protocol. An update index of 2 is proposed.

Table 103: Table 10, annex X, proposal of potential updates in ELVs for dust emissions released from waste incineration plants

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
86	**Table 10**: Limit values for dust emissions released from waste incineration Municipal waste incineration plants (> 3 Mg/hour): **10 mg/m^3**	**Update Index 2** GP ELV is in the range of current abatement technique emissions	The techniques are (wet) electrostatic precipitators (ESP), fabric bag filters, or cyclones and multi cyclones for pre-dedusting, and wet scrubbers (mainly for SO_2, HCl and HF) [50]	Almost 100 %	**5 mg/m^3** with bag filters and wet scrubber **5-20 mg/m^3** with wet ESP and multi cyclone systems (daily average) [50]
	Hazardous and medical waste incineration (> 1 Mg/hour): **10 mg/m^3 at 11 % oxygen content in the dry base**	**Update Index 2** GP ELV is in the range of current abatement technique emissions	The techniques are (wet) electrostatic precipitators (ESP), fabric bag filters, or cyclones and multi cyclones for pre-dedusting, and wet scrubbers [50]	Almost 100 %	**5 mg/m^3** with bag filters and wet scrubbers **5-20 mg/m^3** with wet ESP and multi cyclone systems (daily average) [50]

6.10. Limit values for dust emissions released from titanium dioxide production

Dust is a major concern during raw material preparation for titanium dioxide production, while in the digestion step and the following processing steps wet acid and caustic scrubbers as described in section above are used to avoid SO_2 or chlorine emissions. This also removes PM from the waste gases making the initial raw material processing the major source of dust emissions. The best technique to reduce dust emissions from the handling, drying and milling of the ore is to use high integrity bag filters with appropriate filter cloth material and a maintenance routine to control dust losses. According to the EU BREF document [38], the achievable emission levels both for the sulphate process and the chloride process are below the current ELVs in Table 11, Annex X of the Gothenburg Protocol. Hence, there is potential for adjusting the ELVs. The proposals of update of ELV are characterised as update index 1:

Table 104: Table 11, annex X, proposal of potential updates in ELVs for dust emissions released from titanium dioxide production

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
86	**Table 11:** Limit values for dust emissions released from titanium dioxide production Sulphate process, total PM emissions: **50 mg/m^3**	**Update Index 1** Update possible according to BAT related emission levels from the EU BREF documents	The techniques are high integrity fabric bag filters with appropriate filter cloth [38]	Almost 100 %.	**5-20 mg/m^3** as daily average, or 0.004-0.45 kg/t TiO_2 [38]

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Chloride process, total emission: **50 mg/m^3**	**Update Index 1** Update possible according to BAT related emission levels from the EU BREF documents	The techniques are high integrity fabric bag filters with appropriate filter cloth [38]	Almost 100 %	**<20 mg/m^3** as daily average, or 0.1-0.2 kg/t TiO_2 [38]

6.11. Limit values of dust for residential combustion installations with a rated thermal input < 500 kW

6.11.1. Context

Domestic biomass and fossil solid fuel burning is source of large $PM_{2.5}$ emissions including BC and PAH, in the UNECE region. According to the UNECE assessment "Prioritizing reductions of particulate matter from sources that are also significant sources of black carbon - analysis and guidance" of 2021 [21], measures to reduce $PM_{2.5}$ emissions from domestic wood burning in boilers and stoves should be prioritized to also achieve reduction of BC emissions. This is the conclusion in any of the three regions[1] of UNECE covered by the assessment.

In the Frame of the UNECE Air Convention the "*Code of good practice for wood-burning and small combustion installations" was developed and adopted in 2019* [23]. This document responds to the needs to inform the general public of the impact of wood burning, on air pollution and human health and how the final users can contribute to the reduction of PM emissions, which have multiple sources. The following main topics are addressed in the document:

a) Available best practices for domestic wood heating in order to minimize emissions and increase efficiency, reducing expenditure due to decreased use of wood and storage needs and the use of wood, while reducing the negative impact on the environment and the human health;

b) The best heating devices currently available on the market;

c) The proper origin and characteristics of wood biomass with a focus on the need to burn dry, clean wood and thus avoiding use of composite, treated and/or contaminated wood.

The aim of the current chapter is the assessment of the ELVs proposed for residential combustion installations burning solid fuels, with a rated thermal input < 500 kW, as of annex X, table 12 to the Gothenburg Protocol, which could be potentially updated as consequence of the technological progress made in this type of installations, during the 12 years after the adoption of the AGP.

In this chapter, the possible evolution of standards and possible implementation of ELVs for domestic appliances are examined.

---

[1] The three regions assessed. The first region consists of Belarus, the Republic of Moldova, the Russian Federation (European part only) and Ukraine, the four Eastern European countries available for analysis with the European online version of the GAINS model. The second region consists of Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia and Turkey, as well as Kosovo. The third region consists of the Member States of the European Union and Norway, Switzerland and the United Kingdom of Great Britain and Northern Ireland.

6.11.2. PM and BC emission measurement methods and test procedures

A complex issue to discuss PM emissions and possible new ELVs for domestic heating appliances using solid biomass or solid fossil fuels, is linked to the definition of PM and the measurement methods of PM. This issue has already been examined in the scope of the Air Convention especially with the assessment report: “How should condensable be included in PM emission inventories report to EMEP/CLRTAP?”, of the expert group on condensable organics organised by MSC-W in 2020 [25] and it is still being discussed in the scope of EMEP, recognising the importance of condensables. If it appears clear that condensable PM need to be included in models to better reflect PM concentrations and better assess health impacts of real-world ambient PM concentrations, currently PM emission inventories are still a mix of different PMs, as illustrated below.

Primary particulate matter (PPM), also named total particulate matter (TPM), is the sum of filtrable particulate matter (FPM) or solid particulate matter and condensable particulate matter (CPM) [25]. The FPM fraction includes soot/black carbon (BC), ash, non-volatile (filterable) organic matter (FPOA), and other compounds. The CPM fraction includes inorganic compounds (mostly sulphates from sulphur present in fuels) and the particle phase of ‘condensable’ organic aerosol (CPOA) which is a class of compounds, of low volatility, which are in form of vapour phase inside the flue stack (or exhaust), but which may partition between the gas and particle (condensed) phase upon cooling and dilution.

Currently measurement methods may determine the solid fraction of PM only (filtrable particles) or both the filtrable solid fraction and condensable of PM, together.

The PM limit values in annex X of the Gothenburg Protocol can be considered representing FPM only, due to the methods used to measure PM concentrations, in most of the cases.

6.11.2.1. PM emission measurement methods

The test methods, used for standardisation of domestic heating appliances with solid fuels, for controlling PM emissions in stack and for estimating PM emissions from the appliances, are numerous and different, both including or not including condensables in total PM (filtrable plus condensable). Such situation leads to confusion, conflicting results and difficulty of interpretation of measurement results and appliance efficiency.

The recent assessment made by IEA Bioenergy “Status of PM emission measurement methods and new development” [75], provides an excellent overview of the situation and the complexity of the issue. This report draws attention to the diversity of gravimetric PM emission measurement methods and to the need for method development and international harmonization. An inventory of existing standards and their characteristics was prepared, followed by a compilation of laboratory experience concerning method-based factors which influence the measured particle emissions. The recent approach for a modified international method was also discussed, the so-called "EN-PME method" [76].

The following figure illustrates the different types of measurement methods and their capacity to represent solid particles (or FPM or SP) and condensables [77] (CPM). The EM_PME_Test has been added by INERIS [87]. The filter method is the most frequently used method to measure PM concentrations in stack, in most of EU Member states, able to provide concentrations of solid particles only, sampled from hot flus gases on filter at 160°C (SP). In Norway, the dilution tunnel, able to monitor both SPM and CPM, is used. In the US, methods able to monitor both SPM and CPM are used and are based on the dilution tunnel method or on the SPC method (filter and impinger). PM ELVs, as they are indicated in the Annex X to the Gothenburg Protocol [1], are considering solid particles, only.

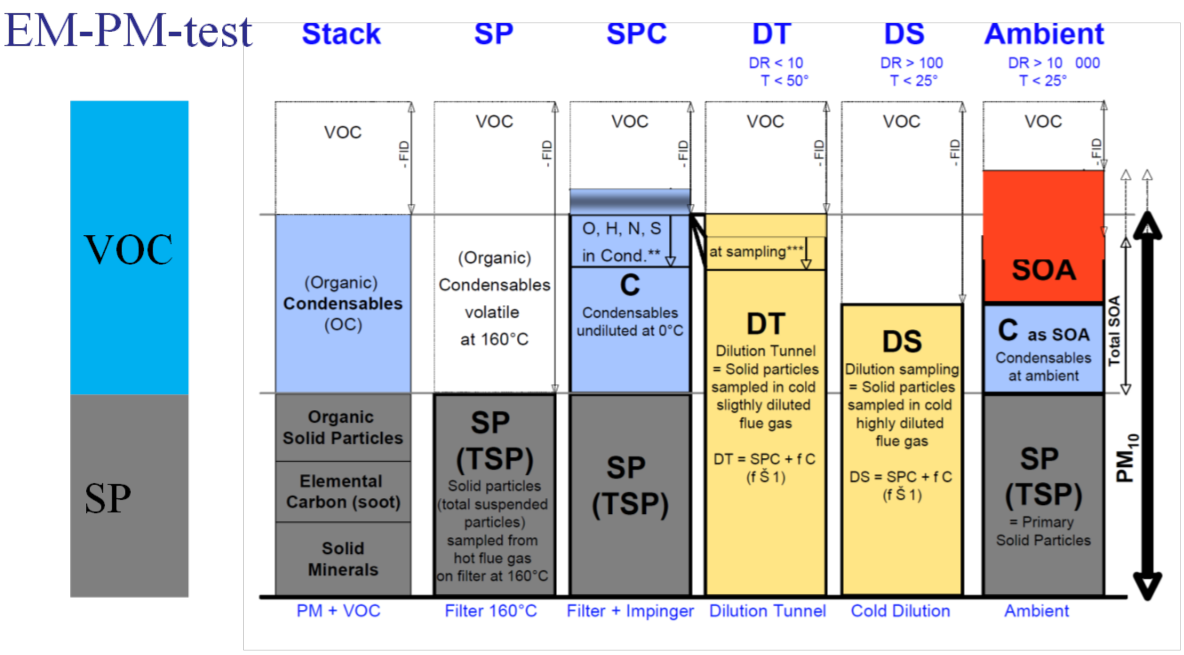


Figure 7: Comparison of PM sampling with PM in the ambient [77] and for the comparison with EM-PME-test [87]

SP: Filter (Method a) resulting in solid particles SP (total suspended particles TSP).

SPC: Filter + Impinger (Method b) resulting in solid particles and condensables SPC.

DT: Dilution Tunnel (Method c) with typical dilution ratio (DR) in the order of 10 resulting in a PM measurement including SPC and most or all C. DT is identical or slightly smaller than SPC + C due to potentially incomplete condensation, depending on dilution ratio and sampling temperature (since dilution reduces not only the temperature but also the partial pressure of contaminants).

DS: Dilution Sampling with high dilution ratio (DR > 100).

PM10: Total Particulate Matter < 10 microns in the ambient including SP and SOA

SOA: Secondary organic aerosols, consisting of condensables C at ambient and SOA formed by secondary reactions such as photochemical oxidation.

The following table presents the PM measurement methods, used by or for different standards in the EU, in Norway or in the US. This table form INERIS [87], was adapted by TFTEI with information provided by reference [111].

Table 105: PM measurement methods used in the different standards, from [87] adapted and completed by TFTEI

Methods of measure of PM	SP	SPC	DT	Electro-filter
EN 13240 for Room heaters fired by solid fuels – requirement and test methods Methods for PM measurement according to CEN TS 15883	x		x	x

Methods of measure of PM	SP	SPC	DT	Electro-filter
EN 13229 for inset appliances including open fireplaces– requirement and test methods Methods for PM measurement according to CEN TS 15883	x		x	x
EN 14785 for Residential space heating appliances fired by wood pellets - Requirements and test methods Methods for PM measurement according to CEN TS 15883	x		x	x
EN 15250 for slow heat release appliances fired by solid fuels - requirement and test methods (mass stoves) Methods for PM measurement according to CEN TS 15883	x		x	x
EN 12809 Residential independent boilers fired by solid fuel - Nominal heat output up to 50 kW - Requirements and test methods Methods for PM measurement according to CEN TS 15883	x		x	x
EN 303-5 – 2020 for central heating boilers up to 500 kW	x			
EN 16510-1 (2018)(1) PrEN 16510-1 modified to be adopted in 2022	x x with EnPME		x	
US EPA 5H		x		
US EPA 5G			x	
NS 3058			x	
EU regulation 1185/2015	x		x	x
“Flame Verte” label (F)	x			
Blue Angel (D)	x			

(1) In 2018, part 1 of the **new standard EN 16510** 'Domestic combustion appliances for solid fuels - Part 1: General requirements and testing methods' was published [21]. It replaces standards EN 13240 for freestanding stoves, EN 13229 for inset appliances and open fireplaces, and EN 12809 for boiler-stoves up to 50 kW. The new standard describes the test methods and the measurement methods for CO, NOx, OGC and dust in a more detailed manner than the existing standards but without contradicting them [9].

As it stands currently, the main regulatory requirements to be met by manufacturers of solid fuel burning appliances include the Construction Products Regulations (CPR), Energy Labelling Regulations requirements for efficiency and safe use [112][111].

From 1st January 2022 (1st January 2020 for independent boilers), appliances will also be required to meet the recently published Eco-design regulations [17][18], which sets new efficiency and emission criteria for appliances to be legally sold on the EU market.

The existing European standards such as EN 13240, EN 13329, EN 14785, EN 15250, EN 12809, specify requirements relating to the design, manufacture, construction, safety and performance (efficiency and emission) instructions and marking together with associated test methods and test fuels for the appliances they cover.

They are still in operation even if the new standard EN16510-1 (2018) (Residential solid fuel burning appliances – emissions test methods) has been published in 2018 for domestic combustion appliances with solid fuels [21]. The standard EN16510-1 (2018) contains the newly developed general provisions relating to the design, manufacture, construction, safety and performance of appliances fired by solid fuel. To meet compliance with the appropriate regulations detailed above, manufacturers are required to verify the safety of their products through testing to the applicable test standard aligned with the regulation. The scope of EN 16510-1 currently covers solid fuel room heaters, inset appliances, open fires, cookers, independent boiler up to 50kW, slow heat release appliances and pellet appliances. These items will be covered under the subsequent sub parts to the standard parts 2-1 to 2-6 [112]. This standard is still under development with the purpose of superseding the current set of test standard in publication (i.e., EN 13229 (inset room heaters & open fires), EN 13240 (freestanding room heaters, EN 12815 (cookers) and EN 12809 (up to 50kW independent boiler appliances)).

In these existing European standards (before EN 16510-1 published in 2018), only CO measurement was required and measured. The Commission published technical specifications in 2008 to help measurement of different parameters required in the standards and notably the measurement of PM emissions of residential solid fuel burning appliances. These technical specifications [20] described three measurement methods of PM: a method named in the technical standard “Austrian and German particle test methods” corresponding to the solid particles (SP) method, the Norwegian particle test method based on the dilution tunnel and the UK particle test method using an electrostatic precipitator (ESP).
In fact, any of these measurement methods could be used, however most of countries in Europe used the SP method, Norway and Nordic countries the dilution tunnel method and UK the ESP method.

For more information, the references [9][75][76] provide more details on the different measurement methods and standards used in the EU, Norway, US and Canada.
In summary, C. Schön [75] concludes that the need for method harmonization is obvious and that efforts for harmonisation and comprehensive specification of methods for determining PM emissions need to be strengthened.

In EN 16510-1 the emission measurement methods for NOx, OGC and PM (Annexes D, E and F of the standard) are specified in a more detailed way than the previous specifications and the test procedure for the type test is specified more clearly than in the previous CEN / TR 15883 [20], which will be replaced by EN 16510-1. The new EN 16510-1 includes the methodologies for the heated filter and a variant of the dilution tunnel methodology [21] (For those manufacturers wishing to confirm compliance by the electrostatic precipitator they can still use TS15883 methodology in line with UK clean air act requirements [112].

Research works to implement many of the findings of the study [75] were carried out and the results were the setup of a new method in the EN-PME project [76]. The EM-PME method [76] is basically requiring the use of a new probe for a heated filter method with a controlled and constant temperature of 180 °C at the filter, a simplified 90° orientation of the nozzle in the flue gas duct, a fixed inner nozzle diameter of only 7.5 mm to guarantee high sampling gas velocities and a quantification of PM deposit in the probe by clean purge air rinsing which is then conducted over a clean filter after each measurement. Furthermore, VOC shall inseparably and always be determined along with PM emissions. This requirement follows the hypothesis that VOC is a suitable parameter to characterize the potential formation of aerosol particles from incomplete combustion. Thus, a parallel VOC measurement becomes an integral and inseparable part of the EN-PME method, and VOC shall be analysed at the same sampling temperature of 180 °C as applied during PM filtration.

It has to be well understood that the EN-PME method is not a method to determine condensables. Recently, a scientific project suggested EN-PME test method as temporary test method for particles (similar to heat filter technique) from wood heating [41]. The direct comparison of the EN-PME sampling method and NS3058 (based on dilution tunnel) in parallel from the current experimental campaign showed that emissions from the NS measurements are 11 times higher with 108 mg MJ^{-1} compared to EN-PME test with 14 mg MJ^{-1}. The differences range between 2 until 60 times and is largely due to condensables [95].

There were discussions concerning the use of this EN-PME method within the European standardization group of CEN TS 295 (WG 5). The EN-PME has been finally adopted and a revised standard EN16510-1 should be published in 2022 [111]. This new EN standard will be fully operational for the revision of the Eco design directive (scheduled by 2024) and the regulation 2015/1185.

6.11.2.2. Test procedures

Another issue concerning official type test in the EU, is that stove performances and efficiencies are assessed under well-defined conditions. **This approach enables a high reliability of test results but leads to test results which are usually out of reach in the real-life operation** [88].

The following table is taken from a study, carried out by INERIS, on the impact of different combustion conditions on PM emissions [93].

NOx emissions are only lightly influenced by the combustion parameters. This consideration confirms that the improvements in the combustion quality does not lead to an increase in the temperature, sufficient to generate thermal NOx. The latter are produced at higher temperatures. NOx is mainly due to the presence of nitrogen in the wood. The impact on the efficiency of all the analysed parameters is relatively modest, apart from the comparison between the tests made on the complete combustion cycle and the normative tests (duration 30 minutes). The failure to consider the entire burned fuel, in the calculations, leads to an overestimation of the thermal efficiency. The condensable fraction can represent, on average, 64% of the total particles, but it has not been systematically studied in the cases examined in ref [87], resulting in lowering the quality of knowledge of the emissions. The solid and condensable fractions of PM can change both as absolute value and as fraction, according to the parameters tested.

