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Diesel engines emit exhaust gas, which includes poisonous components, such as nitrogen oxide ($NO_x$), sulphur oxide ($SO_x$) and particulate matter (PM) causing environmental pollution and damage to human health. In line with the EU's air quality policy, the objective is to progressively reduce the emissions from new engines being brought on the market and, thereby, replace the old, more polluting ones over time. For these reasons, the Regulation (EU) 2016/1628 enforces more stringent limits to gaseous and particulate pollutant emissions, so called Stage V, for engines being used for inland vessels. With this emission regulation after-treatment solutions will be required for diesel-propelled inland waterway vessels in the future. This fact sheet offers insight into after-treatment solutions, ranging from relevant regulations and technical concepts to information on economics and environmental sustainability.

# FACT SHEET N° 3

# AFTER-TREATMENT

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In cooperation with INDanube Centre for Innovation Transfer
EIBIP | European Inland Barging Innovation Platform



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# REGULATIONS AND SOLUTIONS IN DEVELOPMENT

## REGULATIONS

The requirements relating to gaseous and particulate pollutant emissions for Stage V engines are regulated in Regulation (EU) 2016/1628. Amongst other engines for non-road machinery it is relevant for the categories IWP (engines for inland waterway vessels propulsion), IWA (auxiliary engines for inland waterway vessels) and NRE (non-road engines that may replace IWA and IWP engines with less than 560 kW). The emission limits for CO, HC, $NO_x$ and particle mass are greatly reduced. In addition to the reduction of the particle mass the new regulation restricts the number of particles for larger engines. In order to meet the new emission standard, technical solutions will become more complex. Internal combustion control concepts were up to now largely sufficient to comply with the emission limits. To fulfil the emission limits in the future, external device technologies will be required. For the reduction of $NO_x$ in the exhaust gas of diesel engines a **S**elective **C**atalytic **R**eduction (SCR) with an additional catalytic stage for CO and HC will be a possible choice. Sulphur oxide is toxic for most catalyst. Therefore, the fuel used with these technologies should harmonise with the standard EN 590 for diesel. To reduce particle mass and particle number a **D**iesel **P**article **F**ilter (DPF) system will be necessary.

## SOLUTIONS IN DEVELOPMENT

Not all details how to meet the Stage V emission limits in inland waterway vessels are fully clear today. However, three options are considered:

### SOLUTION 1 LIES WITH THE ENGINE MANUFACTURERS

It is expected that some engine manufacturers will come with an overall solution: a combination of a diesel engine with after treatment, where the engine manufacturer is the responsible party. With this solution the vessel operator will get a NRMM Stage V emission certificate on an ex-works basis, whereby there is no need for emission tests on-board.

### SOLUTION 2 LIES WITH THE SUPPLIERS OF AFTER-TREATMENT

It is expected that some suppliers of SCR catalysts and DPF will come with an overall solution: after treatment combined with a diesel engine, where the supplier of the SCR catalyst and diesel particulate filter is the responsible party. With this solution the vessel operator will receive a NRMM Stage V emission certificate on an ex-works basis, whereby there is no need for emission tests on-board.

### SOLUTION 3 LIES WITH EMISSIONS MEASUREMENT SYSTEMS ON BOARD

It is expected that the vessel operator can meet the Stage V emission limits with an existing diesel engine in the near future. For example, by adding an EU Stage V ready SCR catalyst and diesel particulate filter combined with an on board and real time emissions measurement system, whereby the vessel operator can demonstrate the level of emissions.

# TECHNICAL CONCEPT

Emissions from inland vessels using combustion engines contain several components which must fulfil limits. To fulfil these limits different exhaust gas after-treatment technologies will be used. In the following four technologies are presented which contribute to the compliance with the limit values of Stage V.

## AFTER-TREATMENT TECHNOLOGIES

### EXHAUST GAS RECIRCULATION (EGR)

The **nitrogen oxide ($NO_X$)** concentration in the exhaust gas of a diesel engine is reduced by the **Exhaust gas recirculation (EGR).** The concentration of $NO_X$ depends on the production rate of $NO_X$ which grows exponentially with rising temperature. To **reduce** the peak temperature and the oxygen concentration a part of the exhaust gas is returned to the combustion chamber. This effect could be enhanced by cooling the recircled exhaust gas. Lowering the combustion temperature to reduce the $NO_X$ concentration is limited, because the production of soot particles is favoured at lower temperatures and the engine power is affected. In addition a residue of HC and CO remains in the exhaust gas.

