Guidance Document on Control Techniques for Mobile Sources

CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

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Background information

- The 1999 **Gothenburg Protocol (GP)** under the UNECE LRTAP Convention entered into force in 2005 and was revised in 2012
- **Guidance Document** on control techniques for selected mobile sources adopted in 1999
- **Update of the GD** considered necessary to
  - include major advances in engine / exhaust control techniques
  - extend scope of pollutants (e.g. PM control)
  - extend range of sources covered (e.g. sea going ships, aircrafts)
- Service request by European Commission (**DG Environment**)
- Framework contract with **IIASA** (AT, project management) and **EMISIA** (GR, technical work) from Dec. 2013 to Dec. 2014
- Project acronym: **BAT** (Best Available Techniques)

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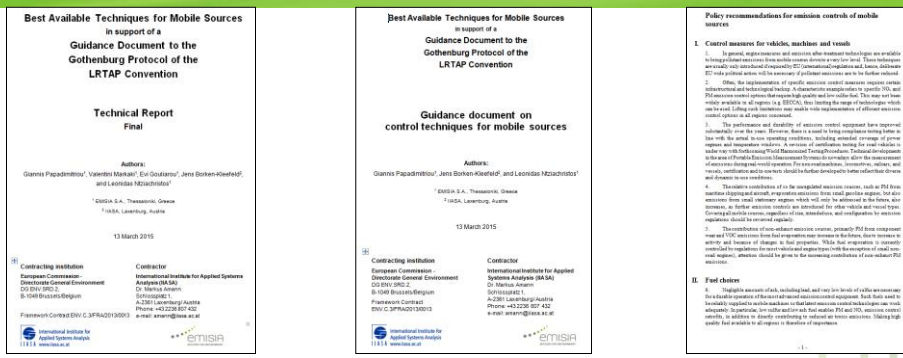
Main outcomes of the BAT project



- **Technical Report:** A 204p. document with detailed technical information and analysis to support the GD
- **Guidance Document:** A 35p. document to update and replace the 1999 GD
- **Policy Recommendations:** A 3p. document with policy context

The project team

emisia
MISSION FOR ENVIRONMENT

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Jens Borken-Kleefeld, Ph.D.
Project management and consultation

EMISIA

- **EMISIA** is a spin-off company of Aristotle University of Thessaloniki (AUTH) established in 2008
- Permanent **staff**: 5 Ph.D. engineers, 4 M.Sc. engineers, 3 IT developers
- Managing director: Dr. **Giorgos Mellios**
- Academic support: Profs. **Zissis Samaras**, **Leonidas Ntziachristos**
- Key **customers**: EC (DGs), EU institutes and associations, industry

Areas of work

- **Emission** and energy inventories, **modeling** and **projections**
- Impact assessment studies of **environmental policies**
- **Transport data** (fleet, activity, energy, emissions)
- **Software** development and customer support
- Transport emission and projection **tools** copert sibyl

Emisia is ISO 9001 certified

Acknowledgements

- Peter **Meulepas** and Andre **Zuber** (DG ENV)
- Tiziano **Pignatelli**, Jean-Guy **Bartaire**, and Nadine **Allemand** (TFTEI)
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  - Paul **Greening** (ACEA)
  - Robert **Ilg** (Fraunhofer IBP)
  - Inmaculada Gómez **Jimenez** (OBSA)
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  - Graeme **Wallace** (EFOA)

The Guidance Document: organization

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Introduction (1/2)

- **Aim of GD:**
  *"provide the Parties to the LRTAP Convention with **guidance on identifying best abatement options for mobile emission sources**, in order to assist in meeting the obligations of the Gothenburg Protocol"*
- Emphasis is given to **"technical measures"** → techniques that can be implemented on each single vehicle or engine
- Other measures discussed: changes to **fuel type**, fuel specifications, and **"non-technical measures"**
- **BAT:** several techniques can be identified as BAT for reducing a specific pollutant
  - already applied in **wide scale real-world applications**
  - **economic** viability
  - boundary conditions and **limiting** factors
  - potential **synergies** and trade-offs