Table 106: Main parameters influencing PM emissions according to INERIS [93]

	Humidity > 25%/15%	Burn rate (reduced / nominal	Type of wood	Bark (with / without)	Ignition mode
CO	high	high	medium	no impact	Warm/cold: medium Bas/haut: high
VOCt	high	high	medium	medium	Warm/cold: medium Bas/haut: high
NOx	low	medium	low	low	Warm/cold: low Bas/haut: low
PM	high	high	high	high	Warm/cold: high Bas/haut: high
Energy efficiency	medium	medium	low	no impact	Warm/cold: low Bas/haut: high

	Combustion phase	Load (partial/nominal)	Test plat form	Furnace aging
CO	high	low	low	unknown
VOCt	high	low	medium	unknown
NOx	medium	low	no impact	unknown
PM	high	low	low	high for tight appliances
Energy efficiency	medium	low	low	unknown

The study “*advanced test methods for firewood stoves”* [88] provides an overview of the most important test methods, adopted worldwide. The major differences regarding the testing procedure and applied measuring methods are illustrated. The report also presents an overview of different scientific studies, in which test protocols, allegedly better reflecting the real-life operation, were applied, for example, to investigate emission factors in different stove technologies. In the analysis, those test procedures (as well as the beReal test protocol [96]) are illustrated and the emission and efficiency results are compared to official type test results, results of field tests and proposed emission factors.

The comparison of field test results shows basically a technological improvement in the firewood stoves, over the last decades. But in comparison with official type test results, the improvements are significantly higher. Furthermore, serial-produced stoves, initially tested in accordance with the former EN 13240 standard, and then re-tested according to the EN16150, now used, show much higher level of emissions and lower efficiency, compared to official type test results of the respective stove models. The beReal test was examined and it showed a good agreement between the test results in lab and test results on field. However, the thermal efficiency is still overestimated by the lab test, compared to the test on field.

The following key findings and conclusions are provided by [88]:

- Testing conditions of current European standards evaluating the emissions and thermal efficiency of firewood ambient heating appliances are well controlled and provide the basis for optimal results for the tested appliance. The most relevant difference of EN type test standards, compared to international standards, is that in most of the cases the nominal load is evaluated only whereas, for example, test protocols in Canada and US, evaluate the performance at several load values.

- PM emission results highly depend on the applied measuring method. For a better comparability of the different test results, a PM measurement method, commonly adopted in Europe, is needed, in order to achieve sufficient comparability between different products.
- The comparison of field test results showed a general trend of technological improvement in firewood stoves, over the last decades. However, the comparison of official type test results with tests on field, confirmed that usual heating operation results in significantly higher emissions and lower efficiencies.
  - Official type test results were not replicable on serial-produced stoves, in comprehensive lab tests. The implementation of a market surveillance concept represents an effective measure to guarantee a constant product quality of appliances on sale.
- In future, the new Eco-design requirements will set an equal benchmark of performance criteria for new stove technologies, in Europe. However, the effect of improving the real-life situation is limited due to the fact that the new requirements are still referred to the official type test results.
- Real-life oriented test concepts (e.g., beReal) are able to reflect the real-life performance of the appliances, better compared to existing EN standards. The implementation of a real-life oriented test protocol. as quality label or standard, should be considered as an instrument to push the technological development towards the optimized real-life operation and to enable a better differentiation of good and poor quality products for the benefit of the end user customers.

It is concluded that the implementation of a real-life reflecting test protocol (e.g., beReal), as a quality label or standard, should be considered as an instrument to push further the technological development towards the optimized real-life operation. Additionally, this would also enable a better differentiation of good and poor quality products for the benefit of the end user customers, regarding typical real-life use.

6.11.2.3. BC emission measurement methods

No country (including the EU Member States, the Nordic countries and U.S./Canada) has BC standards so according to the International Cryosphere Climate Initiative (ICCI) a great potential exists for regulation and voluntary ”climate-friendly” standards, for new stoves, through producers and eco-labelling programs [101].

Currently, a protocol has been developed and subsequently tested in 2012–2015 by Nordic test and research institutes, with Danish Technological Institute as project manager [102]. This protocol describes a potential standardized procedure for measurements of BC in terms of both EC (Elemental Carbon) and OC (Organic Carbon) generated in residential wood burning stoves. According to the authors, such the standardized test, Nordic Swan Ecolabel could be used for voluntary eco-labelling of wood stoves, and also by manufacturers interested in testing and developing extremely low-emission, low-black carbon, “climate-friendly” stoves. The development of this testing protocol was part of a project supported by the Nordic Council of Ministers, the Climate and Clean Air Coalition (CCAC) and implemented by the International Cryosphere Climate Initiative (ICCI). Such testing protocol (ICCI protocol) could be used by national laboratories interested in establishing a standardized baseline for stove comparison, in terms of black carbon emissions.

The protocol provides for a “piggyback test”, which could be conducted on top of the NS3058 Full Flow Dilution Tunnel test, or similar multiple burn rate testing procedures for EC and OC (such as those indicated by the U.S.E.P.A.). Also in this case, the testing protocol could be used by national laboratories interested in establishing a standardized baseline for stove comparison, concerning the black carbon emissions [102].

The on-going work will also ascertain the applicability of some of these procedures to so-called single burn rate or “hot gas” testing procedures, currently in use in many countries of the European Union [102].

Such a protocol, although adapted to the specific case, was used in study [104]. Three stoves spanning a range of manufacturing year/certification status were tested using a slightly modified BC protocol at the U.S. EPA wood stove test facility. Continuous measurements of gas phase emissions (CO_2, CO, THC (Total Hydrocarbon Compounds), and NOx) and particle phase emissions (PM, BC) were conducted throughout the test. Filter samples were collected as specified in the BC protocol to derive BC emission factors.

BC emission factors were calculated by several different methods: total capture, carbon balance, and online sampling/measurement. The total capture method is specified in the BC protocol and requires accurate measurement of the duct velocity, sample velocity, and mass loss during the test. The carbon balance requires measurement of all carbon containing pollutants and it is assumed that all the carbon in the fuel is emitted in the exhaust gases. The online method uses the carbon balance for calculating the emission factor but relies on the online BC measurement from the Aethalometer-33, as opposed to the filter measurement of EC, used in both the BC protocol and the BC carbon balance emission factor. Difficulties were encountered at several levels, in filter samples, due to some discontinuities during the test.

The BC protocol emission factors are generally higher than the values in the two other methods (0.9 – 3.8 times greater). However, for most of the tests, the BC protocol and the online BC emission factors resulted similar, with a few tests skewing the average ratio toward higher values. The protocol calls for an adjustment.

Most of the deviations from the BC protocol were made to face the high PM concentrations and to prevent filter overloading. Stoves with larger combustion chamber volumes had longer test durations, which also made difficult to avoid the overloading of the filter. ICCI BC emission factors were generally higher than those calculated using the carbon balance method, likely due to the adjustment for particle losses included in the ICCI calculation. A further analysis was recommended by this study to determine the impact of the test facility on the BC emission factor.

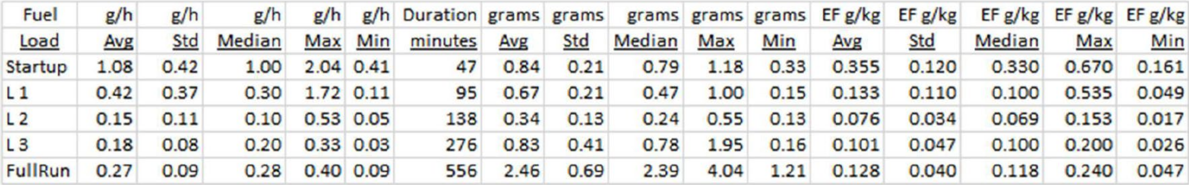
Under the project [103], NESCAUM measured black carbon from wood stoves, by using an optical transmission method. A modified Magee Scientific AE-22-ER Aethalometer BC analyser was run, in manual tape advance mode, to make 5-second BC measurements in a Method 5G dilution tunnel (the Aethalometer filter spot loading artefact was corrected using a specific approach). No difficulty was highlighted, but the study is not completely finished, yet. The BC emissions are as follows according to the different burn phase. Ignition phase is also considered.

Table 107: Stove descriptions, PM certification values, and average dry BC EF [103]

Stove #	# of test runs	Construction Type	Firebox Size	Emission Controls	EPA 2015 NSPS Certification Value	Dry BC EF, g/kg
Stove 1	4	High mass	Large	Non-catalytic	Step 1 cert value <3.0 g/hr	0.116
Stove 2	1	High mass	Small	Catalytic	Step 2 cert value <2.0 g/hr	0.107*
Stove 3	1	Steel	Large	Catalytic	Step 1 cert value <2.0 g/hr	0.047*
Stove 4	1	Cast iron	Small	Non-catalytic	Step 1 cert value <4.0 g/hr	0.240*
Stove 5	4	Cast iron	Medium	Non-catalytic, non-tube	Step 1 cert value <2.0 g/hr	0.125
Stove 6	4	Steel	Medium	Non-catalytic	Step 1 cert value <4.0 g/hr	0.142
Stove 7	3	High mass	Medium	Hybrid - catalytic and non-catalytic	Step 2 cert value <2.0 g/hr	0.126

* Stoves with a single run may not be representative of typical performance, and BC from IDC protocol V1 may not be comparable to V2. Project resources did not allow for additional BC testing of stoves 2, 3, and 4 on IDC protocol V2.

Table 108: Range of BC emission rates (g/h), total BC emitted (grams), and BC emission factors (g/kg) on the 7 stoves tested for the direffernt burning phase [103]



Fuel Load	g/h Avg	g/h Std	g/h Median	g/h Max	g/h Min	Duration minutes	grams Avg	grams Std	grams Median	grams Max	grams Min	EF g/kg Avg	EF g/kg Std	EF g/kg Median	EF g/kg Max	EF g/kg Min
Startup	1.08	0.42	1.00	2.04	0.41	47	0.84	0.21	0.79	1.18	0.33	0.355	0.120	0.330	0.670	0.161
L 1	0.42	0.37	0.30	1.72	0.11	95	0.67	0.21	0.47	1.00	0.15	0.133	0.110	0.100	0.535	0.049
L 2	0.15	0.11	0.10	0.53	0.05	138	0.34	0.13	0.24	0.55	0.13	0.076	0.034	0.069	0.153	0.017
L 3	0.18	0.08	0.20	0.33	0.03	276	0.83	0.41	0.78	1.95	0.16	0.101	0.047	0.100	0.200	0.026
FullRun	0.27	0.09	0.28	0.40	0.09	556	2.46	0.69	2.39	4.04	1.21	0.128	0.040	0.118	0.240	0.047

The study “Emission factors for SLCP emission from residential wood combustion in Nordic countries” [105], aimed at better estimating pollutant emissions from domestic appliances, provides interesting information of EC/BC/OC emissions in 10 boilers and 9 room heaters (stoves), commonly used in the Nordic countries, were tested. All samplings for particulates ($PM_{2.5}$, EC, OC, BC) were done in a full flow dilution tunnel according to specifications in NS3058. Samples were collected on quartz filters for subsequent analysis. Analysis of $PM_{2.5}$ was made gravimetrically, while EC/OC were analysed thermo-optically according to NIOSH protocol 870. BC was analysed optically (using an OT21 aethalometer) on the filter samples before they were analysed for EC and OC. The results for BC from the aethalometer analyses showed a weak correlation with the EC results, and BC results were considerably lower than the EC results, generally, about one third. Such results were considered questionable, since, in theory, BC should be on the same values or higher than the EC results. Due to that, the NIOSH protocol 870 for analysis of EC is considered a method more reliable established than the aethalometer analysis (including the calculation algorithm), for BC. By the end, the measurement of BC by aethalometer was not used due to the lack of consistency.

BC measurement methods widely used do not exist, yet. At the current stage, it seems too early to propose limit values for BC, for the classification of the stove performances. Additional research is deemed necessary to achieve a robust measurement method well accepted.

6.11.3. Existing standards and labels on domestic appliances

In several sub-regions of UNECE, domestic appliances are subject to standardisation and have to comply with given limit values to be allowed on sale. In the EU, two regulations related to solid fuel boilers, with a rated heat output of 500 kW and solid fuel ambient space heaters, with a rated heat output of not higher than 50 kW (refer to the following chapter) will rule and change the current regulations existing in some Member States, if the requirements in the two EU regulations [17][18] are stricter than the existing requirements in the Member States regulations. The Vito study [9] offers a survey of regulations existing in the EU Member States. In the current report, only the regulations requiring the strictest PM limit values are described.

6.11.3.1. Existing standards for domestic appliances in the UNECE region

EU

In the EU, the Eco-design Directive [78] establishes a framework under which manufacturers of energy-using products are obliged to reduce the energy consumption and other adverse environmental impacts occurring throughout the product life cycle. It is complemented by the Energy Labelling Directive and several associated regulations such as for domestic heating appliances with solid fuels.

- Regulation 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Eco-design requirements for solid fuel boilers with a rated heat output of 500 kW or less [17].
- Regulation 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Eco-design requirements for solid fuel local space heaters with a rated heat output of 50 kW or less [18].

The limit values laid down by the above two EU regulations for solid fuel boilers, since January 1st, 2020, and for solid fuel small appliances, such as stoves and inserts, since January 1st, 2022, are reported in the following tables. The regulation 2015/1185 considers three different measurement methods for PM and the limit values result different according to these methods ((1) based of filtrable solid particles only, (2) and (3) considering condensables):

Table 109: Limit values laid down for solid fuel local space heaters with a rated heat output of 50 kilowatt or less by EU regulation 2015/1185 [18]

Appliances[2]	Efficiency	TSP	VOC	CO	NO_x
		Test according to analytical method described in annex III, point 4(a)			
	%	at 13% O_2			
		mg/m^3 (1) or g/kg (2) (3)	mg Ceq/m^3	mg/m^3	mg/m^3
Open fronted solid fuel local space heaters	30	50 mg/m^3 (1)	120	2000	300

---

[2] Definition according to the regulation :

(1)‘solid fuel local space heater’ means a space heating device that emits heat by direct heat transfer or by direct heat transfer in combination with heat transfer to a fluid, in order to reach and maintain a certain level of human thermal comfort within an enclosed space in which the product is situated, possibly combined with a heat output to other spaces, and is equipped with one or more heat generators that convert solid fuels directly into heat;

(2)‘open fronted solid fuel local space heater’ means a solid fuel local space heater of which the fire bed and combustion gases are not sealed from the space in which the product is fitted and which is sealed to a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion;

(3)‘closed fronted solid fuel local space heater’ means a solid fuel local space heater of which the fire bed and combustion gases can be sealed from the space in which the product is fitted and which is sealed to a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion;

(4)‘cooker’ means a solid fuel local space heater, using solid fuels, that integrates in one enclosure the function of a solid fuel local space heater, and a hob an oven or both to be used for preparation of food and which is sealed to a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion;

Appliances[2]	Efficiency	TSP	VOC	CO	NO_x
		Test according to analytical method described in annex III, point 4(a)			
	%	at 13% O_2			
		mg/m^3 (1) or g/kg (2) (3)	mg Ceq/m^3	mg/m^3	mg/m^3
		6 g/kg (2)			
Closed fronted solid fuel local space heaters using solid fuel other than compressed wood in the form of pellets and cookers	65	40 mg/m^3 (1) 5 g/kg (2) 2.4 g/kg (3) In case of biomass 5.0 g/kg (3) in case of solid fossil fuel	120	1500	200
Closed fronted solid fuel local space heaters using compressed wood in form of pellets	79	20 mg/m^3 (1) 2.5 g/kg (2) 1.2 g/kg (3)	60	300	200

(1) Test according to the following analytical method (described in annex III, point 4(a) (i) 1)
PM measurement by sampling a partial dry flue gas sample over **a heated filter**. PM measurement as measured in the combustion products of the appliance shall be carried out while the product is providing its nominal output and if appropriate at part load;

(2) kg of dry matter. Test according to the following analytical method (described in annex III, point 4(a) (i) 2)
PM measurement by sampling, over the full burn cycle, a partial flue gas sample, using natural draft, from a diluted flue gas using a **full flow dilution tunnel** and a filter at ambient temperature;

(3) kg of dry matter. Test according to the following analytical method (described in annex III, point 4(a) (i) 3)
PM measurement by sampling, over a 30-minute period, a partial flue gas sample, using a fixed flue draft at 12 Pa, from a diluted flue gas using **a full flow dilution tunnel** and a filter at ambient temperature or an electrostatic precipitator.

In addition to the different analytical methods which can be used, considering condensables (2) and (3) or not considering them (1), the conditions for measuring the emissions are different, in the three methods: nominal output in method (1), full burn cycle in method (2) and a 30 minute period in method (3).

Table 110: Limit values laid down for solid fuel boilers with a rated heat output of 500 kilowatt or less by EU regulation 2015/1189 (seasonal space heating emissions) [17]

	Efficiency	TSP	VOC	CO	NO_x
	%	at 10% O_2			
		mg/Nm^3	mg Ceq/m^3	mg/m^3	mg/m^3
Automatic boilers	≤ 20 kW: 75 > 20 kW: 77	40	20	500	200
Manual Boiler	≤ 20 kW: 75 > 20 kW: 77	60	30	700	350

The seasonal space heating emissions E_s of respectively particulate matter, organic gaseous compounds, carbon monoxide and nitrogen oxides are calculated as follows:

(1) for manually stoked solid fuel boilers that can be operated at 50 % of the rated heat output in continuous mode, and for automatically stoked solid fuel boilers: $E_s = 0{,}85 \times E_{s,p} + 0{,}15 \times E_{s,n}$

(2) for manually stoked solid fuel boilers that cannot be operated at 50 % or less of the rated heat output in continuous mode, and for solid fuel cogeneration boilers: $E_s = E_{s,n}$

where:

(a) $E_{s,p}$ are the emissions of respectively particulate matter, organic gaseous compounds, carbon monoxide and nitrogen oxides measured at 30 % or 50 % of rated heat output, as applicable;

(b) $E_{s,n}$ are the emissions of respectively particulate matter, organic gaseous compounds, carbon monoxide and nitrogen oxides measured at rated heat output.

(c) Emissions of particulate matter shall be measured by a gravimetric method excluding any particulate matter formed by organic gaseous compounds when flue gas is mixed with ambient air.

(d) Emissions of nitrogen oxides shall be calculated as the sum of nitrogen monoxide and nitrogen dioxide, and expressed in nitrogen dioxide.

For boilers gravimetric methods only are used to measure PM emissions.

Denmark

In Denmark a new legislation on wood stoves and boilers entered into force in 2018 [9]. The emission requirements, in manually and automatically fired wood boilers are the same as in the EU regulation 2015/1189. For wood stoves, however, the requirements for dust emissions are stricter than in the EU regulation 2015/1185: 4g/kg (measurement by dilution tunnel) and 30 mg/m^3 at 13% O_2 measured in the flue gas pipe.