### DIESEL OXIDATION CATALYST (DOC)

To remove the residue of HC and CO from the exhaust gas by about 90 % a **Diesel Oxidation Catalyst (DOC)** is used. With the after-treatment component DOC the HC and the CO are oxidized into water ($H_2O$) and carbon dioxide ($CO_2$). In combination with the EGR the exhaust gas will be influenced for further after-treatments like SCR and DPF. The process conditions in the DOC are not suitable to degrade the $NO_X$ concentration by reduction.

### DIESEL PARTICLE FILTER (DPF)

A **Diesel Particle Filter** reduces the particle matter from the engine exhaust gases. In addition for Stage V engines the number of particles leaving the DPF is restricted by a number of 1.0e12 particles per kWh. The size of the counted particles is larger than 23 nm. Separating the particles from the exhaust gas is done by flowing through a porous material. The separated particles reduce the flow through the DPF and change the pressure difference between in- and outflow of the DPF. At a maximum pressure difference the collected particles must be removed by changing the filter or filter regeneration. During the filter regeneration the collected particles, mainly soot, are burned to clean the filter. Afterwards the clogging particles are removed, the pressure difference is changed and the operational condition of the DPF is normalized. The ash residue increases with each filter regeneration. The increase of ash is much slower than the growth of soot and therefore the time is much larger until the filter is plugged with ash. If possible, the filter could be cleaned or it must be replaced. To start the filter regeneration a higher temperature is needed. This can be done by heating or a catalyst in combination with injecting fuel in the exhaust stream to initialize the burning of soot. The **separation of soot** is **more than 90 %.**

### SELECTIVE CATALYTIC REDUCTION (SCR)

To reduce the $NO_X$ concentration at the exhaust gas a **Selective Catalytic Reduction** technology can be used. A reagent is injected in the exhaust gas before entering the SCR which starts a chemical reaction to convert nitrogen oxides, with the aid of the reactant as catalyst, to **diatomic nitrogen ($N_2$)** and **water ($H_2O$)**. **Ammonia ($NH_3$)** is suitable but toxic. Therefore, the handling will be problematic on board. To avoid these problems a urea-water solution (AdBlue) is used as reagent, which is not classified as dangerous good. After injecting the urea in the exhaust gas the Ammonium is built by dissociating the urea. Afterwards the $NO_X$ is oxidized to $N_2$ and $H_2O$. The dosing of the urea is important. At low urea concentration the $NO_x$ emission rises, because not all $NO_X$ could be oxidized. If the urea dosing is too high the toxic $NH_3$ leaves the SCR. The usage of urea raises the operational costs. The **$NO_X$** emissions can be **reduced from 70 % up to more than 90 % depending on the system and configuration.**

## COMBINATING AFTER-TREATMENT TECHNOLOGIES

The exhaust gas after-treatments explained above must be combined to fulfil the Stage V emission standard. This is usually done in the following sequence: EGR, DOC, DPF and SCR.

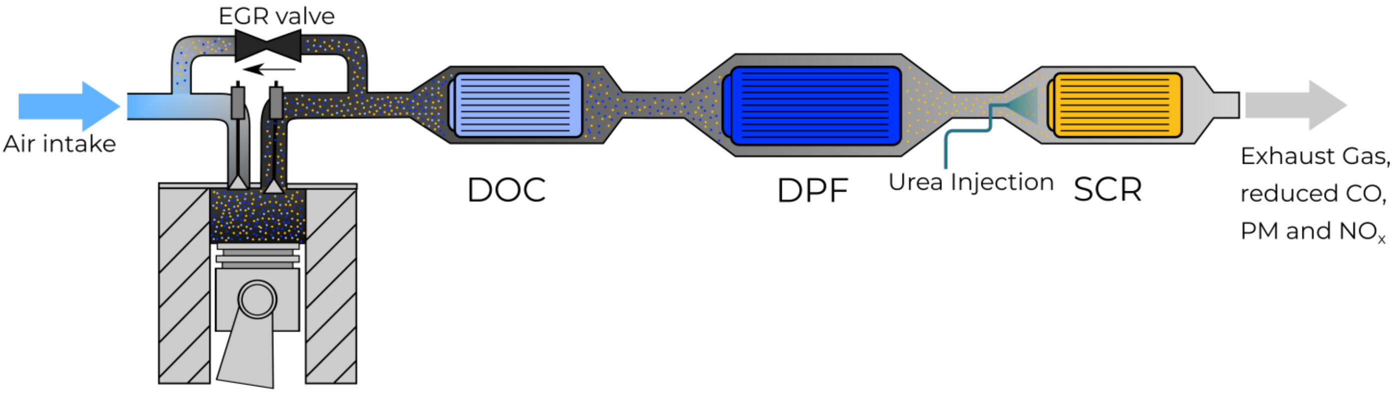


Figure 1 Exhaust after-treatment system with EGR, DOC, DPF and SCR.