Introduction (2/2)

- Recommendations given **per category** of vehicle or machinery
  - differentiation between BAT applicable for **newer** and **older** types
  - **emerging techniques** or on experimental scale addressed separately
- **Key messages:**
  - GD provides **general guidance** of possible emission control techniques, **not an exhaustive list** of all possible techniques
  - under specific **local conditions**, other techniques might be judged equally good BAT
  - technical, financial, infrastructural **limiting factors** may exist in particular cases
  - BAT is not necessarily the latest technology, **emphasis on existing stock**
  - technology for **latest Euro standards** is considered by definition as BAT for new vehicles

Coverage: pollutants

- **Main pollutants:** nitrogen oxides (**NO_x**), particulate matter (**PM**), volatile organic compounds (**VOC**)
- **Black carbon (BC):** a large fraction of PM emissions consists of BC, therefore, techniques considered for PM reduction practically also address BC emissions
- **Other pollutants:** sulfur oxides (**SO_x**), ammonia (**NH_3**), ozone precursors carbon monoxide (**CO**) and methane (**CH_4**), addressed **only** when deemed relevant

Coverage: mobile sources

Road vehicles	Spark-ignition engines • Mopeds and motorcycles • Light duty vehicles (passenger cars, light commercial vehicles) Compression ignition engines • Light duty vehicles (passenger cars, light commercial vehicles) • Heavy duty vehicles (trucks, buses)
Non-road mobile machinery (NRMM)	Spark-ignition engines • Handheld and non-handheld equipment (household, gardening, agricultural and forestry machinery) Compression ignition engines • Industrial, construction, agricultural and forestry machinery / tractors • Railcars, locomotives
Inland waterways	• Compression ignition engines (passenger ships, freight vessels)

- **Supplementary** to the GP Annex VIII:
  - **sea going ships** (short sea or deep sea shipping)
  - **aircrafts**
  - electric **trams**, **metro**, and **trolley buses**
  - **non-exhaust** emissions (evaporative, component wear)

Emission processes

Exhaust emissions

Addressed by:

- **engine measures** (combustion efficiency, control of fuel properties)
- **aftertreatment** devices in exhaust line
- **fuel switching**, alternative powertrain
- **non-technical** measures

PM from component wear and abrasion (non-tailpipe primary emissions)

- measures for **abatement**
- **brake** measures

Evaporative emissions

- measures to prevent **gasoline** fuel evaporation from the tank

Emission contributions

- Mobile sources contribute about
  - **40% to 60%** of all **NO_x** emissions and about
  - **10% to 30%** of all **$PM_{2.5}$** emissions in the different UNECE regions
  - **20%** of all **VOC** emissions in the different UNECE regions
- Largest single sources of **NO_x** and **$PM_{2.5}$**
  - **diesel** powered **cars** and **trucks**
    - agricultural **tractors** and construction **machinery**
      - diesel powered rail and shipping activities
- Largest single sources of **VOC**
  - **gasoline** powered **light duty vehicles** including two wheelers
    - smaller machinery, agricultural machines
- Source: IIASA GAINS (values here for 2010)

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Assessment methodology

- Detailed methodology steps for the assessment of BAT is presented in GD for **diesel HDVs** and **NRMM**
  - as an example, to justify how we reached our recommendations
  - these categories considered of most importance
- For the remaining categories, details are **omitted**
  - they can be found in the technical report
- **2-step** assessment approach
  1. various options are evaluated in terms of emission reduction potential (**environmental benefit**) and **cost**, relative to a reference technology
  2. possible **limiting factors** examined (environmental side effects, energy efficiency, technical difficulties, infrastructural needs, etc.)

