EPA Small Gasoline Engine Program

US EPA Technical Workshop on Small Engine Emission Control

October 5, 2005
Overview

- Air Quality and Inventory Contributions
- Industry and Product Characterization
- Legislative and Regulatory Background
- EPA Safety Study
- Small SI Technology Assessment and Safety Work
- Closing Comments
Nearly 150 million people live in areas with unhealthy air...

...and small gasoline engines contribute to unhealthy air

- NO₂
- O₃: 68.0 (1-hour), 136.4 (8-hour)
- SO₂
- PM₁₀: 15.0
- PM₂.₅: 59.2
- CO: 0.7
- Pb: 0.2
- ANY NAAQS: 146.2

Number of people living in counties with air quality concentrations above the level of NAAQS in 2002.
Air Quality Impacts

- **Current widespread air pollution**
  - 474 counties designated as 8-hour ozone nonattainment in 2004
    - Ozone levels above 85 ppb or contributing to high ozone levels
  - 225 counties designated as PM$_{2.5}$ nonattainment in 2004
    - PM$_{2.5}$ levels above 15 ug/m$^3$ or contributing to high PM$_{2.5}$ levels

- **Pending HC and NOx standards are expected to reduce ambient ozone, PM, air toxics and CO**
  - Ambient ozone projected to be reduced by 1.3 ppb in Eastern ozone nonattainment areas in 2030
  - PM, air toxics and CO will also be reduced

- **Acute exposure is also a concern**
  - Exposure to VOCs, PM and CO will be reduced for operators and those in close proximity to the engines and equipment
Potential Benefits of Cleaner Lawn and Garden Equipment

- Further emission reductions from small gasoline engine will improve air quality. This can result in fewer:
  - Nonfatal Heart Attacks
  - Chronic Bronchitis
  - Respiratory / Cardiovascular Hospital Admissions
  - Acute Bronchitis Attacks in Children
  - Lost Work Days Due to Illness
  - Premature Deaths
2004 Small SI HC Inventory

Evaporative Emissions by Source

Small SI HC inventory is about 1 million tons
National Mobile Source Hydrocarbon Inventories in 2020

- On Highway: 53%
- Recreational: 10%
- Marine: 10%
- Nonhandheld: 17% (<25HP)
- Other Nonroad: 20% (Handheld, >25 HP NHH, etc.)
Inventory Trend

Small SI (NHH and HH) Exhaust and Evap Inventories

HC+NOx Inventories, t or

Year

0 200,000 400,000 600,000 800,000 1,000,000 1,200,000 1,400,000

2000 2010 2020 2030 2040 2050
Small Spark Ignition Engines

- Includes gasoline-powered engines used in a wide variety of consumer and commercial equipment
- Industry sales dominated by lawn/garden, pressure washers, generator sets, and snow equipment
- Industry is diverse in its size and structure
  - Engine and equipment manufacturing dominated by large manufacturers
    - Many small equipment manufacturers
  - Integrated and non-integrated manufacturers
EPA Regulatory Structure

- **Small SI Engines (≤25 hp or ≤19 kW)**
  - Divided into five classes based on displacement and application
  - Classes I-II (Nonhandheld); Classes III-V (handheld)

- **Nonhandheld Engines (NHH)**
  - Class I - < 225 cc
    - I-A < 66cc, I-B ≥ 66cc but < 100cc
  - Class II - ≥ 225 cc

- **Handheld Engines (HH)**
  - Class III - < 20 cc
  - Class IV - ≥ 20 but <50 cc
  - Class V - ≥ 50 cc
Class I

Engine Applications

- pressure washer
- generator
- string trimmer
- walk-behind mower

Class II

Engine Applications

- go-kart
- utility vehicle
- riding mower
- zero turn mower
- Hydro Drive Walk Commercial Mower
NHH Engine and Equipment Industry Characterization

- Engine Mfrs:
  - Briggs
  - Tecumseh
  - Honda
  - Kohler
  - Onan
  - Fuji
  - Kawasaki
  - Other

- Equip Mfrs:
  - MTD
  - Briggs
  - Honda
  - Toro
  - Deere
  - Other
  - Murray
  - Ariens
  - EHP
Existing EPA Standards

- Prior to 1990 CAA Amendments there were no small engine emission standards

- **Phase 1 standards took effect in 1997**
  
  - Standards represented a 33% reduction in HC+NOx from uncontrolled levels for all engines