According to Vito [9], wood stoves and boilers may be installed only if these emission requirements are met. To demonstrate that the emission requirements have been met, appliances are subject to a (type) inspection and the release of an ad hoc certificate. The owner of the appliance installed, must have the test certificate checked and signed by a skilled chimney sweep operator, at his own expense. The regulation provides for the necessary enforcement options (e.g. fines) and the possibility for municipalities to enforce additional regulations in specific zones, if necessary.

Germany

As described in reference [9], in Germany the 'Verordnung über kleine und mittlere Feuerungsanlagen (1. BImSchV) applies to appliances for domestic wood heating (updated in 2010 [106], [97]). The regulation applies to construction, characteristics and operation of those firing installations which do not require a licence, in accordance with section 4 of the Federal Immission Control Act (*Bundes-Immissionsschutzgesetz*) [106].

Boilers for solid fuels

Limit values for new boilers using solid fossil fuels or solid biomass are illustrated in the following table [106].

These limit values apply for boilers which are constructed (installed) from 22 March 2010 onwards (Level 1) or after 31 December 2014 (Level 2). Existing boilers may only continue to be operated if the limit values of level 1 of section 5 subsection (1), first sentence, depending on the date of their construction, are complied with from the dates in Section 25 subsection (1). The limit values are measured and must be complied with when boilers are in service.

In the regulation 1. BImSchV, limit values are expressed at 13% O_2 A proper conversion has been made to have the values at 10% O_2 so to allow an easier comparison with limit values of regulation 2015/1189 [18]:

Table 111: Limit values for new boilers using solid fuels (1 to 8) and some specific fuels (9 to 13) [106]

	Rated heat output (kW)	Limit values for dust		Limit values for CO	
		g/Nm^3 at 13% O_2	g/Nm^3 at 10% O_2	g/Nm^3 at 13% O_2	g/Nm^3 at 10% O_2
Level 1 for installations constructed after 22/03/2010					
Fuels 1 to 3a	≥ 4, ≤ 500	0.09	0.1238	1.0	1.375
	> 500	0.09	0.1238	0.5	0.6875
Fuels 4 to 5	≥ 4, ≤ 500	0.10	0.1375	1.0	1.375
	> 500	0.10	0.1375	0.5	0.6875
Fuels 5a	≥ 4, ≤ 500	0.06	0.825	0.8	1.100
	> 500	0.06	0.825	0.5	0.6875
Fuels 6 to 7	≥ 30, ≤ 100	0.10	0.1375	0.8	1.100
	< 30, ≤ 500	0.10	0.1375	0.5	0.6875
	> 500	0.10	0.1375	0.3	0.4125
Fuels 8 to 13	≥ 4, < 100	0.10	0.1375	1.0	1.375
Level 2 for installations constructed after 31/12/2014					
Fuels 1 to 5a	≥ 4	0.02	0.0275	0.4	0.55
Fuels 6 to 7	≥ 30, ≤ 500	0.02	0.0275	0.3	0.413
	> 500	0.02	0.0275	0.3	0.413
Fuels 8 to 13	≥ 4, < 100	0.02	0.0275	0.4	0.55

1. hard coal, non-pitch-bonded hard coal briquettes, hard coal coke,
2. brown coal, brown coal briquettes, brown coal coke,
3. fuel peat, pellets made of fuel peat,
3a. barbecue charcoal, barbecue charcoal briquettes in accordance with DIN EN 1860, edition September 2005,
4. untreated chunky wood, including the attached bark, in particular in the shape of split logs and chips, as well as brushwood and cones,
5. untreated non-chunky wood, in particular in the shape of sawdust, shavings and sander dust, as well as bark, 5a. pellets made of untreated wood in the shape of wood briquettes in accordance with DIN 51731, edition October 1996, or in the shape of wood pellets in accordance with the requirements made of fuels by the DINplus Certification Scheme "Wood pellets for use in small furnaces in accordance with DIN 51731-HP 5" edition August 2007, as well as of other wood briquettes or wood pellets made of untreated wood of equivalent quality,
6. painted, lacquered or coated wood, as well as residues thereof, insofar as no wood preservatives were applied or are contained therein as the result of treatment, and coatings do not contain any halogen organic compounds or heavy metals,
7. plywood, chipboard, fibreboard or other glued wood, as well as residues thereof, insofar as no wood preservatives were applied or are contained therein as the result of treatment, and coatings do not contain any halogen organic compounds or heavy metals, 8. straw and similar plant-based materials, cereals not intended as food such as cereal grains and broken cereal grains, whole grain plants, tailings, husks and cereal stalk remnants, as well as pellets made of the abovementioned fuels,
9. fuel oil EL in accordance with DIN 51603-1, edition August 2008, and other light heating oils of equivalent quality, as well as methanol, ethanol, untreated plant-based oils or plant-based oil methyl ester, 10. gases from public gas supply, untreated natural gas or petroleum gas with comparable sulphur contents, as well as liquid gas or hydrogen,
11. sewer gas with a volume content of sulphur compounds up to 1 per thousand, stated as sulphur, or biogas from agriculture,
12. coke oven gas, mine gas, steel gas, blast furnace gas, refinery gas and synthesis gas with a volume content of sulphur compounds up to 1 per thousand, stated as sulphur, as well as
13. other renewable raw materials insofar as they comply with the requirements in accordance with subsection (5).
(1) The fuels no. 6 or no. 7 may only be used in firing installations with a rated heat output of 30 kilowatt or more, and only in wood treatment and wood processing businesses.

(2) The fuels nos. 8 and 13 may only be used in automatically-stoked firing installations which according to information from the manufacturer are suitable for these fuels.

For boilers, the 1st BImSchV has more ambitious limit values for dust as compared to the EU regulation 2015/1189. Measurements are made at nominal load.

For boilers, after a transition period of 5 to 15 years (depending on the age of the installation), new provisions also apply to existing boilers (2015-2025).

Single room firing installations

New installations must comply with the emission and energy efficiency requirements shown in the following table. Currently the second level applies to appliances put into service after 31/12/2014 (level 2). The emission requirements are expressed at nominal heat output. The reference oxygen content is 13%.

Table 112: Limit values at test bench (type test) for small domestic appliances in Germany according to the 1-BImSchV (13% O_2) [106]

		Level 1: construction from 22/03/2010		Level 2: construction from 31/12/2014		Construction from 22/03/2010
Type of furnace	Technical standard	CO g/Nm^3 at 13% O_2	PM g/Nm^3 at 13% O_2	CO g/Nm^3 at 13% O_2	PM g/Nm^3 at 13% O_2	Efficiency
Room heater with flat fuelling	DIN EN 13240 (edition October 2005) non-continuous burning	2.0	0.075	1.25	0.04	73
Room heater with fill firing	DIN EN 13240 (edition October 2005) continuous burning	2.5	0.075	1.25	0.04	70
Individual storage firing installations	DIN EN 15250/A1 (edition June 2007)	20.	0.075	1.25	0.04	75
Fireplace insert (closed operation)	DIN EN 13229 (edition October 2005)	2.0	0.075	1.25	0.04	75
Tiled stove inserts with flat fuelling	DIN EN 13229/A1 (edition October 2005)	2.0	0.075	1.25	0.04	80
Tiled stove inserts with fill firing	DIN EN 13229/A1 (edition October 2005)	2.5	0.075	1.25	0.04	80
Cook stoves	DIN EN 12815 (edition September 2005)	3.0	0.075	1.5	0.04	70
Heating and cooking stoves	DIN EN 12815 (edition September 2005)	3.5	0.075	1.5	0.04	75
Pellet stoves without water compartment	DIN EN 14785 (edition September 2006)	0.40	0.05	0.25	0.03	85
Pellet stoves with water compartment	DIN EN 14785 (edition September 2006)	0.4	0.03	0.25	0.02	90

For dust, emission limit values at test bench for stoves are identical to the EU regulation 2015/1185.

For existing appliances, older than 22/03/2010, transitional periods have been allowed (until 2015 to 2025 according to the age of installations). The dust limit value applied after the transition period is 0.15 g/m^3 for stoves.

Single-room firing installations for solid fuels which were constructed and in operation prior to 22 March 2010 may only be further operated if these limit values are not exceeded.

Interestingly, according to the regulation 1. BImSchV the controls are carried out when the appliances are installed. These controls are made by a chimney sweeper operator [106]:

- For boilers, the chimney sweeper operator carries out measurements on-site, every two years, to check the compliance with the emission requirements. The chimney sweeper operator runs measures of CO and PM, at nominal load (the measurement is carried out according to VDI 4207-2 - Emission measurements at small firing installations - Measurements at installations for solid fuel. VDI 4207-2 Number 5.2.3)
- For stoves, the chimney sweeper operator checks the proper functioning and technical conditions of the appliance, twice in 7 years. This is also the case when a new appliance is put into operation or in case of change in the ownership of the appliance.

The operator of a hand-stoked firing installation for solid fuels shall seek the advice of a chimney sweep subsequent to construction, or to a change of operator, within one year as to the proper operation of the firing installation, the proper storage of the fuel, as well as the particularities related to handling solid fuels, in connection with other work performed by a chimney sweeper (Section 4 subsection (8)).

Moreover, the chimney sweeper operator measures the moisture content of the stored wood and provides advice to the owner about the optimal operation of the appliance.

For stoves, the status of compliance with emission limit values must be demonstrated by a type approval report provided by the manufacturer (if available) or by an on-site emission measurement [106]. If the stove does not comply with the emission requirements, the appliance has to be dismissed (decommissioned) or retrofitted with a proper device to reduce particulate matter emissions (filter - e.g., electrostatic precipitator). Exceptions are foreseen, among others for stoves which are the sole heating existing source in a dwelling and also for 'historical' stoves (built before 1950) as well as for cook stoves and baking ovens not used for commercial purposes, for open-hearth fireplaces, and masonry heaters (Section 25 subsection (3) Number 1 -5).

US

It is recognised that in North America, manufacturers of wood domestic appliances have developed technologies enabling them to achieve low emissions of particles and to fulfil the limit values fixed by national/local authorities. Such limit values cannot be easily compared with European limit values because the test protocols, in EU and North America are very different. In particular, for what concerns the impact of the burn rate on the pollutants emissions, and the inclusion of condensables in PM in North America, as compared to the solid PM only, in the EU and most of EU Member States [84], also taking into account that the EU regulation 2015/1185 considers three measurement methods (see above).

Table 113: US 2015 and 2020 standards [89][90]

Wood Heater	2015 / 2016 / 2017 Standards	2020 Standards
Adjustable burn rate stoves, single burn rate stoves and pellet stoves (Subpart AAA)	PM emission limit ≤ 4.5 g/hr (using crib, pellets or cord wood) On May 15, 2015 See §60.532(a)	**PM emission limit ≤ 2.0 g/hr (using crib wood or pellets)** See §60.532 On May 15, 2020 See §60.532(b) **Or PM emission limit ≤ 2.5 g/hr (using cord wood)** On May 15, 2020 See §60.532 (c)
Hydronic heaters (Subpart QQQQ)	PM emission limit ≤ 0.32 lb/mmBtu heat output (weighted average) and a cap of 18 g/hr for each individual burn rate (using crib, pellets or cord wood) On May 15, 2015 See §60.5474(b)(1)	PM emission limit ≤ 0.10 lb/mmBtu heat output for each individual burn rate (using crib wood or pellets) On May 15, 2020 See §60.5474(b)(2); Or PM emission limit ≤ 0.15 lb/mmBtu heat output for each individual burn rate (using cord wood) On May 15, 2020 See §60.5474(b)(3)

Remarks concerning test methods to be used [89]:

(1) Fuelling and Operating Methods[1]

Conduct testing using EPA Method 28R[2] or ASTM E2779-10[3], or an alternative test method approved by the Administrator

Cord Wood Option: Conduct testing with cord wood using a cord wood test method approved by the Administrator (*e.g.*, ASTM E2780-10)[4]

(2) Sampling and Analytical Methods

PM concentrations must be measured by the test method specified in ASTM E2515-11.[5]

Thermal efficiency, CO and heat output must be measured using CSA Method B415.1-10.[6]

[1] Prior to testing, the heater must be operated for a minimum of 50 hours using a medium burn rate, at manufacturer's facility or at test lab. Douglas fir may be used in ASTM E2779-10, ASTM E2780-10 and CSA B415.1-10 (and Method 28R).

[2] Method 28R covers the fuelling and operating protocol of wood stoves, including pellet stoves, and requires using ASTM E2515-11 to measure emissions (not Method 5H). Method 28R incorporates the provisions of ASTM E2780-10, with burn rate and start up modifications based on Method 28. For single-burn rate stoves, Method 28R includes the burn rate protocol detailed in Appendix X1 of ASTM E2780-10. ASTM E871–82 may be used as an alternative to the procedures in Method 5H or Method 28 for determining total weight basis moisture in the analysis sample of particulate wood fuel.

[3] ASTM E2779-10 covers the fuelling and operating protocol for determining PM emissions from pellet stoves.

[4] For the 2015 standard, stoves tested with cord wood must meet the same PM emission limit as if tested with crib wood. For the 2020 standard, stoves tested with cord wood have an alternative PM emission limit (shown above). ASTM E2780-10 (cord wood annex) is an example of an alternative cord wood-based method, which is used in conjunction with ASTM E2515-11. When using ASTM 2780-10, the four burn rate categories and weighting factors in Method 28R must be used.

Switzerland

The Swiss ordinance on air protection has been revised and requirements for small domestic appliances, with nominal power lower than 70 kW, were introduced [99][91]. Small domestics appliances < 70 kW are ruled by limit values.

For what concerns the sale of the appliances, the ordinance ensures compatibility with EU eco-design regulations: EU 2015/1185 solid fuel local space heaters < 50 kW and EU 2015/1189 solid fuel boilers < 500 kW. Since the 01/01/2022, the requirements of the two EU regulations are applied (communication of R. Kegel (communication of R. Kegel (Federal Office of Environment [100]) to Citepa of 21/12/2021)

The regulation tightens the ELVs for CO and introduces ELVs for dust under operating conditions with obligation for periodic inspections and monitoring.

Heat accumulators are mandatory for boilers up to 500 kW except for pellet boilers, with nominal power lower than 70 kW.

The limit values are in force since the 01/06/2018. Transitory requirements, for 10 years, are allowed for existing appliances [100].

The limit values are as in the followings:

Table 114: Swiss limit values for appliances < 70 kW (new and existing ones) [99][91]

Category	CO mg/m^3 at 13% O_2	Dust mg/m^3 at 13% O_2
Cooking stoves	4000	100
Single room heaters	2500	100
Boilers manually stoked	2500	100
Boilers automatically stoked	1000	50

The requirements concerning the enter into service of appliances and the periodical checks are as in the following:

Table 115: Requirement for controls [91] [100]

Category	Putting in service	Periodic check
Cooking stoves	Declaration of performance or acceptance measurement of CO and dust or ESP	Periodic inspection and informative guidance Monitoring may be required in case of neighbourhood complaint
Single room heaters		
Boilers manually stoked	Acceptance measurement CO and dust	Periodic monitoring CO (and dust) every 4 years (every 2 years for boilers higher than 70 kW)
Boilers automatically stoked		

During the periodic inspections of installations, visual inspections and soft measures such as in the following, are performed:

- Fuel wood quality control (moisture, size, naturalness, no waste content)
- Residues in combustion chamber (ash, soot)
- Operating conditions (ignition from top, air supply)
- Technical condition of heating device (airflow, tightness)

In case of non-compliance, the retrofit with an ESP may be required, or even the replacement of the heating device.

Transitory requirements are allowed for 10 years, for existing appliances [100].

6.11.3.2. Labels

Germany

In 2020, the criteria of the Blue Angel label for stoves have been updated. The environmental label may be awarded to stoves which burn efficiently the fuel and are characterized by significantly low pollutant emissions. In addition to the statutory regulations for the type testing process, for the stoves, the special requirements established by the Blue Angel are such as stoves have to comply with significantly lower particulate and CO limit values. This condition must be verified also during the ignition phase when a particularly high level of emissions is observed. In the case of organic gaseous carbon (OGC) and nitrogen oxides (NO_x), their emissions have already to be below the limits defined in the EU Eco-design requirements, generally applicable since January 2022 [30].

The above basic award criteria apply to wood stoves, which, according to the manufacturer operating instructions are designed for natural wood (split logs), including barks, compressed wood (such as briquettes, pellets) or for multiple combination of these fuels.

The stoves, also designed by the manufacturer to burn coal, are out of the scope of the Basic Award Criteria.

The limit values are as in the following:

Table 116: emission limit values for the Blue Angel criteria in 2021 and test methods [30]

Parameter	Test method for the measurement specifications according to Appendix B	Limit value (1) for emissions	Limit value (1) for emissions from stoves before a downstream separator
Particle mass concentration	DIN EN 16510-1:2018 (2)	0.015 g/m³	0.040 g/m³
Particle count concentration	See Appendix C (Measurement obligatory from 01/01/2020)	From 01/01/2024: 5 x 10⁶/cm³	No value
CO mass concentration	DIN EN 16510-1:2018 (2)	0.50 g/m³	0.50 g/m³
OGC mass concentration	DIN EN 16510-1:2018 (2)	0.07 gC/m³	0.07 gC/m³
NOx mass concentration	DIN EN 16510-1:2018 (2)	0.18 g/m³	0.18 g/m³
(1) Based on dry flue gas, normalised to 0 °C, 1013 mbar and 13% oxygen by volume. (2) Residential solid fuel burning appliances - Part 1: General requirements and test methods			

The requirements can be fulfilled in two ways [30]:

a) Testing the overall system:

   If the mean values from the individual measurements as described in the Blue angel document Annex B (measurement specifications for the particles, CO, OGC and NO_x mass concentrations) that were carried out on the tested stove, including all of the intended fixtures and attachments, do not exceed the relevant limits specified in the above Table, Column 3.

b) In combination with an efficient particle separator:

- The requirements will have been fulfilled if the mean values from the individual measurements described in the Blue angel document Annex B that were carried out on the stove do not exceed the relevant limits specified in the above Table, Column 4 and the stove is sold and installed together with a particle separator. For particle separators, a minimum separating efficiency of 75% of the particle mass and (from 01/01/2024) 90% of the particle count must be verified. The limit value in the above Table, Column 3 must be complied with reliably when taking into account the separating efficiency
- If a particle separator for which this minimum separating efficiency has been verified, is already integrated into a chimney, the manufacturer can also sell the stove without the separator. The fact that the stove must be installed together with the associated particle separator that is integrated into the chimney must be indicated during the sale of the product and also in the installation instructions. The particle separator integrated into the chimney must already have been named and tested when submitting the application for the stove.