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BAT for emission control from mobile sources

- **Guidance** for emission control is gives as
  - BAT for **new** vehicles, current situation (e.g. DPF OEM)
  - BAT for the **existing** stock, in-use vehicles (e.g. DPF retrofit for HDVs)
  - **Future** vehicle types (potential for early introduction of promising techniques to achieve better performance than latest Euro standards)
- Terms **'new'** vehicles and **'latest'** (or 'current') applicable Euro standards considered relative to 2014 (preparation of GD)
- A short description of **all** individual emission reduction techniques or measures ('BAT candidates') given in **Annex I** of GD (more technical details can be found in the technical report)

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A. Mopeds and motorcycles (gasoline) (1/3)

- Significant emitters of **VOC** (and CO), especially **2-stroke** mopeds
- Contribution to **urban** air pollution in densely populated areas

- A1. **New** vehicles (exhaust emission/fuel evaporation control)
  - **technologies:** port-fuel injection, stoichiometric combustion (with lambda sensor), catalytic aftertreatment (two- or three-way oxidation)
  - **secondary air injection** (increase oxygen content, improve oxidation of HC and CO)
  - **2-stroke engines:** recent trend to be phased out, otherwise significant investments in the emission control is requested
  - **fuel evaporation control:** carbon canisters, low permeability tanks (applicable mainly to larger vehicle types)

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A. Mopeds and motorcycles (gasoline) (2/3)

- A2. **Existing** stock (in-use vehicles)
  - old 2-stroke engines **without aftertreatment control**
    - **retrofitting** a catalytic converter **cannot be recommended** due to space limitations and simple design characteristics of small engines
    - focus on **accelerated replacement schemes** boosted by financial incentives
  - recent technology motorcycles **with catalyst** (newer existing stock)
    - emission control **system maintenance** (e.g. annual I/M schemes) to identify failures and malfunctions and require repairs
    - fuel and **lubrication oil of good quality** (manufacturer recommended) to avoid catalyst deactivation caused by impurities
    - lube **oil changes** at recommended intervals

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A. Mopeds and motorcycles (gasoline) (3/3)

- A3. **Alternative fuels** (e.g. LPG/CNG) for gasoline replacement
  - **do not offer** substantial improvements in air quality without further (aftertreatment) emission control
  - **cannot be recommended** due to safety and space limitations
- A4. **Future** vehicle types
  - **three-way catalysts** and stoichiometric combustion for motorcycles
  - **larger catalysts** and overall better engine strategies for mopeds
    - cost and space limitations in smaller vehicles
  - trend to **replace 2-stroke with 4-stroke** engines to be continued
  - **electric vehicles** have the potential to provide significant air quality benefits (challenges in terms of weight, space constraints, cost)

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B. Spark-ignition (gasoline) on-road LDVs (1/4)

- Significant contribution to **VOC**, lower contribution (than diesel) to **NO_x** and **PM** (mainly from **GDI** vehicles)
- B1. **New** vehicles (exhaust emission/fuel evaporation control)
  - Port-fuel injection (**PFI**) engines
    - typical configuration: stoichiometric combustion with **closed-loop TWC** and oxygen sensor (very efficient among all conventional technologies)
  - Gasoline direct injection (**GDI**) engines
    - more recent technology to **improve** fuel efficiency and power output
    - stoichiometric combustion with **TWC**, lean operation with **LNT** (lean NO_x trap), engine measures or **GPF** (gasoline particle filter) to control PM
  - **Fuel evaporation control:** activated carbon canisters, low permeability tanks

B. Spark-ignition (gasoline) on-road LDVs (2/4)

- B2. **Existing** stock (in-use vehicles)
  - The majority of gasoline LDVs are **already equipped with TWC** (Western Europe and North American countries)
  - A **well maintained** TWC equipped gasoline vehicle is generally considered a **low emitter** (exceptions may exist, i.e., extreme temperatures)
  - Focus to maintain their **good overall performance**
  - Emission control **system maintenance:** I/M schemes to identify failures and malfunctions, remote sensing coupled to number plate recognition to identify high emitters, OBD usage, etc.
  - Once a malfunction has been identified: component **replacement** (e.g. catalyst), re-calibration, cleaning (e.g. injectors) → positive **side effect** on NH_3 emissions, since aged catalysts reduce NO_x preferably to NH_3 than N_2
  - In regions where a significant fraction of **non-catalytic vehicles** is still in operation, efforts should focus on **accelerated replacement schemes** boosted by financial incentives

