US MARINE ENGINE AIR POLLUTION CONTROL MEASURES

INTERNATIONAL WORKSHOP ON REDUCING AIR EMISSIONS FROM SHIPPING

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AGENDA

- History of US Mobile Source Emission Regulation
- Marine Air Pollution Control Methods
  - Emission Standards for new US engines
  - Rebuild Requirements for in-use US engines
  - Enforce IMO Regulations for non-US vessels in US waters
  - Sulfur Restrictions on Marine Fuel
- Enforcement
- Technology Path
- Cost of Compliance
- Repower Case Study
- Lessons for China
HISTORY OF US MOBILE SOURCE REGULATION

The diagram illustrates the history of US mobile source regulation for various categories of vehicles and equipment. It shows the progression from unregulated status to progressively stricter regulations labeled as Tier 1 to Tier 4. The timeline includes model years from 1980 to 2020, with key stages marked as EPA 1998, EPA 2010, and ICAO 2005 for NOx only. The key at the bottom color-codes the regulations from unregulated to the most stringent.
US CONTROL METHODS FOR MARINE AIR POLLUTION

1. Emission standards for NEW ENGINES
2. Rebuild requirements for IN-USE ENGINES
3. Sulfur restrictions for MARINE FUEL
4. Enforce international requirements under IMO MARPOL ANNEX VI

APPLY TO US-FLAGGED VESSELS

APPLY TO NON US-FLAGGED VESSELS
USEPA MARINE NEW ENGINE STANDARDS

- Apply to US-flagged vessels only
- Includes both propulsion and auxiliary engines
- Apply to all new engines and new vessels
  - “Freshly manufactured” engines (US-made and imported)
  - Used engine installed in new vessel
  - Engines in vessel re-flagged as US vessel
  - Older vessels that are “significantly modified” are considered new

- Have become more stringent over time
  - Tier 1, Tier 2, Tier 3, Tier 4

- Three categories of engine, based on cylinder displacement
  - Stringency and implementation dates vary by category and displacement
  - Certification procedures are the same, but test cycles vary by engine use and type

- Mass-based limits (g/kWh) for NOx, PM, CO, HC are based on “end of life” not a new engine
MARINE ENGINE REGULATORY CATEGORIES

- **Category 1 Engines (<7 liters/cylinder)**
  - Similar to large land-based engines (power generation, construction);
    Typically 37 - 3,000 kW
  - Engines in ferries, tugs, fishing and work boats
  - Burn distillate fuel

- **Category 2 Engines (7 – 30 liters/cylinder)**
  - Similar to US locomotive engines; typically 1,100 – 4,500 kW
  - Propulsion engines in ferries, tugs, fishing and work boats
  - Burn distillate fuel

- **Category 3 Engines (>30 liters/cylinder)**
  - Unique, medium and slow speed engines, up to 75,000 kW
  - Exclusively used in ocean-going vessels
  - Burn residual fuel
EPA NO\textsubscript{x} & PM STANDARDS FOR MARINE ENGINES

For Category 1 and 2 engines, standards vary by displacement.
MARINE ENGINE REBUILD REQUIREMENTS

- Rebuild Requirements Apply to:
  - Category 1 and 2 marine engines >600 kW
  - Built between model year 1973 and model year 2013

- Engines considered new “when next remanufactured”:
  - Must be upgraded to reduce PM by at least 25%
  - NOx emissions can not increase

- “Remanufacture” means replacement of all cylinder liners
  - Done at the same time
  - Replaced individually over a 5-year period.

- “Certified remanufacturing systems” must be commercially available for the specific engine
  - Economic test – total marginal cost <$45,000/ton of PM reduced

- There are certified kits currently available for most Caterpillar and EMD marine engines
IMO REGULATIONS

- US adopted MARPOL Annex VI, negotiated via the International Maritime Organization (IMO)

- MARPOL Annex VI Applies to:
  - All engines >130 kW
  - Installed in vessels built since 2000
  - All such vessels that operate in US waters

- Also applies to any engine that undergoes a “major conversion” after Jan 2000
  - Engine replacement with a used engine is a major conversion

- MARPOL Annex VI only limits NOx emissions, not PM, CO, or VOC
  - Three levels of regulation: Tier 1, Tier 2, Tier 3

- MARPOL Annex VI also allows countries to designate “Emission Control Areas” (ECA) in which fuel sulfur can be limited
MARPOL ANNEX VI NO\textsubscript{X} STANDARDS

- NOx limits vary by engine speed
- IMO Tier 3 is similar in stringency to EPA Tier 4 NOx limits for Category 1 and 2 engines
- Apply to all engines in foreign-flagged vessels, and to Category 3 engines in US vessels

- NOx limits vary by model year and location - Tier 3 only required in ECA

<table>
<thead>
<tr>
<th>Tier</th>
<th>Area of Applicability</th>
<th>Model Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>All U.S. navigable waters and EEZ</td>
<td>2004 - 2010</td>
</tr>
<tr>
<td>Tier 2</td>
<td>All U.S. navigable waters and EEZ, excluding ECA and ECA associated areas</td>
<td>2011 - 2015</td>
</tr>
<tr>
<td>Tier 3</td>
<td>ECA and ECA associated areas</td>
<td>2016 and later</td>
</tr>
</tbody>
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US MARINE FUEL SULFUR STANDARDS