The concentration of particles of 0.015 g/m^3 is significantly lower than the limit value implemented by the EU regulation 2015/1185 of 0.040 g/m^3 for stoves burning log woods, and of 0.020 g/m^3 for stoves burning pellets [18] which are not covered by the Blue Angel. The following comparison has been made and it is illustrated in the table below:

Table 117: Comparison of emission limit values from the ecodesign regulation and the Blue Angel criteria in 2021 [30]

	Efficiency %	Dust/PM mg/m^3	CO mg/m^3	NO$_x$ mg/m^3	HC (OGC) mg/m^3
Appliances with closed front solid fuel other than wood pellets (EU regulation)					
Eco-design requirements	65	40	1500	200	120
Eco-design: indicative benchmark of best performing appliances	86	20	500	50	30
Eco-design: example of good combination	83	33	1125	115	69

Measurement of the “total particle mass” parameter should be carried out according to DIN EN 16510-1:2018-11 A 4.7 and Appendix F. Alternatively, other gravimetric measurement methods for this parameter that have been approved for the type testing process for stoves by notified testing institutions in Germany may be used.

The measurement of CO, CO_2, O_2, H_2O, VOC, total dust mass concentrations and particle number are made on test procedures as in the following [92]:

- Continuous measurement over all 7 burn cycles, from "cold start" to “residual coal bed weight”,
- Ignition ("cold start" = first two burns) with natural draft,
- Ignition, nominal and partial load in one test cycle,
- No selection of the best burns, all burns counted and averaged.

Natural draft and cold start (Increased emissions due to "cold" combustion) are used for representing realistic behaviour, at ignition.

Therefore, the testing requirements for the Blue Angel go beyond the specifications for the type testing process, as in the EU regulation 1185/2015 [30].

In addition, there are requirements on the combustion chamber, the tightness, the air regulation (if nominal and partial load operation is not recognized by the automatic stove control independently of the operator, the stove manufacturer must specify exact control modes (switch on the device, smartphone application or similar) for the purpose of selecting nominal and partial load by the operator. A corresponding note as well as an exact specification of the wood support (wood mass, dimensions, log wood geometry) for both operating modes must be included in the Quick User Guide and the operating instructions (along with photos for clear illustration). It must be made clear to the operator that only these log wood properties defined in the accredited emissions test, are permitted in the respective control modes and that different properties of the defined wood supports lead to non-compliance with the requirements of the Blue Angel), combustion monitor (a display must be provided for the user to indicate any deviation from the optimal operating state and to request that the user stokes the fire using wood), rational use of energy (the efficiency with respect to the fuel energy at nominal load (nominal heating output) and the “partial load” intended by the manufacturer (smallest output stated by the manufacturer) must be determined. The efficiency must not fall below 75%, neither at nominal load or “partial load”).

Nordic countries (Sweden, Norway, Iceland, Denmark and Finland): the Nordic Swan

The Nordic Swan label was introduced in 1989. Wood stoves and boilers are covered. The criteria are as in the following [9][98]:

Table 118: Criteria for energy efficiency and emissions in the Nordic Swan (13% O2 for stove, 10% O_2 for boilers) [9][98]

Appliance	CO (mg/Nm^3)	OGC (mg/Nm^3)	Dust (1)	NOx (mg/Nm^3)	Energy efficiency (%)
Manually fired stove or inset stove for non-continuous use	1250	100	2 g/kg fuel (average for max. 4 loads) 5 g/kg fuel (for each load)		76
Manually fired slow heat release appliances	1250	100	50 mg/m^3		83
Pellet stove with automatic feed	200	10	15 mg/m^3		87
Manually fired boiler	350	15	40 mg/m^3	200	87 + log(output)
Automatically fired boiler	250	10	30/40 mg/m^3	200	88 + log(output)

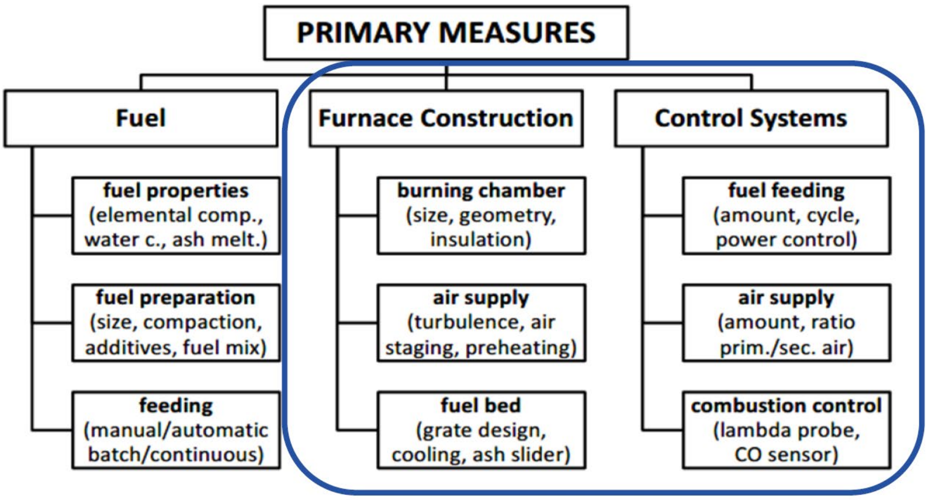
The emissions expressed in g/kg are measured with the dilution tunnel and those expressed in mg/m^3 directly in the hot flue gas [9].

For manually operated stoves, or insert stoves, for intermittent use, NS 3058 and NS 3059, with loads defined in class 1 and class 2, for test of particles are used [98].

For other appliances, CEN/TS 15883:2009 for particles are used [98].

6.11.4. Development of low emission appliances and best available techniques

In order to reduce pollutant emissions, the manufacturers of appliances work on primary design measures, as presented in the following figure, but also possibly considering secondary measures. Catalysts are used in the US and Canada but they are less frequent in the EU. Catalysts are efficient on CO and VOC, respectively around 90% for CO and 50-70% for VOC [8]. Small electrostatic precipitator can also be used.



Source: http://task32.ieabioenergy.com/iea-publications/events/workshop-highly-efficient-clean-wood-log-stoves-berlin-november-2015/

Figure 8: Primary options studied to improve efficiency of stoves [8]

From TFTEI [23], the following list of new technologies were identified. New advanced stoves equipped with improved air control, reflective materials and two combustion chambers; New smart stoves with automated control of air supply and combustion, thermostatic control, Wi-Fi-connected to collect and send combustion data to the manufacturer for better service; New advanced masonry stoves, operating at high efficiencies and low emissions; New advanced pellet boilers: fully automated boilers (electronic control of air supply, lambda sensors), condensing boilers, using standardized pellets; Wood carburettor boilers using log wood or chip wood; Heat accumulating equipment with heat accumulating reducing stop/start frequencies and operation at partial load, which generates higher emissions than operation at full load; Other: flue gas recirculation, reverse combustion, gasifier [95].

The reduction of PM emissions is pursued through optimisation of the combustion conditions, by several means, to ensure the best optimized conditions in terms of temperature, residence time (sufficient time is required) and turbulence (to ensure good mixing of flue gases) (the three T's rules), but also the geometry of the combustion chamber, air supply and reducing the user's intervention, by the combustion automated systems. The solutions for these three T's parameters can be applied in stoves, as example in [8].

<u>Temperature:</u>

- Refractory lining in the combustion chamber,
- Shape and size of combustion chamber,

- Material and isolation of the door as well as size of window and its radiation coefficient or alternatively coated glasses or double/triple windows with air chambers in between,
- Windows should be of appropriate limited size.

Sufficient residence time:

- Gas volume flow,
- Distribution of flue gases over combustion chamber,
- Distribution of air,
- Height and width of the combustion chamber.

Turbulence or mixing of flue gasses:

- Distribution of purge air windows,
- Direction and geometry of additional inlet air,
- Velocities of flue gas and combustion air,
- Geometry of the main and the post combustion chamber,
- Geometry of deflection plate and the use of baffles in post combustion chamber,
- Avoidance of leakage streams (sealing),
- Avoidance of short-circuiting of the flue gas stream.

There are several projects aiming at improving the wood stoves and boilers, recognising that, for PM emissions and the fuel consumption, the technologies can be improved considerably, compared to the existing situation.

As an example, the project wood stove 2020 [79] is aimed at a comprehensive improvement of log wood stoves. The focus of the project lied not only on the furnace technology itself, but rather on the whole system. This also implies technical improvements of automatic combustion air control, heat storage, chimney draught control and minimization of user's intervention and standing losses. The following parameters have been optimized [83]:

- Appropriate insulation of main combustion chamber and post combustion chamber for almost complete burnout
- Efficient mixing of the flue gases with the combustion air
- Application of air staging
- Phase Change Materials heat exchanger to maximise the efficiency
- Automatic control

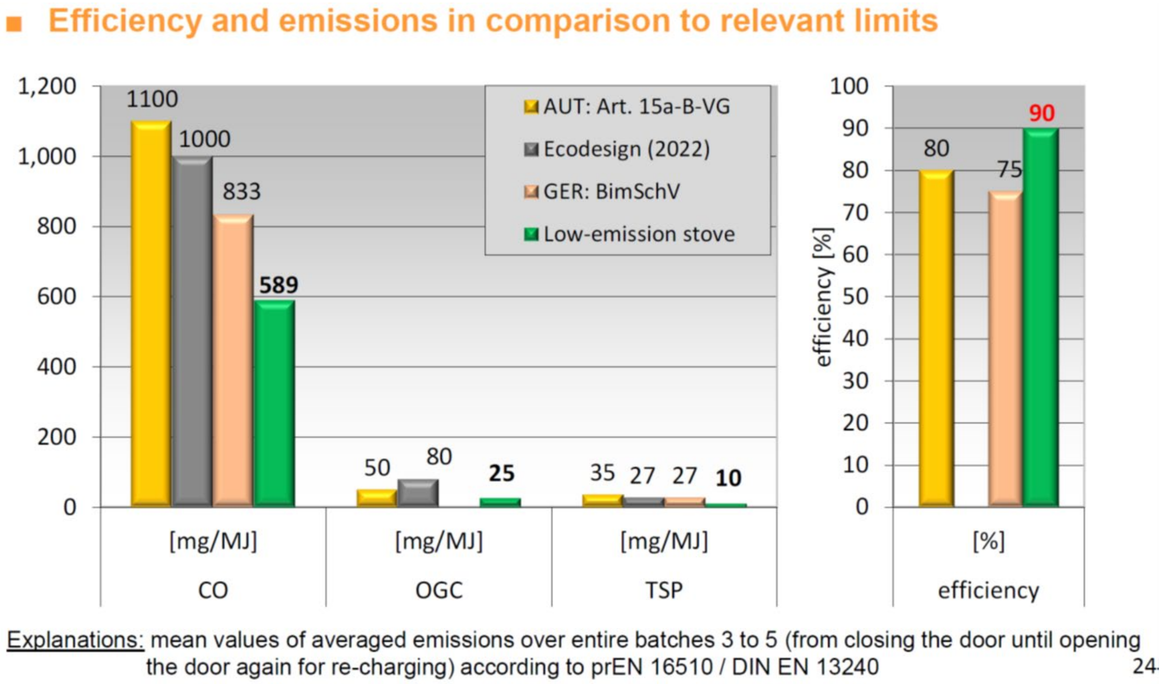
With the new technologies developed in the project, an emission reduction estimated between 50% and 80 % and an increase of the efficiencies above 90 % were targeted (the reference is not given). Performances and emissions have been assessed on a test cycle including ignition batch, 4 full load batches and charcoal burnout batch. PM were measured according to prEN 16510 / DIN EN 13240 (which implies condensables not considered).

In the project 'Wood stove 2020", guidelines have been developed for low emission and high efficiency stove concepts:

- Guidelines on low emission and high efficiency stove concepts [80],
- Guidelines on automated control systems for stoves [81],

- Guidelines on heat storage units based on phase change materials [82].

Through the solutions developed during the project “stove 2020”, the pollutant emissions changed as presented in the following figure. In terms of PM emissions, the stove emissions are as of 10 mg/MJ, compared to 27 mg/MJ in a stove in compliance with the new eco design requirements.



Explanations: mean values of averaged emissions over entire batches 3 to 5 (from closing the door until opening the door again for re-charging) according to prEN 16510 / DIN EN 13240

Figure 9: Efficiency and emissions of the new concept stove developed in the project STOVE 2020 [83]

The study [84] carried in France by INERIS on behalf of ADEME, with two French stove manufacturers (Chazelles and Supra), had the objectives of characterising the technologies used in two of the best performers among North America appliances and their impacts on air emissions, by testing these devices and comparing their environmental and energy performances with the performance of two French appliances of last generation, at different burn rates and two different types of wood. Pollutant concentration measurements have been made on four appliances:

- Two French stoves selected among the best performing of the two manufacturers involved in the project (Chazelles and Supra),
- Two US stoves (not using catalysts): Scan (PM emissions 1.1 g/h according to the US standard test method) and Quadra Fire (PM emissions 1.1 g/h according to the US standard test method).

The pollutant measurement protocol used has been established to simulate real conditions of operation of the stoves such as burn rates, wood loads, types of wood. The measurement plan is as in the following:

- Wood load: 100% and 170% of the nominal load,
- Burn rates: 3 levels: currently used in real life by stove owners (18 Pa), nominal (12 Pa (as in the European norm)), reduced (8 Pa) (also very frequent in real life),

- Type of wood: pine and beech.

In order to maintain the representativeness of real-life operating conditions, measurements have been carried out on a complete combustion cycle. Before measurement, all the 4 stoves were pre-heated.

Gaseous pollutants were measured by common standardized methods. For PM, the solid fraction and condensable parts have been measured. PM including condensables have been measures according to two methods:

- The US method 5H ((hot filtering + series of impingers at 20°C (trapping condensable in isopropanol)),
- Filtrable PM by hot filtration and condensable PM with a ratio of VOC monitored by a flame ionisation detector (FID).

The EC/OC (Element carbon/Organic carbon) and EBC (Equivalent Black Carbon) have been measured after dilution of hot gases with a ratio of 100 (FPS 4000 Dekali). EC and OC are measured by a thermo optical method (EC-OC sunset Lab) and EBC by optical absorption (AE33).

The environmental characteristics of the stoves measured according to the European protocol NF EN 13229 in normalised conditions, were also measured and are showed in the following:

Table 119: Overview of environmental characteristics of two french stoves of last generation and two US stoves among the best performing appliances according to EU standard 13229 [84]

	Unit	Chazelles	Supra	Krog Iversen	Quadra fire
Model		**HP 700**	**Neo 55**	**Scan DSA 4**	**3100 Millennium**
Thermal input capacity	kW	10	7	6	9.4
Efficiency	%	78	77	78.3	70.7
CO	%	0.09	0.04	0.10	0.09
PM solid fraction	mg/m^3 at 13% O_2	11	22	33	16
TVOC	mg C eq/m^3 at 13% O_2	95	34	188	52
NOx	mg NO_2eq/m^3 at 13% O_2	108	46	120	85

Table A6-1 of the INERIS report

The pollutant concentrations, measured according to the experience plan setup to better reflect the real use of stoves, are showed in the following:

Table 120: Overview of concentrations of pollutants measured on two french stoves of last generation and two US stoves among the best performing according to an experimental protocol representing real life conditions [84]

Pollutant	**Unit**	**Supra**	**Chazelles**	**Krog Iversen**	**Quadra fire**
Model		**HP 700**	**Neo 55**	**Scan DSA 4**	**3100 Millennium**
CO	g/kg	46.7	26.3	19.0	38.9
CO_2	g/kg	1775	1774	1795	1757
NOx	g NO_2eq/kg	0.97	1.07	1.2	0.71
TVOC	g eqC/kg	6.3	4.0	1.8	2.8
CH_4	g/kg	2.5	1.4	0.74	1.7

Pollutant	**Unit**	**Supra**	**Chazelles**	**Krog Iversen**	**Quadra fire**
Model		**HP 700**	**Neo 55**	**Scan DSA 4**	**3100 Millennium**
PM solid fraction	**g/kg**	**1.46**	**2.45**	**1.08**	**0.51**
PM condensable	**g/kg**	**2.70**	**3.30**	**2.0**	**1.20**
PM total	**g/kg**	**4.16**	**5.75**	**3.08**	**1.71**
EC	mg/kg	0.22	0.64	0.52	0.08
EBC	mg/kg	0.55	0.97	0.57	0.17

Tables 8 and 9 of the INERIS report

Table 121: Overview of environmental characteristics of two french stoves of last generation and two US stoves among the best performing according according to an experimental protocol to representing real life conditions [84]

	Unit	**Chazelles**	**Supra**	**Krog Iversen**	**Quadra fire**
Model		**HP 700**	**Neo 55**	**Scan DSA 4**	**3100 Millennium**
Efficiency	%	61.0	69.4	61.7	71.7
CO	%	0.175	0.302	0.127	0.264
PM solid fraction	**mg/m^3 at 13% O_2**	**202**	**119**	**89**	**43**
PM total	**mg/m^3 at 13% O_2**	**274**	**217**	**168**	**100**
TVOC	mg C eq/m^3 at 13% O_2	332	508	152	238
NOx	mg NO_2eq/m^3 at 13% O_2	90	78	101	60

Table A6-3 of the INERIS report

According to these results, the solid PM fraction in total PM (including condensables) is 56 ± 7%. The solid fraction is the largest at nominal burn rate, of 72%. It is of 46% and 51% at current used burn rate and reduced burn rate respectively. The fraction values also change with the appliances. In the two French stoves, the values result larger (58% and 70%) than in the US stoves (48% and 51%).

For the two French stoves, an excellent correlation has been found between condensables and TVOC. The correlation results in lower quality when all stoves are considered, because the condensable content in the two US stoves is lower than in the French stoves

The pollutant emissions in real life are much higher, compared to the concentrations obtained according to the EU standard 13229, at nominal output, as illustrated in the following table. The ratios are reported in the table:

Table 122: Ratios of emissions measured in nearly real lile conditions and in standard conditions (EN 13229) [84][3]

	Chazelles	Supra	Krog Iversen	Quadra fire
CO	1.9	7.6	1.3	2.9
Solid PM	18.4	5.4	2.7	2.7
TVOC	3.5	14.9	0.8	4.6

---

[3] Calculated by TFTEI from Table A6-1 and A6-3

NO_x	0.8	1.7	0.8	0.7

It is noticed that in the case of the two US stoves, the ratio for solid PM is smaller than in the case of the two French stoves. This effect highlights the good standardisation methods, able to represent real conditions of use, so concluding that the stoves are designed to efficiently limit emissions, on the entire wood burning cycle.

The fraction of EBC in total PM is 25 ± 6%. This value does not evolve in a statistically significant manner. However, the appliance, the burn rate, and the type of wood may have a significant role. The fraction is 18% in the Quadra fire, significantly lower than in other stoves (27 to 29%). The fraction of EBC is around 35% at nominal burn rate, and only 22 and 19%, at currently used burn rate and reduced burn rate.

Table 123: Fraction of EBC in PM in % [84]

	Chazelles	Supra	Krog Iversen	Quadra fire	Average value
Average burn rate	36	14	20	20	23
Nominal burn rate	20	44	46	29	35
Reduce burn rate	25	24	22	4	19
Beech	23	39	19	9	23
Pine	33	15	40	27	29
Nominal load	30	28	33	25	29
Nominal load x 1.7	25	26	26	11	22
Average of all tests	27	27	29	18	25

Table 20 of 84

The aim of this French project was, in addition, to define what best solutions can be to reduce emissions. The assessment carried out enables to define a certain number of parameters, on which it is possible to take actions.