B. Spark-ignition (gasoline) on-road LDVs (3/4)

- B2. **Existing** stock (in-use vehicles) (cont'd)
  - **Fuel evaporation control**
    - **retrofitting** activated carbon canisters and low permeability tanks (technical difficulties may exist)
    - include canister efficiency tests in regular inspection programs and **replacement** for older vehicles
- B3. **Alternative fuels** (LPG, CNG, bio alcohols) for gasoline replacement
  - when compared to gasoline, most alternative fuels offer **limited or no** net emission improvements (may increase other, non-regulated, pollutants)
  - retrofits entail **risk** of increased emissions due to limited technical sophistication of technology and lack of efficient verification mechanisms
  - **cannot be recommended** with regard to regulated pollutants
  - ongoing regulatory efforts stem from **energy** security considerations (e.g. natural gas) and the need to reduce **GHG** from transport

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B. Spark-ignition (gasoline) on-road LDVs (4/4)

- B4. **Future** vehicle types
  - Stoichiometric combustion with **advanced TWC** will continue to be the main component for emission control in gasoline vehicles
  - **GPF** or **engine measures** for PM control in GDI vehicles, **LNT** in lean burn engines for NO_x control
  - **Hybrid and electric vehicles:** advanced vehicle types primarily aiming at reducing energy consumption and GHG emissions
    - they have the **potential** to achieve significant reductions in air pollutants
    - small market penetration up to now due to technical, economical, infrastructural **limitations**

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C. Compression-ignition (diesel) on-road LDVs (1/3)

- In general, produce high **NO_x** and **PM** emissions (PM include a large fraction of **BC** and are associated with elevated **PN** emissions
- C1. **New** vehicles (exhaust emission control)
  - NO_x control: i) **engine measures** only, including exhaust gas recirculation (**EGR**), no deNO_x aftertreatment, ii) **LNT**, iii) **SCR** with urea injection
  - PM control: diesel particle filter (**DPF**)
  - Well-known problem with real driving emissions (**RDE**): much higher than corresponding emission limits (type approval)

→ can be addressed with **recalibration** of engine/aftertreatment systems, and **combination** of engine measures, EGR and SCR with increased urea injection

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C. Compression-ignition (diesel) on-road LDVs (2/3)

- C2. **Existing** stock (in-use vehicles)
  - A good candidate for emission reduction measures (especially NO_x), but with **limited options**, in particular for the older stock
  - **Retrofits** (e.g. SCR) encounter **technical difficulties** and limited space availability (difficult wide scale application, e.g. as a retrofit program)
  - For **newer** existing stock (vehicles of more recent technology), proper **calibration** and **retuning** to improve functioning of control systems
  - **Alternative fuels** as diesel replacement
    - only **renewable diesel** can lead to realistic (but rather moderate) reductions
    - natural gas retrofit cannot be recommended due to technical limitations
    - biodiesel has low emission reduction effectiveness
  - Hence, **non-technical measures** appear to be a good option
    - **access restrictions** (e.g. to city centers) and enforcement of **environmental zones**
    - **accelerated scrappage schemes** boosted by financial incentives
    - **inspection and maintenance:** include NO_x tests, detect broken DPF, OBD usage

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C. Compression-ignition (diesel) on-road LDVs (3/3)

- C3. **Future** vehicle types
  - **Typical diesel emission control:**
    - **combination** of EGR, DOC, SCR (or LNT for smaller vehicles), and DPF
    - new **calibration** and control strategy of the whole system (RDE testing)
    - long term performance **monitoring** by means of OBD
    - **ammonia** slip catalyst (downstream of SCR) to avoid ammonia slip
  - **Alternative fuels and powertrains:**
    - **CNG** can be used as a diesel replacement (to achieve emission reductions and reduce dependence on oil)
    - not much information on second generation **biofuels** (apart from GHG savings that they can achieve)
    - limited experience in diesel **hybrids**