- **Phase 2 standards are phased-in from 2001-07**
  
  - Non-handheld (NHH) standards represented a 60% HC+NOx reduction beyond Phase 1 levels
    - Standards were based on upgrades to 4-stroke and engine improvements
  
  - Handheld (HH) standards represented a 70% HC+NOx reduction beyond Phase 1 levels
    - Standards were based on catalysts for most 2-stroke engines
    - Currently ~2/3 of new HH engines sold in the US have catalysts
Regulatory Background

- CAA empowers California to have their own small engine program except for “farm/construction” equipment
  - Today there are separate California and Federal programs
  - Programs are structured differently, but overall technical requirements are similar
  - Federal standards cover the 49-states and preempted equipment

- Both EPA and California have two phases of exhaust standards for HH and NHH engines

- Driven by air quality concerns, in the Fall of 2003, California adopted a Tier 3 program
  - More stringent exhaust standards for Class I and II engines
  - Aligned with EPA for Class III-V engines
  - New fuel evaporative emissions control requirements for all engines/equipment
California Tier 3 Requirements

- The reductions from the California exhaust standards represent a reduction of ~35% from EPA’s Phase 2 exhaust requirements
  - Class I: 2007
  - Class II: 2008

- The technical premise for the standards is that catalysts will be applied on Class I and II (non-handheld) products
  - No further requirements for exhaust emissions for HH engine beyond current EPA

- ARB has also adopted evaporative emission control requirements for small engines and equipment
  - Fuel tank permeation control for all Classes (I-V)
  - Fuel hose permeation control for NHH
  - Control of diurnal, running loss, and hot soak emissions for Class I and diurnal for Class II
  - 2006-2012 phase-in
Emissions Standards Timeline

- **EPA Phase 1**: In 1997
  - (33% HC+NOx ↓)
- **EPA Phase 2**: Beyond Phase 1 by 2007
  - (60% HC+NOx ↓)
- **Class I/II (CARB Tier 3)**
  - (38%/34% HC+NOx ↓)
EPA Requirement for Phase 3 Rule

- Congress has directed EPA to propose new standards
- Section 428 of the Omnibus Appropriations Bill for 2004 requires EPA to propose regulations under CAA §213 for new non road spark-ignition engines less than 50 hp by 1 Dec 2004 and finalize by 31 Dec 2005
- Section 213 of the CAA states: “… standards shall achieve the greatest degree of emission reduction achievable … giving appropriate consideration to the cost of applying such technology within the time available to the manufacturers and to noise, energy, and safety factors associated with such technology.”
- Within our regulatory structure, there are seven sub-categories of engines/equipment which utilize < 50 hp spark ignition engines:

<table>
<thead>
<tr>
<th>Sub-Categories</th>
<th>Last Rule</th>
<th>Phase-In Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Handheld Lawn/Garden</td>
<td>1999</td>
<td>2007</td>
</tr>
<tr>
<td>Handheld Lawn/Garden</td>
<td>2003 (exh)</td>
<td>2010</td>
</tr>
<tr>
<td>Outboard/PWC marine</td>
<td>1996</td>
<td>2006</td>
</tr>
<tr>
<td>ATVs</td>
<td>2002</td>
<td>2007</td>
</tr>
<tr>
<td>Off-Highway Motorcycles</td>
<td>2002</td>
<td>2007</td>
</tr>
<tr>
<td>Snowmobiles</td>
<td>2002</td>
<td>2012</td>
</tr>
<tr>
<td>Industrial SI engines</td>
<td>2002</td>
<td>2007</td>
</tr>
</tbody>
</table>

- Our standards for the last four subcategories are new and not yet implemented; thus we believe they are consistent with CAA requirements. We are not pursuing further controls at this time.
EPA Staff-Phase 3 Concept

- Exhaust Emissions – adopt ARB Tier 3 with more lead time

<table>
<thead>
<tr>
<th></th>
<th>HC+NOx* g/kW-hr</th>
<th>CO g/kW-hr</th>
<th>Year</th>
<th>Useful Life (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>10.0</td>
<td>610</td>
<td>2010</td>
<td>125/250/500</td>
</tr>
<tr>
<td>Class II</td>
<td>8.0</td>
<td>610</td>
<td>2011</td>
<td>250/500/1000</td>
</tr>
<tr>
<td>Classes III-V</td>
<td>No changes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HC+NOx std is based on averaging; New stds would not apply to snow equip.*

- Evaporative controls – adopt more focused requirements than ARB

<table>
<thead>
<tr>
<th></th>
<th>Class I</th>
<th>Class II</th>
<th>Classes III-V</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose &amp; tank permeation</td>
<td>2009</td>
<td>2009</td>
<td>2009</td>
<td>15 g/m² &amp; 1.5 g/m²</td>
</tr>
<tr>
<td>Running loss*</td>
<td>2010</td>
<td>2011</td>
<td>n/a</td>
<td>Design/Test 18</td>
</tr>
</tbody>
</table>
Section 213 of CAA requires EPA to consider safety during standards setting for nonroad engines – a normal part of our process.