The two French appliances have been modified and their emissions have been checked after these modifications. Some examples of modifications introduced are given hereafter (chapter 6.1 of the INERIS report):

- Removal of two log stops,
- Better regulation of primary air,
- Quaternary air added,
- Regulation of the air of glass,
- Double baffle for a larger number of secondary air inlets,
- Better insulation.

After these modifications, the emissions measured are as in the following:

Table 124: Emissions after modifaction of the french appliances [84]

Pollutant	Unit	Supra modified		Chazelles modified	
Burn rate		Nominal	Reduced	Nominal	Reduced
CO	g/kg	23.7	27.3	28.1	-
CO_2	g/kg	1752	1744	1744	-
NOx	g NO_2 eq /kg	1.23	1.18	1.13	-
TVOC	g/kg Ceq/kg	3.13	4.46	4.16	-

Pollutant	Unit	Supra modified		Chazelles modified	
Burn rate		Nominal	Reduced	Nominal	Reduced
PM solid fraction	**g/kg**	**0.31**	**0.46**	**0.77**	**-**
PM condensable fraction	**g/kg**	**0.62**	**0.79**	**1.57**	**-**
Total PM	**g/kg**	**0.93**	**1.26**	**2.34**	**-**

For the Supra appliance, the performances after modification became similar to the Quadra-fire appliance. PM emissions decreased by a factor 2 to 3 compared to results obtained before the modification. For the Chazelle appliance, the performances after modifications were not so good, due to specific characteristics of the stove.

Recommendations are provided by the study for the development of high efficiency stoves, able to meet US standards in terms of PM emissions.

The study concludes that the poor ability of standardized tests, in France, to reflect the actual operating conditions of the devices, leads to a lower impact on improving air quality when replacing an old device with a new one of the latest generation.

The study "Best available techniques (BAT) for domestic wood heating" provides among other things [9]:

- An overview of techniques that can be applied to improve environmental performances of wood heating appliances,
- Definition of BAT.

A survey of appliances, by manufacturers and importers, was carried out in order to obtain a picture of the currently used technologies, concerning the achievement of a better combustion, the reduction of emissions and the environmental performance of the techniques. The survey covered 41 wood-fired stoves and 14 pellet stoves.

The study provides an assessment of techniques for the following topics (description, application, environment benefit, financial aspects):

- Design of new appliances – Primary measures
    - Flame baffle plate
    - Grate in the combustion chamber
    - Insulation of the combustion chamber(s)
    - Use of heat-reflective material in the combustion chamber
    - Small glass window with double, triple or coated glass
    - Shape of the combustion chamber
    - Presence of a second combustion chamber or zone/duct for post combustion
    - Staged air supply
    - Air supply control – mono-control of air supply
    - Air supply control – automatic control of air supply and air circulation
    - Airtight design of the appliance

    - Preheating secondary supply air combustion
    - Flue gas heat recovery system
    - Offering appliances with different capacity classes and ranges
    - Automatic fuel feeding
    - Advanced combustion process control

- Design of new appliances – Secondary measures
    - Integration of a catalyst
    - Integration of an electrostatic precipitator
- Existing appliances – primary measures
    - Heat recovery from the flue gases (with a focus on (retaining) sufficient draught in the chimney)
    - Heat storage (e.g., extra mass or boiler)
    - Forced draught for sufficient air supply
- Existing appliances – secondary measures
    - Integration of a catalyst
    - Integration of an electrostatic precipitator
- Installation of appliances
    - Choosing an appliance for a particular use
    - Correct installation of the appliance
    - External air supply
    - Correct installation of the flue gas pipe
    - Insulation of the flue gas pipe
    - Forced draught for sufficient air supply in the combustion chamber
    - Installation by a specialist installer
    - Provide dry and ventilated storage space for wood (indoors or outdoors)
- Use of appliances
    - Follow wood burning tips
    - Limit wood burning in the event of high fine dust concentrations and unfavorable weather conditions
    - Follow the manufacturer's instructions
- Maintenance of appliances and flue gas pipes
    - Regular maintenance of appliances + flue gas pipes

The following table presents the observed performances of stoves compared to the limit values of EU regulation 2015/1185:

Table 125: emission values based on the survey for stoves burning log woods according to Vito [9]

Appliances with closed front – solid fuel other than wood pellets (EU) 2015/1185	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC (OGC) mg/m³
Ecodesign requirements	65 %	40	1500	200	120
Ecodesign - indicative benchmark for best-performing appliance	86 %	20	500	50	30
Ecodesign - example of good combination	83%	33	1125	115	69
Survey Best reported performance per parameter	90.2%	6	317	47	20
Appliance survey Lowest CO Lowest HC	81%	26	317	86	20
Appliance survey Lowest PM appliance 1	80%	6	625	127	48
Appliance survey Lowest PM appliance 2	83%	6	835	99	77
Appliance survey Highest efficiency	90.2%	18	435	121	25
Appliance survey Highest NOx	83.5%	32	625	147	34
Appliance survey Highest CO appliance 1	84%	27.1	1250	112	96
Appliance survey Highest CO appliance 2	75%	14	1250	120	83
Appliance survey Highest PM	80.6%	40	1000	88	35
Appliance survey Lowest NOx Highest HC	80%	30	1140	47	110
Appliance survey Lowest efficiency for appliance 1	75%	14	1250	120	83
Appliance survey Lowest efficiency for appliance 2	75%	15	775	58	23
Survey Best reported performance per parameter Capacity < 10 kW	90.2%	6	317	70	20
Appliance survey Lowest CO Lowest HC	81%	26	317	86	20
Appliance survey Lowest PM appliance 1	80%	6	625	127	48
Appliance survey Lowest PM appliance 2	83%	6	835	99	77
Appliance survey Highest efficiency	90.2%	18	435	121	25
Appliance survey	84%	15	875	70	28

Lowest NOx					
Appliance survey Highest CO Highest HC	84%	27.1	1250	112	96
Appliance survey Highest PM	84%	35	1021	139	53
Appliance survey Highest NOx	80.92%	26	898	146	87
Appliance survey Lowest efficiency	75.3%	29	880	105	23
Survey Best reported performance per parameter Capacity >= 10 kW	86.7	10	575	47	23
Appliance survey Lowest CO	76%	31	575	105	26
Appliance survey Lowest PM	82%	10	1087.5	99	88.7
Appliance survey Highest efficiency	86.7%	24	750	91	47
Appliance survey Lowest NOx Highest HC	80%	30	1140	47	110
Appliance survey Lowest HC	75%	15	775	58	23
Appliance survey Highest CO	75%	14	1250	120	83
Appliance survey Highest PM	80.6%	40	1000	88	35
Appliance survey Highest NOx	83.5%	32	625	147	34
Appliance survey Lowest efficiency for appliance 1	75%	14	1250	120	83
Appliance survey Lowest efficiency for appliance 2	75%	15	775	58	23

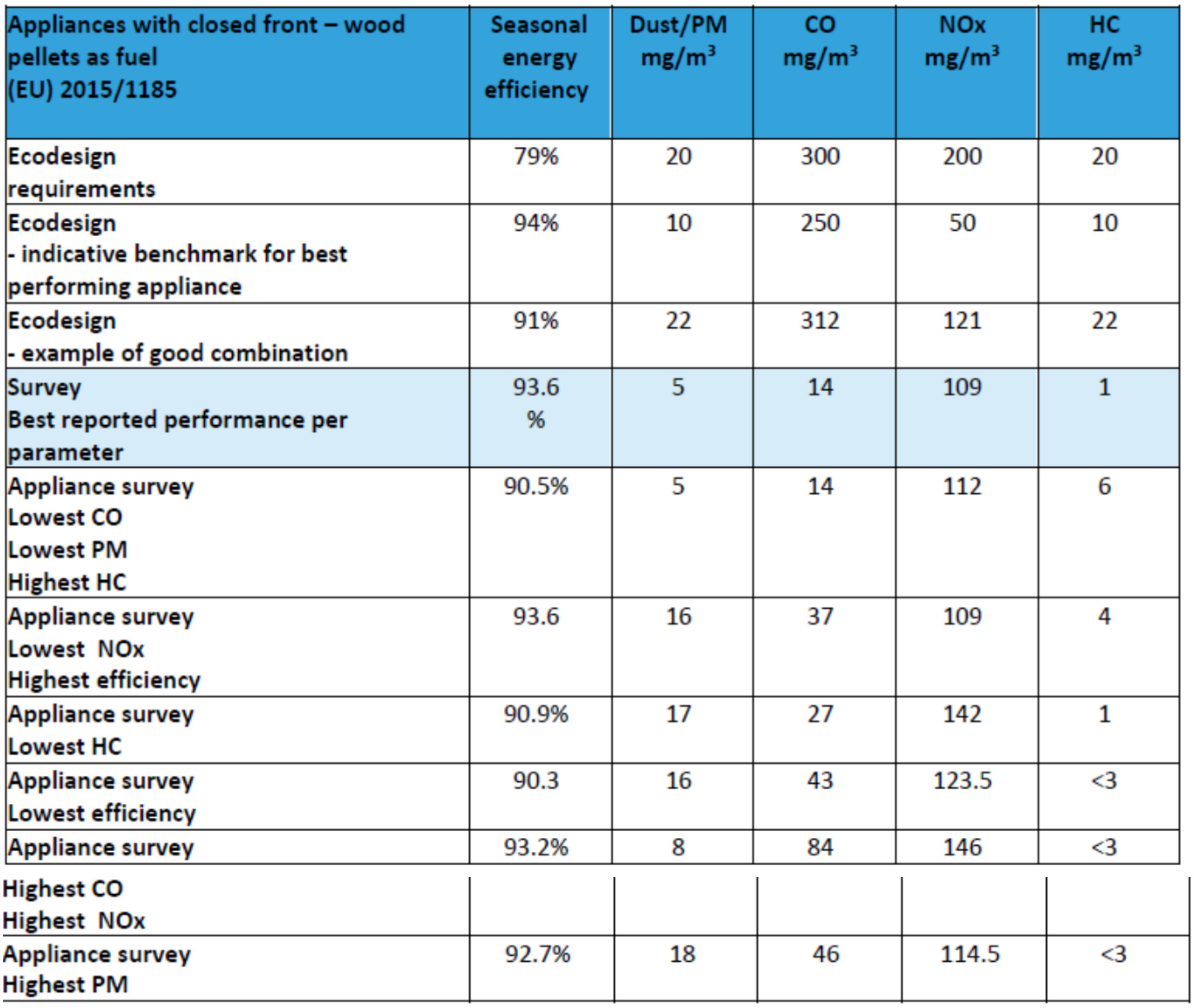
Compared to the Eco-design regulation, example of a good combination, 3 appliances in the survey score better for each of the parameters (following table). All appliances are freestanding appliances, the first two equipped with a central heating connection. All appliances have a flame baffle plate, insulation, post-combustion zone, airtight design, external air supply, pre-heating of the secondary combustion air and heat recovery.

Table 126: emission figures for stoves fired with pieces of wood from the survey with performances better than the example of a good combination in the Ecodesign regulation according to Vito [9]

	Seasonal energy efficiency	Dust/PM mg/m^3	CO mg/m^3	NOx mg/m^3	HC (OGC) mg/m^3
Appliance 1	86.7%	24	750	91	47
Appliance 2	90.1%	22	500	90	22
Appliance 3	84%	15	875	70	28

For pellet stoves, the results are in the following:

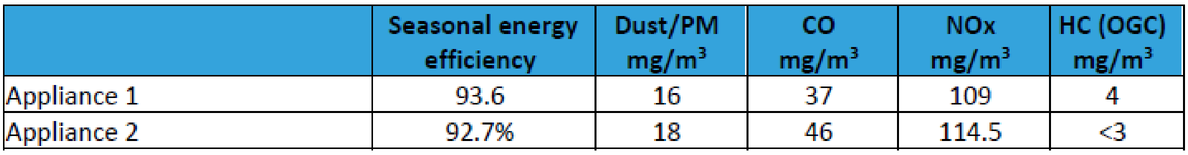
Table 127: emission values based on the survey for pellet stoves according to Vito [9]



Appliances with closed front – wood pellets as fuel (EU) 2015/1185	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC mg/m³
Ecodesign requirements	79%	20	300	200	20
Ecodesign - indicative benchmark for best performing appliance	94%	10	250	50	10
Ecodesign - example of good combination	91%	22	312	121	22
Survey Best reported performance per parameter	93.6 %	5	14	109	1
Appliance survey Lowest CO Lowest PM Highest HC	90.5%	5	14	112	6
Appliance survey Lowest NOx Highest efficiency	93.6	16	37	109	4
Appliance survey Lowest HC	90.9%	17	27	142	1
Appliance survey Lowest efficiency	90.3	16	43	123.5	<3
Appliance survey Highest CO Highest NOx	93.2%	8	84	146	<3
Appliance survey Highest PM	92.7%	18	46	114.5	<3

There are 2 pellet stoves (see Table 128) that score better across the board. Both appliances are freestanding with a flame baffle plate, grate, insulation, heat reflective material, single glazed, vertical combustion chamber, airtight design, external air supply and heat recovery.

Table 128: emission values for pellet stoves from the survey with performances better than the example of a good combination in the Ecodesign regulation according to Vito [9]



	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC (OGC) mg/m³
Appliance 1	93.6	16	37	109	4
Appliance 2	92.7%	18	46	114.5	<3

For boilers, the situation is as in the following:

Table 129: emission values based on the survey for pellet boilers according to Vito [9]

Solid fuel boiler – automatically stoked (EU) 2015/1189	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC mg/m³
Ecodesign requirements	75% (>20 kW) 77% (>20 kW)	40	500	200	20
Ecodesign - indicative benchmark for best performing appliance	96% for cogeneration connection 90% with flue gas condenser 84% other boilers	2	6	97	1
Ecodesign - example of good combination	81%	7	6	120	2
Survey Best reported performance per parameter	107.3	9	9	92	1
Appliance survey Lowest CO Highest NOx Lowest HC Highest efficiency	107.3%	13	9	123	<1
Appliance survey Lowest PM Lowest NOx Lowest efficiency	93.4%	9	22	92	1
Appliance survey Highest CO Highest PM Highest HC	95.3%	19	45	106	1

The environmental-friendly techniques have been assessed in terms of their technical feasibility, environmental impact and economic feasibility, and the study indicates whether or not the above-mentioned environmental-friendly techniques can be regarded as BAT, for domestic wood heating. CBC = has to be evaluated case by case (situation specific)

The BAT for the design of new appliances are aimed at optimising the combustion conditions, reduce emissions and optimise energy efficiency. BAT requires that a combination of techniques (measures) has to be applied, when designing new appliances. How the measures are implemented in practice and combined each other is part of the technical know-how of the several stove manufacturers. The different stove manufacturers may take different choices that may result in equivalent environmental performance.

If the appliances comply with the applicable emission and energy efficiency requirements under standardised test conditions, Vito reminds that environmental performance in real-life conditions of use (varying combustion conditions, which are not always ideal) are lower than the performance measured in labs, under standardised test conditions. The reasons for which the test procedures deviate from the real-life conditions include:

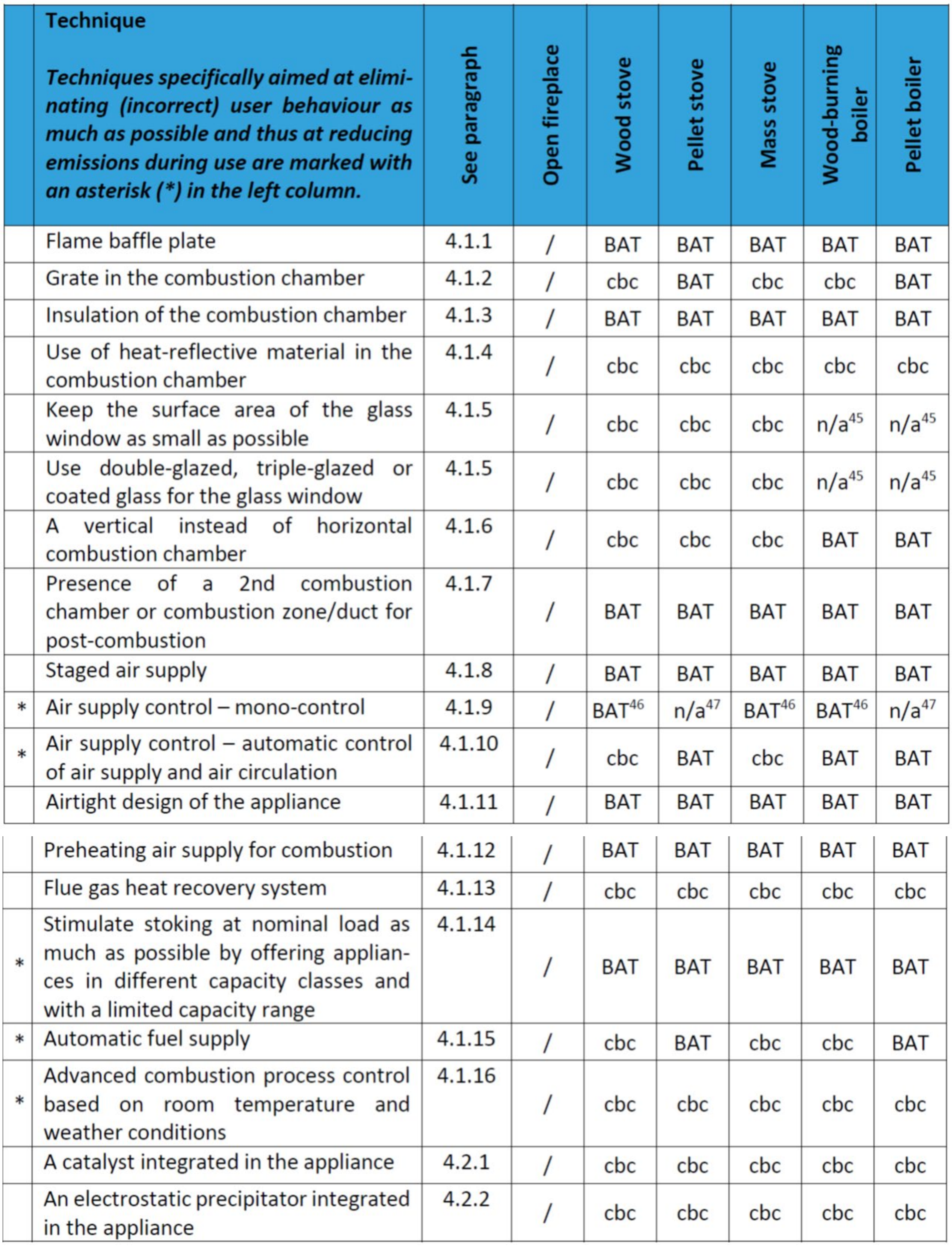
- Starting (and extinction) of the fire generally not included,
- Burning at partial load usually not included,

- The condensable fraction of dust is generally not measured,
- Ideal negative pressure,
- Ideal fuel quality (moisture content, no bark, etc.),
- Ideal wood species (e.g., no resinous coniferous logs),
- Ideal fuel dimensions,
- Ideal fuel quantity,
- Ideal installation,
- Ideal set up and use (e.g., control of air supply),
- Pre-heated appliance.