D. Compression-ignition (diesel) on-road HDVs (1/5)

- Produce high **NO_x** and **PM** emissions, **crankcase** emissions of older engines also contribute to VOC and PM emissions

- D1. **New** vehicles (exhaust emission control)
  - **Engine measures**, including exhaust gas recirculation (**EGR**)
  - **Aftertreatment**: combination of
    - diesel oxidation catalyst (**DOC**) for CO/HC control
    - selective catalytic reduction (**SCR**) for NO_x control, with ammonia slip catalyst (**ASC**) to eliminate excess NH_3 emissions
    - diesel particle filter (**DPF**) for PM control

D. Compression-ignition (diesel) on-road HDVs (2/5)

- D2. **Existing** stock (in-use vehicles)
  - A good candidate for emission reduction measures, e..g. state-owned vehicles or **captive** fleets (urban buses, refuse trucks)
  - Measures such as **retrofits** and **fuel changes** can be materialized
  - **Reference technology** considered for the assessment:
    - turbocharged CI engine with high pressure fuel injection and without aftertreatment (roughly **corresponds** to Euro III)
    - **reference emission levels:** 4-16 g NO_x/km and 0.1-0.5 g PM/km (order of magnitude) → combined with emission reduction (%) gives BAT AEL (associated emission level)
    - this is a technology which does not coincide with latest emission control technology, but it is **still met often** in many countries and has known environmental impacts that should be addressed

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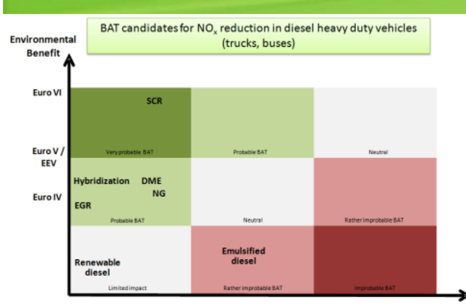
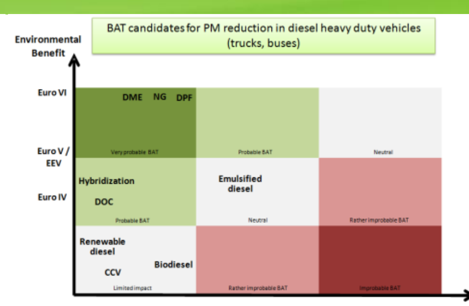
D. Compression-ignition (diesel) on-road HDVs (3/5)





- D2. **Existing** stock (in-use vehicles) (cont'd)
  - Relative **cost-benefit** comparison of BAT candidates for NO_x/PM reduction
  - Dark **green** cells: high environmental benefit at low cost
  - Dark **red** cells: low environmental benefit at high cost
  - Placement of techniques in boxes is **indicative** and relative (not to be scaled, location within the same box is irrelevant)
  - Indicative placement of **Euro standards** only for reference

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D. Compression-ignition (diesel) on-road HDVs (4/5)

- D2. **Existing** stock (in-use vehicles) (cont'd)
  - Based on cost-benefit comparisons and examining infrastructural, technical, and other limitations, following **recommendations** are made
  - **SCR and DPF retrofits:** cost-effective BAT techniques, can be combined for potential cost advantages, several successful retrofit examples around the world (long haul trucks, urban buses)
  - **Other retrofits:** i) **DOC** in combination with DPF and SCR, or as stand-alone in large-scale applications, being more tolerant to fuel sulfur than DPF, ii) **CCV** to control crankcase emissions of older vehicles, iii) EGR has **limited** potential due to technical difficulties integrating this on existing engines
  - **Fuel switching:** i) **CNG** conversion possible (e.g. in urban buses) but with technical complications, ii) **renewable diesel** can deliver measured, yet moderate, reductions, primarily to PM, iii) DME and emulsified diesel **are not recommended** due to technical, economical, or other limitations, iv) biodiesel has **low** emission reduction effectiveness
  - **Hybridization:** recommend for urban buses (fuel consumption benefits)