Current developments aim at a combination of DOC and DPF in one component. The component could be more compact and therefore needs less space. For retrofitting combinations of DOC, DPF and SCR are thinkable, depending on the emission standard of the installed main engine and other prerequisites.

## AFTER-TREATMENT DESIGN

The design of after-treatment systems depends on prerequisites like:

- Exhaust gas temperature
- Allowable back pressure of the engine
- Operational profile (e. g. operational hours)
- Available space in engine room or on the deck
- Mass flow rate of exhaust gas
- Engine maintenance condition

Figure 2: Pictures of exhaust plumes (left: engine reversing, right: typical appearance at steady state operation)

# ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

Reduction of emissions improves the health protection of the crew or passengers in inland waterway transportation. In addition, emissions in ports and urban areas are reduced, which is an intensively discussed topic in public.

The costs for deployment of after-treatment technology on inland vessels are influenced by a number of factors. The investment in eventually needed exhaust technology for newly built ships and new engines to reach the NRMM limits is beyond question. For retrofitting, the question arises as to whether a return on investment can be achieved. In the framework of the H2020 project PROMINENT[1] calculations for investing in exhaust gas after-treatment for different representative journeys in the Rhine or Danube region were made (*PROMINENT Deliverable D2.2*). This was done for investing into SRC only or in the combination of SCR and DPF technology. In none of the examined business cases the return of investment was reached. Financial incentives are therefore needed to reduce emissions from existing vessels.

## INVESTMENT COSTS

Investment costs are provided for an example of combination of DPF and SCR for an inland vessel with a CCNR 2 engine with an engine power of 750 kW in the following table. Alternatively, a rough estimation can be made based on the engine displacement with 2 EUR/cm³ for each SCR and DPF.

| Cost category | Costs in EUR | Comment |
|---|---|---|
| System costs | 100,000.00 EUR | Depending on number of DPF and SCR modules |
| Basis system | 25,000.00 EUR plus 100 EUR/kW installed | |
| Installation costs | 20,000.00 EUR plus one week at shipyard | |

## OPERATIONAL COSTS

Maintenance and operational costs for the example above (combination of DPF and SCR with a CCNR 2 engine of 750 kW) are estimated as follows:

| Cost category | Costs in EUR |
|---|---|
| Maintenance | 6,000 – 10,000 EUR / year |
| AdBlue consumption | approximately 5 % of fuel consumption |
| AdBlue costs | 0.20-0.50 EUR/l which is approximately 25 EUR/1,000 l diesel |

## ENVIRONMENTAL SUSTAINABILITY

Depending on the engine, operational profile and other prerequisites exhaust after-treatment can reduce air pollutants massively. Fuel consumption and the coupled $CO_2$ emissions remain constant or can even be lowered by optimization of engine control parameters. For example most CCNR 2 engines are optimised to reach emission limits without after-treatment at the cost of reduced efficiency. The after treatment system allows to regain efficiency. For proper use-cases, i. e. suitable operational profile with sufficient exhaust temperatures, suitable engine in terms of back-pressure limits and sufficient space / heat discharge capacity, retrofitted after-treatment systems are a very effective measure to improve the environmental performance of inland ships.

[1] www.prominent-iwt.eu (EU Horizon 2020 project from 2015 to 2018 )

## BENEFITS

Reducing emissions leads to further qualitative and quantitative benefits and advantages like the reduced dues listed below. These enable a return on investment which is increased with the number of participating ports, service providers or waterway authorities:

- Owner of the Green Award Inland shipping certificate e.g. benefit from reduced port rates or other advantages. The following list is incomplete (Full list of incentives at www.greenaward.org).
  - Reduction of harbour dues e.g. in
    - Port of Amsterdam, Port of Zaanstad 5 – 20 %
    - Port of Rotterdam 15 – 30 %
    - Port of Utrecht 30 %
    - Port of Papendrecht, Port of Werkendam 15 %
    - Zeeland Seaport Terneuzen 10 %
    - Port of Ghent 10 %
  - Reduction of services or products of several suppliers
- At 2019 the port of Hamburg discounts to reward particularly environmentally conscious behaviour. (Pricelist Inland shipping of port of Hamburg)
- In 2025 some parts of the port Rotterdam will be closed for inland waterway vessels with emission standard lower than CCNR II (see www.portofrotterdam.com).
- Reduced port dues are given at the port of Antwerp in 2019 (see www.portofantwerp.com) for inland vessels which
  - comply with the Stage V emission standard: 7 % reduction.
  - have been built before 2008 and are equipped with a CCNR 2 engine: 7 % reduction
  - make use of a diesel-electric main propulsion in which the diesel engine adheres to the emission standards of the CCNR 2 norm: 15 % reduction
  - make use of a LNG or dual fuel motor (LNG used as main fuel using diesel as ignition fuel) as main propulsion: 15 % reduction
  - make use of an electric motor driven by fuel cells with hydrogen as fuel. 15 % Reduction

# CONSIDERATIONS FOR DEPLOYMENT

## INSTALLING NEW ENGINES

For inland waterway vessels the Regulation (EU) 2016/1628 defines the Stage V categories IWP and IWA of engines. Emission limits for new engines with a reference power lower or equal to 300 kW are effective from 01 January 2019 and for a reference power larger than 300 kW from 01 January 2020. Apart from limited exceptions new engines put into service after these dates will have to comply with the new limits, which usually can only be reached with exhaust gas after-treatment. However, today no IWP/IWA engines have the Stage V type approval yet. For engines with reference power lower than 560 kW it is allowed to install engines of type NRE instead of IWP. Also EURO VI truck engines may be installed in inland ships. How far marinization of NRE engines and EURO VI truck engines affects the type approval is currently being clarified. The emission limits for these replacement options are lower or equal to the ones for IWP engines.

## EXHAUST AFTER-TREATMENT UNCERTAINTIES

During the type approval engine and exhaust after-treatment are combined as unit. It is allowed to distribute the engine without the exhaust after-treatment which was installed during type-approval. The new exhaust after–treatment was therefore not tested during type-approval with the engine. This leads to uncertainties.

The manufacturer, the owner of the type-approval certificate, is responsible to give all relevant information and instructions that are necessary for the correct installation of an engine in non-road mobile machinery, including a description of any special conditions or restrictions linked to the installation or use of engine. This includes the exhaust gas after-treatment devices. Now, based on the prescribed procedure the after-treatment is replaced. There could be differences in the material of the SCR or the filter material of the DPF.

Who is responsible to ensure the emission standard?

- In case the new configuration fulfils the emission standard, the manufacturer is the owner of the type-approval.
- If the new configuration misses the emission standard, than the new manufacturer is the one who modified the system.

## DEPLOYMENT EXAMPLES

### PB DONAU

**Owner:** Frank Rycquart
**Location**: Antwerp, Belgium
**Equipped by**: Multronic NV
**After-treatment since**: 2017

ⓘ www.multronic.be


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**Vessel type**: Push boat
**ENI:** 06105358
**Vessel size**: 22.5 m × 10.0 m (L × W), Draught: 2.35 m
**Propulsion**: 2 Caterp. 3512 (CCNR2)
**Exhaust After-Treatment**:
Starboard: SCR+DPF
Portside: SCR only.
Deployed in 2017 in the project PROMINENT (www.prominent-iwt.eu Deliverable 5.10).
**Outcome**: Starboard: emissions are compliant with Stage V NRMM.
Portside: $NO_X$ emissions are compliant with Stage V NRMM.

### MS MAX PRÜSS

**Operator**: Landesamt für Natur, Umwelt und Verbraucherschutz NRW
**Location**: Düsseldorf, Germany
**Equipped by**: TEHAG Deutschland GmbH
**After-treatment since**: 2015

ⓘ www.tehag.com
ⓘ www.lanuv.nrw.de


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**Vessel type**: Laboratory vessel
**ENI:** 05803790
**Vessel size**: 33.0 m × 7.6 m (L × W), Draught (max): 1.10 m
**Propulsion**: 2 MAN Type D 2866 LXE 43
**Exhaust After Treatment**: SCR + DPF (2015).

## Contact

For further information or suggestions how to improve this fact sheet please do not hesitate to contact:

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