The following table summarises the BAT used in designing of the different appliances. Techniques, specifically aimed at eliminating, as much as possible, incorrect user's interventions so reducing the emissions, are marked with an asterisk (*), in the left column. The assessments of BAT and BAT case-by-case (cbc) is defined, as in the following, by VITO:

- BAT: the technique is considered necessary to achieve the BAT associated performance levels for the type of appliance concerned and should therefore be fitted as standard in every new appliance of this type, regardless of the user's profile.
- BAT cbc: the technique may contribute to achieving the BAT associated performance levels but is not necessarily present in every appliance. More information about the cbc assessment can be found for each appliance type below the table.

Table 130: Overview of BAT and BAT case by case (cbc) per type of appliance accoding to Vito [9]



	Technique *Techniques specifically aimed at eliminating (incorrect) user behaviour as much as possible and thus at reducing emissions during use are marked with an asterisk (*) in the left column.*	See paragraph	Open fireplace	Wood stove	Pellet stove	Mass stove	Wood-burning boiler	Pellet boiler
	Flame baffle plate	4.1.1	/	BAT	BAT	BAT	BAT	BAT
	Grate in the combustion chamber	4.1.2	/	cbc	BAT	cbc	cbc	BAT
	Insulation of the combustion chamber	4.1.3	/	BAT	BAT	BAT	BAT	BAT
	Use of heat-reflective material in the combustion chamber	4.1.4	/	cbc	cbc	cbc	cbc	cbc
	Keep the surface area of the glass window as small as possible	4.1.5	/	cbc	cbc	cbc	n/a[45]	n/a[45]
	Use double-glazed, triple-glazed or coated glass for the glass window	4.1.5	/	cbc	cbc	cbc	n/a[45]	n/a[45]
	A vertical instead of horizontal combustion chamber	4.1.6	/	cbc	cbc	cbc	BAT	BAT
	Presence of a 2nd combustion chamber or combustion zone/duct for post-combustion	4.1.7	/	BAT	BAT	BAT	BAT	BAT
	Staged air supply	4.1.8	/	BAT	BAT	BAT	BAT	BAT
*	Air supply control – mono-control	4.1.9	/	BAT[46]	n/a[47]	BAT[46]	BAT[46]	n/a[47]
*	Air supply control – automatic control of air supply and air circulation	4.1.10	/	cbc	BAT	cbc	BAT	BAT
	Airtight design of the appliance	4.1.11	/	BAT	BAT	BAT	BAT	BAT
	Preheating air supply for combustion	4.1.12	/	BAT	BAT	BAT	BAT	BAT
	Flue gas heat recovery system	4.1.13	/	cbc	cbc	cbc	cbc	cbc
*	Stimulate stoking at nominal load as much as possible by offering appliances in different capacity classes and with a limited capacity range	4.1.14	/	BAT	BAT	BAT	BAT	BAT
*	Automatic fuel supply	4.1.15	/	cbc	BAT	cbc	cbc	BAT
*	Advanced combustion process control based on room temperature and weather conditions	4.1.16	/	cbc	cbc	cbc	cbc	cbc
	A catalyst integrated in the appliance	4.2.1	/	cbc	cbc	cbc	cbc	cbc
	An electrostatic precipitator integrated in the appliance	4.2.2	/	cbc	cbc	cbc	cbc	cbc

* Techniques specifically aimed at eliminating, as much as possible, (incorrect) user's interventions

The survey of stove manufacturers shows that several appliances on the market exceed the Eco-design requirements, by applying BAT, and that may happen for all the parameters, simultaneously. This is an indication that such requirements may need to be updated. Due to the fact that standardised test conditions in the EU Eco-design directive are not representative of the real-life conditions, whether appliances best performing in lab conditions also are best performing in real-life operating conditions, remains uncertain.

For existing appliances, the following measures can be applied in certain situations and are assessed as BAT cbc (case-by-case):

- Flue gas heat recovery
- Heat storage
- Forced draught

The following secondary measures can be implemented to reduce emissions from existing (old or new) appliances, provided a number of technical preconditions are met.

- Installation of a catalyst, especially in case of odour nuisance,
- Installation of an electrostatic precipitator.

Electro filters (a secondary technique used to reduce PM emissions) are becoming part of regulations, as in the case of the new Blue Angel label in Germany [30]. They have been characterised as BAT, on case by case approach, for the different wood appliances, in the Vito study [9] but, according to Hartmann [86], they are part of the new stove concept for the future.

In Saas Fee in Switzerland, the municipality launched a subsidy programme for equipment of chimneys in small domestic heating wood burning appliances, with small electro-filters of type Oeko Tube. 74 systems were equipped [108]. Measurements of PM emissions were made before and after the installation of the electro-filter on 22 units [107].

The following figure presents the results:

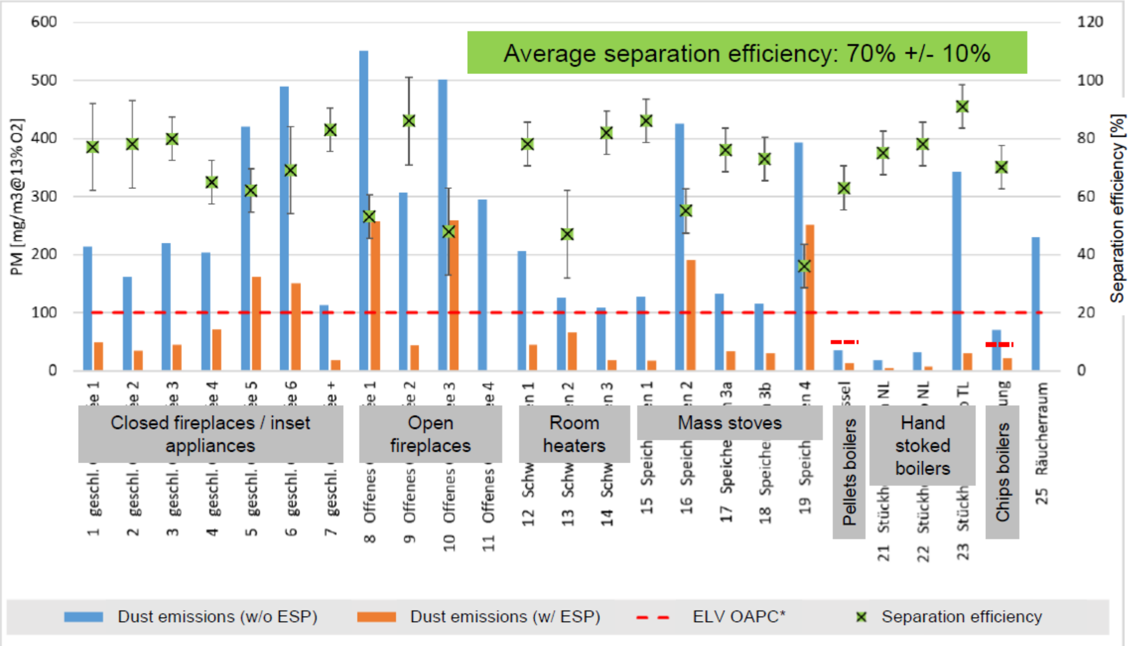


Figure 10: Emissions of PM before and after the installation of an electrofilter in chimneys of 22 small wood appliances [107]

It was demonstrated that the electro-filter (ESP) (*OekoTube*) was a very suitable retrofit solution for wood burning installations, with an average separation efficiency of 70% +/-10%, for 20 installations in Saas-Fee. The ESP operates well, even on high-emission installations (lower separation efficiency in those cases) but could be further improved by better settings of ESP system (activation criteria, voltage). The system is robust and of simple design and installation [107].

In terms of maintenance, the ESP requires a regular cleaning by the chimney sweep, including maintenance of the ESP (frequency depending upon the amount of separated dust). With large amounts of dust and low frequent cleaning, there may be a risk of fire in the chimney [107].

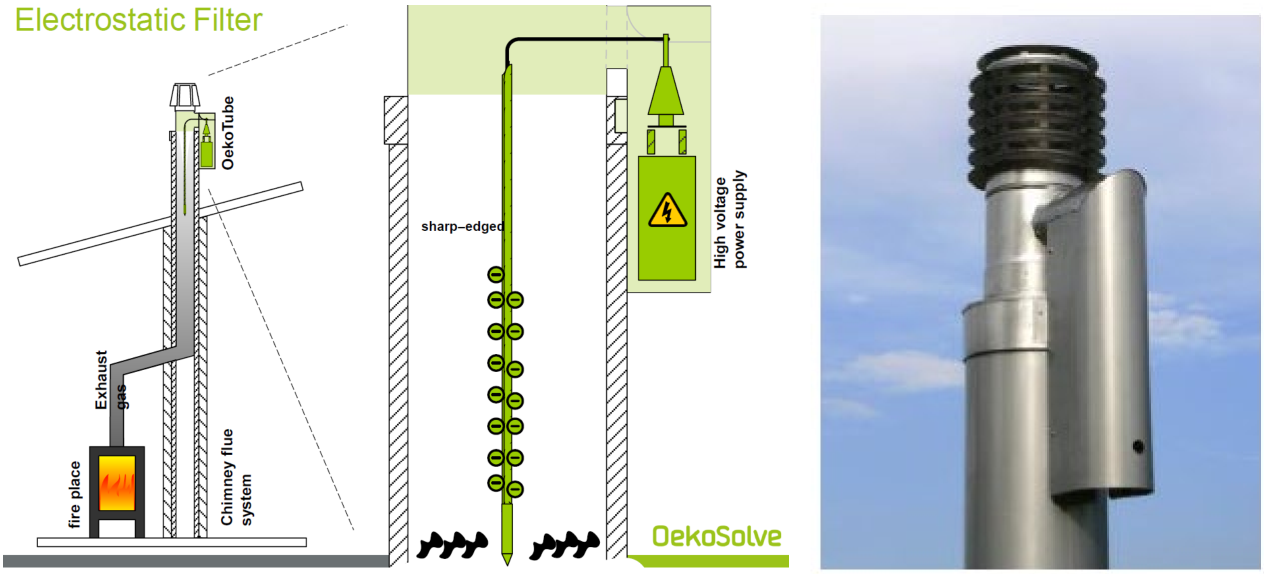


Figure 11: Principle of the electrofilter Oekosolve and picture of a chimney outlet equipped with the system [108]

Some manufacturers of boilers started to propose integrated boilers with electrostatic filters. For small thermal rated power boiler (up to 1 MW), an efficiency of 20 mg PM/m^3 [109][110] is claimed, at 10% O$_2$ (or 27 mg at 6% O$_2$, 15 mg at 13% O$_2$). For larger boiler, a cyclone is used in combination with the electro-filter.

Heizoclean® electrofilter 20 mg PM/Nm^3 at 10% O$_2$

Figure 12: Wood chip boiler with an intergrated electrofilter [109][110].

6.11.5. New developments

The Wood Heater Design Challenge [85] was set up several years ago (in 2013 the first one). The series of previous Design Challenges has led to some of the cleanest and most innovative stoves on the market, available today, in the US. In 2022, the fifth challenge aims to engage and expand the wood heater community, foster relationships between academia, industry and other stakeholders to develop the most innovative cleaner and more efficient wood heaters; and to encourage and create strong teams, able to compete in the Wood Heater Design Challenge coming in 2023. The aim is to design and develop stoves with the lowest emissions values (even almost “zero emissions” under practical operating conditions [86]).

According to I. Hartmann [86], in the scope of the project “Exhaust gas purification plants for emission-free biomass stoves” (Chilian and German project), the stove concept for the future integrates:

- Combustion chamber re-engineering and development, e.g., downdraft combustion,
- Air control and exhaust gas sensors,
- Furnace-integrated catalysts,
- Furnace integrated particulate removal systems,
- Chimney-integrated particulate removal systems,
- Practical testing at all heating appliances,
- Blue Angel/emission tests for all heating appliances.

In the long-term, I. Hartmann [86] recommends developing installations with very low emission values comparable with oil and gas combustion systems (such as in 2050: in real operation < 1 mg/m^3 at 13% O_2 and at full load < 0.1 mg/m^3 at 13% O_2). According to I. Hartmann [86], the first step is the: “Blauer Angel” Eco label for wood log stoves. Particle number limit values should be introduced: first estimate for next years: $< 1.\ 10^6$/cm^3.

Extensive research work has to be carried out on the following issues according to Hartmann [86]:

- Research into combustion processes,
- Further furnace development,
- Catalyst and precipitator development (under high temperature conditions),

6.11.1. Conclusions and possible updates in Emission Limit Values (ELVs) in the Annex X of the Gothenburg Protocol

The paragraph 16 of annex X of the Gothenburg Protocol reads as in the following [1]:

Combustion installations with a rated thermal input < 50 MWth:

This paragraph is recommendatory in character and describes the measures that can be taken insofar as a Party considers them to be technically and economically feasible for the control of particulate matter:

(a) *Residential combustion installations with a rated thermal input < 500 kWth:*

(i) *Emissions from new residential combustion stoves and boilers with a rated thermal input < 500 kWth can be reduced by the application of:*

a. Product standards as described in CEN standards (e.g., EN 303–5) and equivalent product standards in the United States and Canada. Countries applying such product standards may define additional national requirements taking into account, in particular, the contribution of emissions of condensable organic compounds to the formation of ambient PM; or

b. Ecolabels specifying performance criteria that are typically stricter than the minimum efficiency requirements of the EN product standards or national regulations;

(ii) Emissions from existing residential combustion stoves and boilers can be reduced by the following primary measures:

- *a. Public information and awareness-raising programmes regarding:*
  - *i. The proper operation of stoves and boilers;*
  - *ii. The use of untreated wood only;*
  - *iii. The correct seasoning of wood for moisture content.*
- *b. Establishing a programme to promote the replacement of the oldest existing boilers and stoves by modern appliances; or*
- *c. Establishing an obligation to exchange or retrofit old appliances.*

The table 12 of annex X of the Gothenburg Protocol [1] provides the recommended limit values:

Table 131: Table 12 of Annex X of the Gothenburg Protocol [1]

Recommended limit values for dust emissions released from new solid fuel combustion installations with a rated thermal input < 500 kWth to be used with product standards

	Dust (mg/m³)
Open/closed fireplaces and stoves using wood	*75*
Log wood boilers (with heat storage tank)	*40*
Pellet stoves and boilers	*50*
Stoves and boilers using other solid fuels than wood	*50*
Automatic combustion installations	*50*

Note: O_2 reference content: 13%.

As presented in the previous chapters, efficiencies and emission values of small wood burning appliances have evolved and lower emitting appliances are now available.

Standards could be potentially updated, consequently. The literature survey carried out by TFTEI, allows to make some proposals.

One of the key issues is that the test procedures used for standardisation and labelling of appliances should be designed to reproduce the real-life conditions of appliances and consider both the solid and condensable fractions of PM.

Standards should be defined using test procedures reproducing the entire combustion cycle of combustion, from the ignition phase to the residual coal bed weight phase, as currently applied in Germany for the Blue Angel label [30], in US [89] and not only at nominal load, as currently applied in the EU regulation 2015/1185 [17], for the measurement method based on heated filters (solid fraction of PM measured). As presented in the previous chapters, experts recommend such test procedures to push further the technological developments towards optimized real-life operation and to better differentiate good and poor quality products.

The PM limit values proposed are still expressed in solid particles. Preferably, limit values including condensables should be used, but, at this stage of the survey, it was difficult to propose values due to the lack of reliable measurement data, using the dilution tunnel. A large fraction of PM is not represented, considering that condensables are absolutely necessary to better characterize the impacts of PM on air quality. Moreover, optimisation of stoves efficiencies cannot neglect such fraction of PM, because the optimisation factors are not the same for condensables and for the solid fraction of PM. It is recognised that stoves in the US, are among the best performing installations in the UNECE region [84]. Their performances have been improved, since many years, thanks to the use of the dilution tunnel, able to consider both the solid and the condensable fractions of PM, and the consideration of the entire combustion cycle on test procedures.

Proposal of new standards for products to be introduced on the market:

Proposed updates of limit values for solid particles (dust) in appliances ≤ 50 kWth

Closed fronted solid fuel local space heaters using solid fuel other than compressed wood in the form of pellets and cookers:

15 mg/m^3 dust [30] to **40** mg/m^3 dust [17], at 13% O_2 with an update index of 1

Closed fronted solid fuel local space heaters using compressed wood in form of pellets:

5 mg/m^3 dust [9] to **20** mg/m^3 dust [17], at 13% O_2 with an update index of 1

The limit of 5 mg/m^3 comes from the survey made by Vito [9] and the identification of best performing appliances.

Proposed updates of limit for solid particles (dust) in boilers ≤ 500 kWth

Automatically stoked boilers:

20 mg/m^3 dust [110] to **40** mg/m^3 dust [18], at 10% O_2 (29 mg/m^3 at 13% O_2) with an update index of 1

The lower limit value can be achieved with the use of integrated electro filters [110] as presented above.

Manually stocked boilers:

60 mg/m^3 dust [18] (44 mg/m^3, at 13% O_2) with an update index of 1

Proposal of potential updates in limit values:

On the example of several countries, such as Germany [106], Denmark [9], Austria [9], Switzerland [99], the introduction of updated limit values for existing appliances and new installations, could be considered in the review of the current Amended Gothenburg Protocol [1]. Moreover, on the example of the above mentioned countries, periodical controls, by chimney sweepers operators could also be proposed.

The proposed limit values are as in the following and the update indexes proposed are of 1:

Table 132: Proposal of potential update of ELVs of PM emissions in table 12 of Annex X of the Amended Gothenburg Protocol [1]

Appliance	Current limit value for new appliances with a rated thermal input < 500 kW [1]	Updated lower limit values	Updated upper limit values
	mg/m^3 at 13% O$_2$		
Open fireplaces	75	Implementation programmes for replacing this type of appliance or installation of additional equipment with inset (front glass door)	
Closed fireplaces and stoves using wood	75	40 [106][1]	75 [1]
Log wood boilers (with heat storage tank)	40	No proposal	40 [1]
Pellet stoves	50	20-30 [106]	50 [1]
Pellet boilers	50	30	50 [1]
Stoves and boilers using other solid fuels than wood	50	40 [106]	50 [1]
Automatic combustion installations	50	40 [106]	50 [1]

The upper limit values in the table above are the current limit values of the Amended Gothenburg Protocol, Annex X, table 12. The recently modified German regulation [106] has been considered in the current report to define the updated lower limit values. For pellet boiler, the proposed limit is based similarly on the example of stoves. Open fireplaces should be avoided, to the extent possible, and programmes aiming at equipping the fireplaces with inset (front glass door) should be promoted.