D. Compression-ignition (diesel) on-road HDVs (5/5)

- D3. **Future** vehicle types
  - **Typical diesel emission control:**
    - **combination** of EGR, DOC, SCR, and DPF
    - further system **optimizations** and **monitoring** by means of OBD to guarantee efficient long term performance
  - **Alternative fuels and powertrains:**
    - **hybrid buses**, possibly combined with natural gas
    - full electric and fuel cell electric buses: may have a **potential**, but there are limitations in charging, production and distribution of hydrogen
    - DME has issues of production/distribution which must be addressed
    - different versions of renewable fuels for long-haul trucks may be considered

E. PM from component wear and abrasion

- May contribute to total PM emissions, measures considered here tackle **primary** emissions, not resuspension of dust
- Measures for **abatement** (wear dust):
  - minimize the **sources**: adjustments of pavements and gritting material, use of coarser, wear resistant rock aggregates, avoid using studded tyres
  - minimize **dispersion** to air: wet roads, dust binding materials
  - **traffic** measures: decrease share of trucks, calming traffic, gentle braking
- **Brake** measures (brake wear contain toxic heavy metals):
  - change brake **composition**, e.g. ceramic brakes have fewer emissions
  - brake particulate **collection** system that recuperates particulates
  - **regenerative** braking (improves fuel economy and reduces brake pad wear)

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F. Gasoline engines in non-road applications (1/3)

- Highly diverse **category**, handheld and non-handheld equipment (e.g. household, gardening, agricultural and forestry machinery, etc.)
- Pollutants of concern: **VOC** (especially from 2-stroke), **CO**, and **PM** (excess hydrocarbons) for those immediately exposed to the exhaust
- F1. **New** engines (typical emission control)
  - emission control is **less advanced** than gasoline engines in road
  - **limiting factors**: space, maximum operation temperature, noise, limited total lifetime, various position angles
  - focus on reducing scavenging losses from **2-stroke** small engines with improved combustion and mixture exchange control (e.g. chain saws)
  - **replacement** of 2-stroke with 4-stroke engines in larger ground-supported machinery (e.g. lawn mowers, compactors)
  - catalytic control is **less frequent** in small engines due to increase of exhaust gas temperature (used in special machinery only)

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F. Gasoline engines in non-road applications (2/3)

- F2. **Existing** stock (in-use engines)
  - **Replacement:** because of very short lifetime (5-6 years) and relatively low cost, replacement of old machinery with new equipment complying with latest emission limits can be an effective measure
  - **Lubrication oil of good quality:** manufacturer approved lubrication oil of good quality and low additized (e.g. Ca-free and S-free) is important in multiposition tools and for good performance of any catalytic aftertreatment possibly used
  - **Aromatic free (alkylate) gasoline:** start up and normal (hot) operation emissions can be reduced, also reduces PAH, benzene, and other toxic content of pollutants liberated with evaporation

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F. Gasoline engines in non-road applications (3/3)

- F3. **Future** engines
  - **Combustion improvements:**
    - 4-stroke will continue to proliferate, expected to appear for smaller engines as well
    - hybrid engines, where lubrication is similar to 2-stroke, while combustion occurs in 4 strokes, eliminate scavenging losses
    - stratified scavenging for 2-stroke engines, where fuel-less air drives the exhaust out of the 2-stroke cylinder
  - **Evaporation control:**
    - rather simplistic fuel system allows increased fuel evaporation
    - usage of low permeability tanks and fuel lines is recommended