On-road Diesel
- 500 ppm
- 15 ppm

Non-road Diesel
- 3000 ppm
- 500 ppm
- 15 ppm

Locomotive Diesel
- 3000 ppm
- 500 ppm
- 15 ppm

Marine Distillate
- 3000 ppm
- 500 ppm
- 15 ppm

Marine Residual
- 45,000 ppm

EEZ = Exclusive Economic Zone (generally 200 miles from coast)
ECA = Emission Control Area (designated under IMO rules)

MARINE RESIDUAL

EEZ
- 45,000 ppm
- 35,000 ppm
- 5,000 ppm

ECA
- 45,000 ppm
- 10,000 ppm
- 1,000 ppm
US EEZ AND ECAs

[Map showing the U.S. Exclusive Economic Zone (EEZ) and the areas covered by the EEZ, NA ECA (2012), and CS ECA (2014).]
ENFORCEMENT: NEW ENGINE STANDARDS

- Engine manufacturers must demonstrate compliance via testing
  - Certification tests
  - Production line tests

- EPA Issues “certificate of conformity” for engine “families”
  - Engines must be labeled with specific required information
  - Certificates are only valid for one model year

- All engines must be in the “certified configuration” & manufacturers are prohibited from “tampering” or installing “defeat devices”
  - Civil monetary penalties assessed for willful violations

- Selective Enforcement Audit – EPA can inspect testing facilities, production processes, production engines, and records, and conduct in-use testing

- Mandatory Minimum Warranty Periods
  - Manufacturer must report and investigate emission system failures
  - EPA can force a “recall” to fix problems
ENFORCEMENT: REBUILD REQUIREMENTS

- Remanufactured engines must have a Certificate of Conformity issued by EPA
  - “Certifying remanufacturers” obtain a Certificate for engine families
  - Vessel owners can get a Certificate if remanufacturing their own engines
  - Remanufactured engines must be labeled similar to new engines

- Certification requires testing of “baseline” and “remanufactured” configuration

- Vessel owners must follow ALL requirements of Certificate
  - Engine in “certified configuration” – i.e. adjustable parameters in specified range
  - Must follow manufacturer installation instructions

- Warranty and other requirements applicable to new engines apply to remanufactured engines
ENFORCEMENT: MARPOL ANNEX VI

- All engines must have an Engine International Air Pollution Prevention Certificate (EIAPP)
  - Issued by EPA for US-made engines
  - Other MARPOL Annex VI countries issue EIAPPs for their vessels
  - A “recognized classification society” can provide proof of compliance for “non-party” vessels

- Vessels >400 tons must have an International Air Pollution Prevention Certificate (IAPP)
  - Issued by US Coast Guard for US-flagged vessels
  - To get IAPP must have valid EIAPP for all installed engines

- US Coast Guard enforces MARPOL Annex VI in US waters
  - Vessel inspection – look for valid EIAPP and IAPP
  - Evaluate compliance with “NOx Technical File”
TECHNOLOGY PATH TO CLEANER ENGINES

4-stroke cycle from 2-stroke cycle
Better lube oil control
Piston bowl shape
Electronic control of fuel injection
Higher pressure fuel injection
Variable Geometry Turbo-charger
Exhaust Gas Recirculation
After-treatment
  – Diesel Oxidation catalyst
  – Diesel Particulate Filter
  – Selective Catalytic Reduction

EPA TIER 1
EPA TIER 2
EPA TIER 3
EPA TIER 4
COST OF COMPLIANCE – MARINE ENGINES

COST OF NEW MARINE ENGINE IN US

$/kW

$0  $100  $200  $300  $400  $500  $600  $700

Reman  Reman+ 25% Kit  Tier 0  Tier 1  Tier 2  Tier 3  Tier 4

+10%  +20%  +20%  +30 - 50%?
REPOWER CASE STUDY – TUG VESSEL

- 1975 tug engine repower
  - OLD: 1975 EMD 16-645, 1460 kW
  - NEW: 2011 EMD 16-645, 1,500 kW
- New, turbo-charged engines half the size and weight of old engines, but required additional cooling capacity

- Total Cost: $2 million
- Annual Reductions:
  - PM: 2.9 tons
  - NOx: 39.7 tons
  - Fuel: 3,000 gallons
LESSONS FOR CHINA

1. Stringent new engine emission standards are required to drive commercial availability of clean engines
   - Ability to “leap frog” directly to EPA Tier 3 with future EPA Tier 4? (NOx, PM, CO, HC)
   - Minimum should be IMO MARPOL Annex VI (NOx only)

2. Engine and fuel standards are complementary – lower sulfur fuel is required for the cleanest engine technologies
   - EPA Tier 4 requires 15 – 50 ppm distillate fuel
   - MARPOL Annex VI provides basis for all vessels to use lower sulfur fuel in designated ECAs

3. Marine engines have a long life – new engine standards are not enough
   - Rebuild/remanufacturing requirements for in-use engines
   - Programs to encourage/mandate engine turn-over to regulated engines

4. Regulations must include enforcement
   - Warranty requirements provide a basis for surveillance and recall
   - Selective enforcement audits & monetary penalties for violations
   - Engine recall (fix in-use engines); revocation of certificate of conformity (can’t sell new engines)