Controls during the life of the equipment should be recommended:

Boilers: controls every two years or four years, as respectively in Germany (2 years) [106] and in Switzerland (2 or 4 years according to the size of the boiler) [99], with control of dust and CO emissions are recommended.

Inset and stoves: every four years, as respectively in Germany (twice in 7 years) [106], with control of dust and CO emissions.

6.12. Limit values for non-residential combustion installations with a rated thermal input range 100 kWth–1 MWth

The table 13 of annex X of the Gothenburg Protocol [1] provides the recommended limit values, as in the following:

Table 133: Table 13 of Annex X of the Gothenburg Protocol [1]

Recommended limit values for dust emissions released from boilers and process heaters with a rated thermal input of 100 kWth–1 MWth

		Dust (mg/m^3)
Solid fuels 100 kWth–500 kWth	New installations	50
	Existing installations	150
Solid fuels 500 kWth–1 MWth	New installations	50
	Existing installations	150

Note: O_2 reference content: wood, other solid biomass and peat: 13%; coal, lignite and other fossil solid fuels: 6%.

The limit values already implemented in some Member States or other Parties, are used to propose updated limit values, as in the following.

The limit values implemented in Germany are as in the following [106]:

Table 134: Limit values in Germany for boilers with a thermal rate input > 4 kW up to 1 MW [106]

> 4 kW up to 1 MW	ELVs as in the German regulation		Limit value expressed at the O_2 content of the GP		Comments
	Solid fossil fuel	Biomass	Solid fossil fuel	Biomass	
	mg/m^3 at 13% O_2	mg/m^3 at 13% O_2	mg/m^3 at 6% O_2	mg/m^3 at 13% O_2	
New	40	20	75	20	
Existing (put in operation after the 22/03/2010)	40	40	75	40	transition period of 5 to 15 years
Existing (put in operation before the 22/03/2010)	100	100	188	100	transition period of 5 to 15 years

For biomass, limit values are stricter than the values reported in the table 13 of annex X (area highlighted in blue).

The limit values implemented in Switzerland are as in the following [99]:

Table 135: Limit values in Switzerland for boilers with a thermal rate input > 70 kW up to 1 MW [99]

> 70 kW up to 1 MW	ELVs as in the German regulation		Limit value expressed at the O_2 content of the GP		Comments
	Fossil fuel	Biomass	Fossil fuel	Biomass	
	mg/m^3 at 7% O_2	mg/m^3 at 13% O_2	mg/m^3 at 6% O_2	mg/m^3 at 13% O_2	
70 kW-500 kW					
New	50	50	53,6	50,0	Mandatory from 01/06/2018

> 70 kW up to 1 MW	ELVs as in the German regulation		Limit value expressed at the O_2 content of the GP		Comments
	Fossil fuel	Biomass	Fossil fuel	Biomass	
	mg/m^3 at 7% O_2	mg/m^3 at 13% O_2	mg/m^3 at 6% O_2	mg/m^3 at 13% O_2	
Existing	50	50	53,6	50,0	Mandatory from 01/06/2028
500 kW-1000 kW					
New	20	20	21,4	20,0	Mandatory from 01/06/2018
Existing	20	20	21,4	20,0	Mandatory from 01/06/2028

In the blue area, limit values stricter than the values reported in table 13 of Annex X, are highlighted.

The proposed updates in the limit values are as in the following and the update indexes proposed are of 1:

Table 136: Proposal of potential update of ELV for boilers with a thermal rate input > 100 kW up to 1 MW in table 13 of annex X of the Amended Gothenburg Protocol [1]

Size of installations		Limit value of table 13, Annex X [1]		Proposed updated limit values			
		Solid fossil fuels	Biomass	Solid fossil fuels		Biomass	
		mg/m^3 at 6% O_2	mg/m^3 at 13% O_2	Lower limit value	Upper limit value	Lower limit value	Upper limit value
				mg/m^3 at 6% O_2		mg/m^3 at 13% O_2	
100 kW-500 kW	New	50	50	50 [1]	50 [1]	20 [106]	50 [1]
	Existing	150	150	50 [1]	150 [1]	50 [99]	100 [106]
500 kW – 1000 kW	New	50	50	25* [99]	50 [1]	20 [99]	50 [1]
	Existing	150	150	25* [99]	150 [1]	20 [99]	100 [106]

* 21,4 mg exactly in the Swiss regulation.

For existing boilers, a transition period, i.e. 10 years, might be allowed for the compliance with the updated limit values.

As for smaller boilers, controls every two years or four years as respectively in Germany (2 years) [106] and in Switzerland (2 or 4 years according to the size of the boiler) [99], with control of dust and CO emissions could be recommended.

6.13. Limit values for non-residential combustion installations with a rated thermal input 1MWth–50 MWth

The table 14 of annex X of the Gothenburg Protocol [1] provides the recommended limit values, as in the following:

Table 137: Table 14 of Annex X of the Gothenburg Protocol [1]

Recommended limit values for dust emissions released from boilers and process heaters with a rated thermal input of 1 MWth–50 MWth

		Dust (mg/m^3)
Solid fuels > 1 MWth–5 MWth	New installations	20
	Existing installations	50
Solid fuels > 5 MWth–50 MWth	New installations	20
	Existing installations	30
Liquid fuels > 1 MWth–5 MWth	New installations	20
	Existing installations	50
Liquid fuels >5 MWth–50 MWth	New installations	20
	Existing installations	30

Note: O_2 reference content: wood, other solid biomass and peat: 11%; coal, lignite and other fossil solid fuels: 6%; liquid fuels, including liquid biofuels: 3%.

The limit values implemented in some Member States or other Parties and at the EU level have been considered to propose the updated limit values, as in the following, for solid fuels:

Germany has specific limit values for combustion plants from 1 to 50 MW [94]. They are as in the following (German limit values according to the „Vierundvierzigste Verordnung zur Durchführung des Bundes emmissions schutzgesetzes (Verordnung über mittelgroße Feuerungs- Gasturbinen- und Verbrennungsmotoranlagen - 44. BImSchV)")

Table 138: Limit values in Germany for boilers in installations with thermal rate input between 1 MW to 50 MW for new and existing plants [94]

Size of installations	ELVs as in the German regulation 44. BImSchV		ELVs expressed at the O_2 content of the GP	
	Fossil solid fuel	Natural wood	Fossil solid fuel	Natural wood
	mg/m^3 at 6% O_2	mg/m^3 at 6% O_2	mg/m^3 at 6% O_2	mg/m^3 at 11% O_2
New installations				
1-5 MW	20	35	20	23.3
5-20 MW	20	20	20	13.3
> 20 MW	20	20	20	13.3
Existing installations				
1-5 MW	20	50[1,2]	20	33.3
5-20 MW	20	30[1,3]	20	20.0
> 20 MW	20	30[1,3]	20	20.0

[1] only if fabric filters or electrostatic precipitators are used

[2] requirements apply from 1.1.2028 onwards, requirements of TA Luft 2002 apply before this date

[3] requirements apply from 1.1.2025 onwards, requirements of TA Luft 2002 apply before this date

Other dust limit values are implemented for non-natural wood.

In the blue area, limit values stricter than the value reported in table 14 of Annex X, are highlighted.

The limit values implemented in Switzerland are as in the following [99]:

Table 139: Limit values in Switzerland for boilers with a thermal rate input between 1 up to 50 MW [99]

Size of installations	ELVs as in the Swiss regulation		Limit value expressed at the O_2 content of the GP	
	Fossil solid fuel	Biomass	Fossil solid fuel	Biomass
	mg/m^3 at 7% O_2	mg/m^3 at 11% O_2	mg/m^3 at 6% O_2	mg/m^3 at 11% O_2
1MW-10MW				
New	20	20	21.4	20.0
Exiting	20	20	21.4	20.0
10MW-100MW				
New	10	10	10.7	10.0
Exiting	10	10	10.7	10.0

In blue, stricter limit values than in table 14 of Annex X are highlighted.

The EU directive on Medium Combustion Plants establishes the following limit values [19].

Table 140: Limit values established by the EU directive on Medium Combustion Plants with a thermal rate input beteween 1 MW to 50 MW, for solid fuels [19]

	ELVs as in the EU MCP Directive [19]		Limit value expressed at the O_2 content of the GP	
	Fossil solid fuel	Biomass	Fossil solid fuel	Biomass
	mg/m^3 at 6% O_2	mg/m^3 at 6% O_2	mg/m^3 at 6% O_2	mg/m^3 at 11% O_2
1MW-5MW				
New	50	50	50.0	33.3
Existing	50	50	50.0	33.3
5MW-20MW				
New	30	30	30.0	20.0
Existing	50	50	50.0	33.3
20MW-500MW				
New	20	20	20.0	13.3
Existing	30	30	30.0	20.0

In the blue area, limit values stricter than the values reported in table 14 of Annex X, are highlighted.

The proposed updates in the limit values are as in the following and the update indexes suggested are 1:

Table 141: Proposed updates in the limit values for boilers with a thermal rate input from 1 MW to 50 MW

Size of installations		Limit value of table 13, Annex 10 [1]		Proposed updated limit value			
		Solid fossil fuels	Biomass	Solid fossil fuels		Biomass	
		mg/m^3 at 6% O_2	mg/m^3 at 11% O_2	Lower limit value	Upper limit value	Lower limit value	Upper limit value
				mg/m^3 at 6% O_2		mg/m^3 at 11% O_2	
1MW-5MW	New	20	20	20 [99]	20 [1]	20 [99]	20 [1]
	Existing	50	50	20 [99]	20 [94] [99]	20 [99]	30 [19]
5MW-10MW	New	20	20	20 [99]	20 [1]	20 [99]	20 [1]
	Existing	30	30	20 [99]	20 [94] [99]	20 [99]	30 [1]
10MW-20MW	New	20	20	10 [99]	20 [1]	10 [99]	20 [1]
	Existing	30	30	10 [99]	20 [94] [99]	10 [99]	30 [1]
20MW-50MW	New	20	20	10 [99]	20 [1]	10 [99]	20 [1]
	Existing	30	30	10 [99]	20 [94] [99]	10 [99]	20 [19]

For liquid fuels, the ELVs of the Gothenburg Protocols can be compared with the ELVs of the MCP Directive [19].

Table 142: Limit values established by the EU directive on Medium Combustion Plants with a thermal rate input between 1 MW to 50 MW for liquid fuels [19]

	Liquid fuel
	mg/m^3 at 6% O_2
1MW-5MW	
New	50
Existing	50
5MW-20MW	
New	20
Existing	30
20MW-50MW	
New	20
Existing	30

Considering the comparison with the existing regulations in the EU, there is no need to propose updated limit values, in the Annex X.

7. Annex XI: limit values for emissions of VOC content from products

Very few information is available to enable the update of ELVs. An in-depth study would be necessary which could not be carried out in the scope of this review. However, the contacts made with some coating manufacturers confirm the current limit values are still quite demanding.

Table 143: Table 1, annex XI, proposal of potential update of ELV for emissions of VOC content from products

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
96	Table 1: **Maximum VOC content for paints and varnishes** Interior matt wall and ceilings (Gloss ≤ 25@60°): WB: 30 g/l; SB: 30 g/l Interior glossy walls and ceilings (Gloss > 25@60°) WB: 100 g/l; SB: 100 g/l Exterior walls of mineral substrate WB: 40 g/l; SB: 430 g/l Interior/exterior trim and cladding paints for wood and metal WB: 130 g/l; SB: 30 g/l Interior/exterior trim varnishes and wood stains, including opaque wood stains WB: 130 g/l; SB: 400 g/l Interior and exterior minimal build wood stains WB: 130 g/l; SB: 700 g/l Primers WB: 30 g/l; SB: 350 g/l Binding primers WB: 140 g/l; SB: 500 g/l One pack performance coatings WB: 140 g/l; SB: 500 g/l Two-pack reactive performance coatings for specific end-use WB: 140 g/l; SB: 500 g/l Multi-coloured coatings WB: 100 g/l; SB: 100 g/l Decorative effects coatings WB: 200 g/l; SB: 200 g/l	**Update Index 3** No identified necessary update			
97	**Table 2:** Maximum VOC content for vehicle refinishing products	**Update Index 3** No identified necessary update			

Pag.	Reference and Update Index	Potential update	Description	Potential Applicability (%)	Potential ELVs
	Preparatory and cleaning: preparatory: 850 g VOC/liter; pre-cleaner: 200 g VOC/liter Bodyfiller/stopper: all types: 250 g VOC/liter Primer: surfacer/filler and general (metal) primer: 540 g VOC/liter; wash primer: 780 g VOC/liter Topcoat: all types: 420 g VOC/liter Special finishes: all types: 840 g VOC/liter.				

8. Conclusions

The review work of the Technical Annexes (TA) to the Amended Gothenburg Protocol carried out by TFTEI, in 2021 and the beginning of 2022, specifically concerned:

1. Annex IV: limit values for emissions of sulphur from stationary sources
2. Annex V: limit values for emissions of nitrogen oxides from stationary sources
3. Annex VI: limit values for emissions of volatile organic compounds from stationary sources
4. Annex VIII: limit values for fuels and new mobile sources
5. Annex X: limit values for emissions of particulate matter from stationary sources
6. Annex XI: limit values for emissions of volatile organic compounds of products

Key message:

From a technological point of view, potential new ELVs have been identified as technically feasible/consistent with the new/upgraded technologies now available, which would allow significant emission reductions, in many of the sector/fuel(activity)/technology combinations.

For what concerns the Industrial Processes and Large Combustion Plants (> 50 MW):

In Annex IV, V, VI and X, the abatement techniques are rather the same compared to the tecniques considered during the previous review of the GP, in 2008-2010, but, in many cases, their performances have evolved and the innovations introduced significantly improved the abatement efficiency of the technologies and/or expanded their domain of application. These technologies deliver lower emissions compared to the levels achieved by the limit values in the existing TA, in many cases. As an example, higher efficient primary measures are available for the reduction of NO_X emissions from combustion of liquid and gaseous fuels.

The performances of the techniques are available, as range values, for the industrial processes and large combustion plants concerned in the 4 annexes on stationary sources.

For what concerns the Small and Medium size Combustion Installations (< 50 MW):

Small and Medium size Combustion Installations, with a rated thermal input lower than 50 MWth, are covered in Annex X for PM emissions. Updated limit values technically achievable have been identified for:

- Residential combustion installations with a thermal input lower than 500 kWth (mainly domestic small appliances using wood and coal, in this category).
- Non-residential combustion installations with a thermal input ranging between 100 kWth and 1 MWth.
- Combustion installations with a thermal input ranging between 1 MWth to 50 MWth.

The new/updated technically achievable lower limit values, for appliances in the residential combustion sector, are a consequence of the technology progress made in the development of small domestic appliances. New types of small high efficiency electrostatic precipitators are now available, also for domestic appliances. Similar improvements are also registered for new electrostatic precipitators used on boilers, with a rated thermal output below 2 MW, characterized by lower costs with respect the common electrostatic precipitators.

PM emissions from domestic sources are recognized to be one of the main sources responsible of high PM and BC emissions, and therefore also high concentrations in ambient air, especially in urban areas. For all regions of the UNECE , the overall guidance "*Prioritizing reductions of particulate matter from sources that are also significant sources of black carbon - analysis and guidance* [21]", developed by TFIAM, in collaboration with TFTEI, adopted by EB at its 41st

Session, classifies domestic wood burning (and coal burning) as the priority source to be addressed to reduce BC emissions. The "*Code of good practice for wood-burning and small combustion installations* [23]*",* adopted by EB at its 39th Session provides (a) Good practices for domestic wood heating installations and (b) Best available techniques to reduce $PM_{2.5}$ emissions from domestic wood from domestic wood burning (and coal burning) in boilers and stoves which should be prioritized to also achieve reduction of BC emissions.

For what concerns products containing VOC

As result of the review, in this field, no significant new information has been found, till now, which would justify the proposal for potential updates in the Annex XI.

Analysis of sections in the TAs which could be considered obsolete and therefore cancelled

In general, sections in Annexes which are eligible for deletion have not been identified, with the exception of some tables in annex VIII on mobile sources, which are considered obsolete and therefore an updated is possible (but not necessarily cancelled).

Analysis of sections in the TAs which could be simplified

For all Annexes related to stationary sources, the cross paragraphs on compliance checking of ELVs and measurement, ***are rather complex***, but, at the same time deemed necessary to ensure a good implementation of limit values and make progress in emission reduction. Rather than simplifications, some updates would be suggested on definition of ***the mean value considered*** (monthly, daily or other means). TFTEI would like to propose, in the next future, consistently with other priority tasks, the development of a guidance document on pollutant measurements for SO_2, PM and NO_x (similarly, TFTEI developed, in 2016, guidelines for estimation and measurement of emissions of volatile organic compounds) [24].

Analysis of possible gaps in the Annexes

The technical annex V on limit values of NO_x, developed before 2012, is not focussed on a large number of industrial sources, potentially responsible for high emissions of NO_x, nor on combustion installations lower than 50 MWth. Considering the new WHO air quality guideline for NO_2 in ambient air (10 $\mu g/m^3$ as an annual average compared to the current value of 40 $\mu g/m^3$), which is likely taken in consideration, in the review of the Gothenburg Protocol, the introduction of a set of additional industrial processes and combustion plants, with power lower than 50 MWth, is suggested, in the technical annex V. The related abatement technologies are available.

Implementation of Limit values for condensables and black carbon

In the conclusions of the EMEP report "*How should condensable emissions be included in PM emission inventories reported to CLRTAP/EMEP?*[25]", it is noticed that condensables cannot be defined easily. Measurement techniques for condensables and black carbon exist but have not yet largely agreed standards applied across Europe and North America. For condensables, different analytical protocols may give different concentrations. Standardised methods should then be developed to ensure a correct measurement of total PM concentrations in flue gases for the purposes of identifying technically feasible limit values for PM, including condensables and BC, which are mainly generated in small domestic wood burning appliances. There is also a lack a measurement of PM emissions including condensables on appliances. The limit values identified for filtrable PM (or solid PM) in this kind of appliances, allow significant emission reductions of BC and the condensable part of PM.

Analysis of possible updates in the Guidance Documents

All the technical and descriptive information collected on the new/upgraded technologies, discussed above, will be the main documentation material to be included in the Guidance Documents associated to the Annexes IV, V, VI, VIII, X and IX, as possible update.

Informal background document on the TAs and GDs review

The current comprehensive informal document with background information regarding BATs and related ELVs is offered by TFTEI as informal document for WGSR 60 (11 - 14 April 2022).