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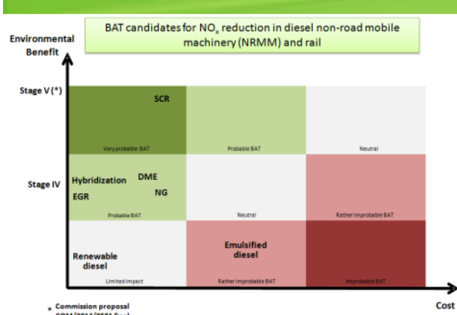
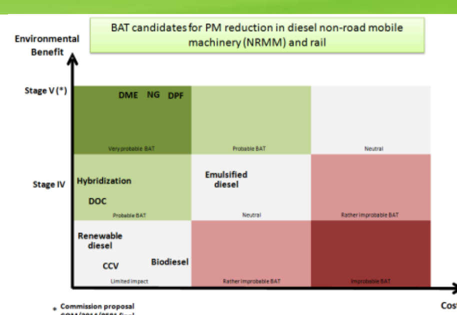
G. Diesel non-road mobile machinery (NRMM) and rail (1/4)

- Environmental problems similar to on-road HDVs: high **NO_x** and **PM** emissions, VOC from **crankcase** emissions of older engines
- Intense problem in **sensitive** environments, e.g. tunnels, mines
- G1. **New** engines (typical exhaust emission control/configuration)
  - **direct injection** diesel engine with turbocharging and intercooler
  - **EGR** may be present, but **SCR** is usually sufficient for NO_x control
  - **ammonia slip catalyst** to achieve regulatory limit of 25ppm
  - for PM control, diesel oxidation catalysts (**DOC**) or particle oxidation catalysts (**POC**) are usually used
  - wall-flow DPF is generally **not necessary** to achieve Stage IV limits (this will change with the upcoming Stage V)

G. Diesel non-road mobile machinery (NRMM) and rail (2/4)





- G2. **Existing** stock (in-use engines/machinery)
  - Relative cost-benefit comparison of BAT candidates for NO_x/PM reduction
  - **Reference technology** considered for the assessment:
    - conventional CI diesel engine without aftertreatment (roughly **corresponds** to Stage IIIA)
    - **reference emission levels:** 5-15 g NO_x/kWh and 0.2-1.0 g PM/kWh

G. Diesel non-road mobile machinery (NRMM) and rail (3/4)

- G2. **Existing** stock (in-use engines/machinery) (cont'd)
  - Based on cost-benefit comparisons and examining infrastructural, technical, and other limitations, following **recommendations** are made
  - **SCR and DPF retrofits:** a widely used practice with usually very good results, which is important to achieve in sensitive environments (tunnels, mines)
  - **Other retrofits:** i) **DOC** in combination with DPF and SCR, or as stand-alone in large-scale applications, being more tolerant to fuel sulfur than DPF, ii) **CCV** to control crankcase emissions, iii) EGR has **limited** potential due to technical difficulties integrating this on existing engines
  - **Fuel switching:** i) only **renewable diesel** can be suggested for existing engines, but with moderate reductions, ii) NG, DME, and emulsified diesel **cannot not be recommended** for widespread implementation due to technical, economical, or other limitations, iv) biodiesel has **low** emission reduction effectiveness
  - **Hybridization:** not at mass production yet and with limited experience
  - **Repowering:** replacing only the existing engine with a new one can be an effective strategy because of the long useful lifetime of the machinery

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G. Diesel non-road mobile machinery (NRMM) and rail (4/4)

- G3. **Future** engines/machinery
  - **Emission control for diesel concepts:**
    - the major update expected in upcoming Stage V is the introduction of **wall-flow DPF** to control PM (and PN) emissions
    - in-use **recording** of emissions using PEMS will guarantee efficiency
    - SCR **optimization**, combination of SCR and DPF in same component
  - **Alternative fuels and powertrains:**
    - more **difficult** to penetrate in NRMM market
    - diesel combustion is by far **preferable** due to its high efficiency, durability, and torque characteristics
    - concepts that **may** have a potential in the future: NG, DME, hybrid engines in specific applications, very limited current experience

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H. Diesel vessels (inland waterways) (1/2)