9. References

[1] Economic Commission for Europe, Executive Body for the Convention on Long-range Transboundary Air Pollution, *1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the Convention on Long-Range Transboundary Air Pollution, as amended on 4 May 2012,* **2012**

[2] T. Lecomte, J.F. de la Fuente, F. Neuwahl, M. Canova, A. Pinasseau, I. Jankov, T. Brinkmann, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for Large Combustion Plants*: *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2017.**

[3] European Commission, *Commission Implementing Decision (EU) 2017/1442 of 31 July 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for large combustion plants*, **2017.**

[4] G. Chronopoulos, G.-E. Cakmak, P. Tempany, G. Klein, T. Brinkmann, B. Zerger, S. Roudier, *Best Available Techniques (BAT) Reference Document on Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals*: *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2020.**

[5] European Commission, *Commission Implementing Decision (EU) 2020/2009 of 22 June 2020 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for surface treatment using organic solvents including preservation of wood and wood products with chemicals*, **2020.**

[6] M. Black, M. Canova, S. Rydin, B. M. Scalet, S. Roudier, L. Delgado Sancho, *Best Available Techniques (BAT) Reference Document for the Tanning of Hides and Skins*: *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2013.**

[7] European Commission, *2013/84/EU: Commission Implementing Decision of 11 February 2013 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the tanning of hides and skins*, **2013**.

[8] M. Gottlieb Warming, Danish Technical Institute, *Technical guidelines for design of low emission stoves,* IEA Bioenergy webinar series, May **2021**.

[9] G. Jansens and all, *Best Available Techniques (BAT) for domestic wood heating. Flemish Knowledge Center on BAT (VITO)* **2020.**

[10] Fortum website, Jaworzno III Tauron, low-NOx combustion project, Poland 2010–2016 (https://www.fortum.com/media/2016/11/jaworzno-iii-tauron-low-nox-combustion-project-poland-2010-2016)

[11] Fortum website, Narva power plants, Eesti Energia, Estonia, NOx reduction installations 2013–2015 (https://www.fortum.com/media/2015/11/narva-power-plants-eesti-energia-estonia-nox-reduction-installations-2013-2015

[12] Hoppala (Fortum), *Combustion modification to reduce NOx emissions also improves energy efficiency*, September **2020** (complements here:

https://www.fortum.com/media/2020/11/fortum-enext-implements-combustion-modification-significantly-cut-nox-emissions-coal-fired-power-plant-india)

[13] EES Corp website, *selected references of SNCR system performance for coal plants* (https://www.eescorp.com/wp-content/uploads/2017/10/SNCR-References.pdf)

[14] FIVES Pillard, *High performance combustion process solutions and services – Presentation for Citepa*, 2020 and direct communication with FIVES representative (FIVES website: https://www.fivesgroup.com/energy-combustion/burners-systems/boiler-burners and TFTEI website for some references: https://tftei.citepa.org/en/industrial-sources/reduction-of-nox-emissions#information-provided-by-industry-and-accepted-by-the-clearing-house-evaluation-committee)

[15] M. M. Schorr, J. Chalfin (General Electric Power Generation), *Gas Turbine NO_x emissions approaching zero – Is it worth the price ?,* **1999**

[16] Patel, GE Marks “Ultra Low” NO_x Gas Turbine Technology Triump, Power Mag, **2019**.

[17] European Commission, *Commission regulation (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Eco-design requirements for solid fuel local space heaters,* ***2015.***

[18] European Commission, *Commission regulation 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Eco-design requirements for solid fuel boilers with a rated heat output of 500 kilowatt or less*, **2015.**

[19] European Commission, *Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants,* **2015.**

[20] CEN, CEN/TS 15883: Residential solid fuel burning appliances – emissions test methods, **2008**

[21] EN 16510-1 Residential solid fuel burning appliances - Part 1: General requirements and test methods, 2018

[22] *Prioritizing reductions of particulate matter from sources that are also significant sources of black carbon - analysis and guidance*, **2021.** https://unece.org/sites/default/files/2021-10/ECE_EB.AIR_2021_6-2113500E.pdf

[23] *Code of good practice for wood-burning and small combustion installations*, **2019.** https://unece.org/DAM/env/documents/2019/AIR/EB/ECE_EB.AIR_2019_5-1916518E.pdf

[24] *Guidelines for estimation and measurement of emissions of volatile organic compounds*, **2016.** http://www.unece.org/fileadmin/DAM/env/documents/2016/AIR/WGSR/Docs_December/E_ECE_EBAIR_WG5_2016

[25] David Simpson and all, *How should condensables be included in PM emission inventories reported to EMEP/CLRTAP?* Report of the expert workshop on condensable organics organised by MSC-W, Gothenburg, 17-19th March 2020. ISSN 1504-6206, **2020.**

[26] European Commission, *Best Available Techniques (BAT) Reference Document for Organic fine chemicals*, **2006.**

[27] European Commission, *Commission implementing decision (EU) 2019/2031 of 12 November 2019 establishing best available techniques (BAT) conclusions for the food,*

drink and milk industries, under Directive 2010/75/EU of the European Parliament and of the Council, **2019.**

[28] European Commission**.** JRC, *Final draft of the Best Available Techniques (BAT) Reference Document for Common Waste Gas Management and Treatment Systems in the Chemical Sector*, March 2022

[29] Ceballos DM, Fellows KM, Evans AE, Janulewicz PA, Lee EG and Whittaker SG, *Perchloroethylene and Dry Cleaning: It's Time to Move the Industry to Safer Alternatives*, Front. Public Health 9:638082. doi: 10.3389/fpubh.2021.638082, **2021**.

[30] *The German ecolabel Blue Angel. Stoves for wood, Basic award criteria*, version 6, ***2020.***

[31] European Commission, *Commission implementing decision (EU) 2014/738 of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas*, **2014**

[32] Code of Federation (US) - *Title 40 - Protection of Environment, Chapter I – Environmental Protection Agency ; Subchapter C – Air Programs ; Part 60 - STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES Subpart Da - Standards of Performance for Electric Utility Steam Generating Units* https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-60/subpart-Da

[33] Chinese Ministry of Environmental Protection, State Administration for Quality Supervision and Inspection, *Emission Standard of Air Pollutant for Thermal Power Plants,* **2011**

[34] Indian Ministry of Environment, Forest and Climate Change, *Environment (Protection) Amendment Rules*, amending *Extraordinary Part II, Section 3, Sub-section (i) (1986)*, published in The Gazette of India, **2020.** (https://cpcb.nic.in/uploads/Industry-Specific-Standards/Effluent/tpp_modification_13-1-2021.pdf)

[35] F. van Aart and W. Burgers, *Short and long term averages – extended evaluation*, Rijkswaterstaat Ministry of Infrastructure and the Environment, **2015**

[36] DIN 51603, *Liquid fuels - Fuel oils - Part 1: Fuel oils EL, minimum requirements*, Berlin, Germany **2020**

[37] P. Barthe, M. Chaugny, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2015**

[38] Joint Research Centre (JRC), *Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals - Solids and Others industry*, Brussels, Belgium **2007**

[39] F. Schorcht, I. Kourti, B. M. Scalet, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2013**

[40] European Commission, *COMMISSION IMPLEMENTING DECISION of 26 March 2013: Establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions from cement production*, Brussels, Belgium **2013**

[41] F. Kausch, M. Seljeskog, A. Østnor. New European particulate emission test method for small scale appliances fired by solid fuel - EN-PME+EN16510-1 PM emission test method vs NS 3058/3059:1994 (RISE report 20012-72). RISE, **2020**

[42] R. Remus, Aguad-Monsonet A M., S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for Iron and Steel Production: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2013**

[43] European Commission, *COMMISSION IMPLEMENTING DECISION of 28 February 2012 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for iron and steel production*, Brussels, Belgium **2012**

[44] EnviNOx, *EnviNOx and Best Available Technique* **2021**

[45] G. Cusano, Gonzalo, F. Farrell, R. Remus, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2017**

[46] B. Scalte, M. GARCIA-MUÑOZ, A. Sissa, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for the Manufacture of Glass: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2013**

[47] European Commission, *COMMISSION IMPLEMENTING DECISION of 28 February 2012: Establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the manufacture of glass*, Brussels, Belgium **2012**

[48] M. Suhr, G. Klein, I. Kourti, Gonzalo, G. Giner-Santonja, S. Roudier, L. Delgado-Sancho, *Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2015**

[49] European Commission, *COMMISSION IMPLEMENTING DECISION of 26 September 2014 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the production of pulp, paper and board*, Brussels, Belgium **2015**

[50] F. Neuwahl, G. Cusano, G. Gómez-Benavides, S. Holbrook, S. Roudier, *Best Available Techniques (BAT) Reference Document for Waste Incineration: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)* **2019**

[51] L. Tang, J. Qu, Z. Mi, X. Bo, X. Chang, L Diaz Anadon, S. Wang, X. Xue, S. Li, X. Wang and X. Zhao, *Substantial emission reductions from Chinese power plants after the introduction of ultra-low emissions standards*, Nature Energy, 4(11), pp.929-938. **2019**

[52] LAB website page on FGD system https://lab.fr/en/fgd-system and reference cases Albioma Le Gol (https://lab.fr/sites/default/files/fichiers/Fiches%20usines/Le-Gol-min.pdf) and Solvay Tavaux (https://lab.fr/sites/default/files/fichiers/Fiches%20usines/Tavaux-min_0.pdf)

[53] SOLVAir (SOLVAY) presentation, *Clean air solutions for higher performance DeSOx with SOLVAir – coal power plants*, November **2021**

[54] SOLVAir (SOLVAY) presentation, *Dry Injection of SOLVAir Sodium Bicarbonate Based Sorbent in Flue Gas for Air Pollution Control*, **2019**

[55] SOLVAir (SOLVAY) presentation, *Dry Sorbent Injection (DSI) for SOx control in coal fired power plants*, **2021**

[56] DIN 51603, *Liquid fuels - Fuel oils - Part 1: Fuel oils EL, minimum requirements*, Berlin, Germany **2020**.

[57] S. Khairulin, M. Kerzhentsev, A. Salnikov, Z. R. Ismagilov, *Direct Selective Oxidation of Hydrogen Sulfide: Laboratory, Pilot and Industrial Tests*, Vol. 11.

[58] G. Cinti, V. Maringolo, *EXPERIENCE ON NOx EMISSION REDUCTION IN EUROPEAN CEMENT PLANTS* **2017**.

[59] Scheuch, *Innovative SCR Technologies: Technlogy for Cleaner Air*, Weierfing, Austria **2016**.

[60] R. Beilmann, *NOx in Cement Clinker Production - Formation and Measures to minimize NOx-Emission* **2016**.

[61] C. A. Grande, K. A. Andreassen, J. H. Cavka, D. Waller, O.-A. Lorentsen, H. Øien, H.-J. Zander, S. Poulston, S. García, D. Modeshia, *Ind. Eng. Chem. Res.* **2018**, *57 (31)*, 10180 – 10186. DOI: 10.1021/acs.iecr.8b01483.

[62] E. Schenk, J. Mieog, D. Evers, *Fact sheets on air emission abatement techniques* **2009**.

[63] European Commission, REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 December 2006, concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, **2006**

[64] European Commission, DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

[65] Direction Générale de la santé, Perchloroéthylène, **2013,** https://solidarites-sante.gouv.fr/sante-et-environnement/risques-microbiologiques-physiques-et-chimiques/article/perchlorethylene

[66] Arrêté du 31 août 2009 relatif aux prescriptions générales applicables aux installations classées pour la protection de l'environnement soumises à déclaration sous la rubrique n° 2345 relative à l'utilisation de solvants pour le nettoyage à sec et le traitement des textiles ou des vêtements, **2009** (https ://www.legifrance.gouv.fr/loda/id/JORFTEXT000021030687/)

[67] European Chlorinated Solvent Association (*ECSA), Infosheet on perchloroethylene,* **2020**

[68] European commission, Regulation n°1272/2008 of the European Parliament and of the *Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006,* 2008

[69] INRS REF: https://www.inrs.fr/risques/cmr-agents-chimiques/ce-qu-il-faut-retenir.html

[70] Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations, 2009

[71] Commission Directive 2014/99/EU of 21 October 2014 amending, for the purposes of its adaptation to technical progress, Directive 2009/126/EC on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations, 2014

[72] European commission, *Best Available Techniques (BAT) Reference Document for the Food, Drink and Milk Industries*, 2019

[73] DieselNet, *DieselNet Emission Standards: Stationary Engines / Non Road Combustion Engines* **2021**

[74] Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC

[75] C. Schön, H. Hartmann, *Status of PM emission measurement methods and new developments*, IEA bioenergy task 32, July **2018**

[76] I. Fraboulet, *"EN_PME_TEST Project Position paper: Determination of particulate matter emissions from solid biomass fuel burning appliances and boilers – Proposal for a common European test method*", **2015**

[77] T. Nussbaumer, *Overview on technologies for biomass combustion and emission levels of particulate matter*, prepared for the Swiss Federal office for the Environment and TFTEI, **2010**

[78] European Commission*, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of Ecodesign requiremlents for energy-related products,* **2009**

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0125

[79] Project Wood stoves 2020 – Development of next generation and clean wood stoves

[80] *Guidelines for Low Emission and High Efficiency Stove Concepts. Report within the scope of the ERA-NET Bioenergy Project "WoodStoves2020" . Development of Next Generation and Clean Wood Stoves*, July **2017**

[81] Mandl C. and all. *Guidelines for heat storage units based on phase changed material. Report within the scope of the ERA-NET Bioenergy Project "WoodStoves2020" – Development of Next Generation and Clean Wood Stoves*, July **2017**

[82] Mandl C. and all, *Guidelines for automated control systems for stoves. Report within the scope of the ERA-NET Bioenergy Project "WoodStoves2020" – Development of Next Generation and Clean Wood Stoves*, July **2017**

[83] Obernberger I. and all, *Improved low emission and high efficiency wood stove with integrated PCM heat exchanger. Project ERA-NET Bioenergy "Stove 2020"*, Workshop: "Wood Stoves 2020 - Towards high efficiency and low emissions" Stockholm (Sweden), 13th of June **2017**

https://www.tfz.bayern.de/mam/cms08/en/dateien/vortrag_obernberger_improved_high_efficiency_low_emission_stove_concept_including_an_pcm_heat_exchanger_2017.pdf

[84] INERIS, Chazelles, Supra, Lermab for ADEME, *Identification of existing technologies to reduce emissions of domestic appliances taking into account different burning cycles, Application of these technologies on two devices*, **2017**

[85] https://www.bnl.gov/woodheater/fifth-challenge.php. Accessed in February 2022, 21st

[86] I. Hartmann, *Wood combustion agenda 2030: Development pathways for low emissions future*, Virtual workshop on advances in wood heater research and development, January 11th and 12th, **2022**

[87] S. Collet, I. Fraboulet, J. Pouleau, *Synthèse des études à l'émission réalisées par l'INERIS sur la combustion du bois en foyers domestiques*, INERIS for the French Ministry for an Ecological Transition, **2018**

[88] G. Reichert, C. Schmidl, *Advanced Test Methods for Firewood Stoves, Report on consequences of real-life operation on stove performance*, IEA Bioenergy Task 32, **2018**

[89] Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces". The final rule was published on March 16, **2015** in 80 FR 13702 for subpart AAA – Standards of Performance for New Residential Wood Heaters and in 80 FR 13715 for subpart QQQQ – Standards of Performance for New Residential Hydronic Heaters and Forced-Air Furnaces

[90] D. Cole, A. Aldridge, *Guide for 'Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces*, EPA 456/B-15-002, **2015**

[91] G. Theis, R. Kegel, *Swiss regulations to control emissions from residential wood burning*, Working Group on Strategies and Review (CLRTAP), May 24, **2018**

[92] I. Hartmann, *The new Blue Angel ecolabel certification method for firewood stoves*, Workshop IEA Task 32, January **2020**

Grazttps://www.tfz.bayern.de/festbrennstoffe/publikationen/216675/index.php

[93] S. Pertant, S. Collet, *Influence de divers paramètres sur les performances environnementales et énergétiques des appareils domestiques fonctionnant au bois*, INERIS for the French Ministry for an Ecological Transition, DRC -17-164787-08043A, **2018**

[94] Vierundvierzigste Verordnung zur Durchführung des Bundes emmissions schutzgesetzes (Verordnung über mittelgroße Feuerungs- Gasturbinen- und Verbrennungsmotoranlagen - 44. BImSchV), Nichtamtliches Inhaltsverzeichnis, 44. BImSchV, Ausfertigungsdatum: 13.06.**2019**

[95] B. Bessagnet, N. Allemand, *Review on Black Carbon (BC) and Polycyclic Aromatic Hydrocarbons (PAHs) emission reductions induced by PM emission abatement*, TFTEI **2019**

[96] ReReal - Advanced testing methods for better real-life performance of biomass heating appliances. Web site (accesses in February 2022). BeReal - Home (bereal-project.eu)

[97] A. Behnke, German Federal Environment Agency, A*batement measures for Small Combustion Installations – German Legislation,* Working Group of Strategies and Review, **2013**

[98] Nordic Ecoloballing for Stoves, version 4.5. 11 June 2014- 31 December 2024. November **2021**

[99] OPair, Swiss ordinance on air protection of 1985, state on 1 April **2020**

[100] **C**ommunication of R. Kegel (Federal Office of Environment) to Citepa of 21/12/**2021**

[101] P. Pearson, Approaches on heatstoves "combined" stoves, coal stoves, Nordic and Artic Councils, CLRTAP and CCAC, Working Group of Strategies and Review, **2018**

[102] J.S. Andersen, M. Jespersen, *A Protocol for Black Carbon Emissions. A Protocol for Measuring Emissions of Elemental Carbon and Organic Carbon from Residential Wood Burning,* Nordic council of Ministers, **2016**

[103] Northeast States for Coordinated Air Use Management, *Measurement of black carbon in a wood stove method 5G dilution tunnel*, prepared for the US environmental protection agency, **2019**

[104] Northeast States for coordinated air use management for US EPA, *Measurement of black carbon in a wood method 5G dilution tunnel*, **2019**

[105] K. Kindbom and alls, Emission factors for SLCP emission from residential wood combustion in Nordic countries, Improved emission inventories of SLCP, Nordic Council of ministers, **2017**

[106] German "*Ordinance on Small and Medium-Sized Firing Installations of 26 January 2010 (Federal Law, Gazette [BGBl.] I p. 38), most recently amended by Article 2 of the Ordinance of 13 June 2019. (Federal Law Gazette I p. 804)*", Version: Most recently amended by Art. 2 of the Ordinance of 13 June 2019 I 804

[107] R. Kegel, *Case study on the use of electrostatic precipitators in domestic heating systems Project «Saas-Fee»,* FOEN, TFTEI Annual Meeting, 29.10.**2021**

[108] Oeko Solve, *Micro-dust filters and heat exchange recovery*, Central European Biomass conference, Graz, 22-24 January **2020**

[109] https://www.heizomat.de/images/kataloge/en/heizomat/mobile/index.html

[110] Saelen énergie, chaudières biomasse plaquettes et granulés Heizomat® de 15 kW à 3 MW. **2021**

[111] **C**ommunication of O. Grelier to Citepa of 21/12/**2021**

[112] https://www.hetas.co.uk/bsen16510-1-explained/ consulted on in February 2022

[113] Citepa, OMINEA report on methodology for French emission inventory of pollutant and green house gases, **2021**, https://www.citepa.org/fr/ominea/