- Amongst the **longest** lived transport equipment (lifetime ≥ 30 years), only a small fraction of them are scrapped and replaced every year
- Measures targeting to **existing** ships are expected to have larger impact than those addressing new vessels only
- **NO_x control with on-board aftertreatment devices:**
  - **SCR** systems conceptually similar to those used on road vehicles, attention to efficiency issues in low loads (<25%) and during slow steaming
- **PM control with on-board aftertreatment devices:**
  - **scrubbers**, mostly known for SO_x emission reduction, can have positive impact on PM (ideal for new vessels, technical difficulties in retrofitting)
  - DPF **cannot** be considered as a mainstream technology for ships, not ready for commercial operation, effect on PM not as high as in automotive/NRMM
- **SO_x emissions control:** with low sulfur fuel

H. Diesel vessels (inland waterways) (2/2)

- **Alternative fuels: switch to LNG**
  - control both **NO_x** and **PM** and additionally eliminate most of **BC** emissions
  - allow operators to reduce **dependence** on fossil fuel oil
  - but, major **modifications** are required, hence, it is economical mainly for newly built vessels
  - fuel **availability** is the largest obstacle against its more widespread use
  - attention to **methane** emissions from natural gas use in ships

I. Sea going ships

- Domestic or international maritime ships use **same** diesel engines as inland waterways vessels (though somewhat larger), hence, **similar** on-board aftertreatment devices can be used, as well as switching to LNG
- Additional issues related specifically to sea going ships
  - **Emission control areas (ECAs):** specifically designed coastal areas where more stringent emission requirements are mandated for ships. The emission control measures required in ECAs can be considered as BAT (e.g. particular fuels with maximum allowed sulfur levels, SCR, scrubbers)
  - **Fuel sulfur restrictions:** final targets for equivalent fuel sulfur content to be achieved with i) use of low sulfur diesel fuel, ii) switch to LNG, iii) scrubbers
  - **Port-level initiatives:** power to the ships while at berth provided by on-shore units instead of running the ship engines (universally agreed power delivery specifications is a limiting factor in extending such programs)

J. Aircrafts

- Low NO_x combustion and aircraft design improvements are emission control techniques implemented by the manufacturer
- **Low NO_x combustion** is achieved with lean premixed combustion and clean combustor design, including design of fuel injector, thermal liner, dynamics and operability, while peak temperature and time spent at this temperature is limited
- **Aircraft design improvements** concern reduction of basic aircraft weight, improvement of aerodynamics and of overall specific performance of the engine, and design of aircrafts that fly at lower altitudes with reduced speed

K. Electric trams, metro, and trolley buses

- Do not generate tailpipe or evaporation emissions, however, they are a source of **heavy metal** emissions due to the wear of their components and **sparking** that occurs in the power lines
- Using these public transportation systems is by itself an effective measure to improve air quality in cities, by **shifting** traffic from private cars (and diesel buses) on to cleaner and higher capacity electric means of transport
- Indicative additional measures:
  - **Fleet and network measures:** modernization of existing stock, fleet management optimization, increase of commercial speed through segregated tracks and traffic management measures, inspection and maintenance of rails
  - **General measures:** make the usage attractive (e.g. by park and ride policies, low fare policies, expansion of network, new routes), increase intermodality and reduce trip duration, use advanced traffic management systems
  - **Technology measures:** reduce friction by better design and materials, eliminate sparking by either mechanical or, most probably, electrical measures

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L. Non-technical measures

- A lot of discussion if they should be **named** "measures" or "techniques" or "policies" or "practices" or …
- In any case, they are **complementary** to the technical measures in order to assist in further emission reductions
- Directly comparing non-technical to technical measures could give **misleading** results
- Therefore, non-technical measures can rather be considered as **'good practices'** and have been referenced wherever deemed necessary
- A short description of the most commonly used non-technical measures is summarized at the end of **Annex I** of GD
- In addition to the measures described, various implementations **may differ in practice** and may be combined with specific funds and incentives schemes, tax exemption or tax reductions, etc.

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Thank you very much for your attention!

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