A rider to the 2006 appropriations bill for EPA (and Senate report language) added several new provisions:
- calls for EPA to publish technical study on the safety issues
- specifically identifies risk of operator burn and fire associated with flammable items and refueling
- requires coordination with CPSC
- prohibits EPA from publishing NPRM before study completed
- requires completion of study within 6 months of enactment (nominally end of Feb 2006)
EPA Safety Study

- EPA safety study to be based on assessment of incremental risk of complying with potential Phase 3 standards relative to Phase 2
- Will consider both normal operator use and atypical events
  - Will explicitly address items laid out in the legislation
  - For temperature related issues, will use laboratory and field thermal imaging analyses to compare thermal signatures of stock Phase 2 and properly-designed catalyst equipped Phase 3 prototypes
    - Are considering both Class I and II, focus on grass-cutting
    - Looking at low and extended hour operation
    - Constructive in addressing field debris, refueling, storage, turf surface, and fuel spillage questions
  - Laboratory experiments and field experience to assess events such as those conditions creating over rich mixtures, air leaks, misfire and afterburn
  - Entire assessment will be backed by engineering analyses
    - Will look at affects on compliance with consensus standards
    - FMEA being conducted by Southwest Research Institute
- We expect to meet the February 2006 deadline
EPA/NVFEL has a long history of engine technology development, exhaust catalyst development, and evaporative emissions control system development.

Our most recent work includes successful demonstration of low emission light trucks that meet the new highway Tier 2 light-duty automotive standards and new NOx and PM emission controls work for heavy-duty highway and nonroad diesel engines.

EPA/NVFEL also has considerable experience with enhanced evaporative emissions controls, onboard refueling controls, and fuel tank permeation requirements.

Our small engine testing capability began in 1994.
Technology Development in EPA’s Ann Arbor Laboratory

- We have been conducting technology development for Phase 3 for approximately 20 months
  - This has involved both laboratory and field work

- The development has focused on consideration of exhaust and evaporative emissions standards
  - Central to this has been gaining a full understanding of the design and operating characteristics of Phase 2 engines

- Based on our technical assessments, we have been evaluating a range of technical solutions for meeting more stringent emissions standards

- Evaluating and addressing potential safety concerns has been a key element of our work from the very beginning

- We have been sharing this information with the major small engine companies and equipment OEMs
  - See public docket (OAR-2004-0008) for available information
Our testing work has been founded on several key precepts:

- Emission controls must be effective for entire useful life of engine
  - Must meet emission design targets
  - No emission related maintenance
  - Consumer perceives no differences between Phase 2 and Phase 3 equipment
- There should be no increase in burn or fire risk in going from Phase 2 to Phase 3
  - Temperatures of key engine surfaces must be comparable to current technology designs
  - Consider risks which occur in normal and atypical operating and use conditions
  - Must still be able to meet other safety-related standards (ANSI, SAE, Forest Service, etc)
- Technology approaches have widespread applicability by both engine design and integrated or non-integrated manufacturer
Observations

- Our assessment work indicates little additional engine out emission reduction is achievable from either SV or OHV engines
  - Class I engine-out emission reductions are cooling and lubrication system limited
  - Class II engines face similar limitations to Class I
    - Engines are generally more robust
    - Emissions must be met to a longer (some cases, much longer) useful life requirement
  - **All engines are not created equal**
    - SV and OHV engines create different technical challenges for further emission reductions
    - Manufacturer/engine model specific approaches to air induction, carburetion, cooling are important to developing a compliance strategy
    - Substantial differences between Class 1 and Class II engines

- **Engine and equipment package; must be considered together**
- **With appropriate engineering, more stringent standards can be met**
  - Safe and effective control involves appropriate combination and designs of engine improvements, cooling upgrades, catalyst, and secondary air (passive or active)
  - It is important to properly design the exhaust system, including cooling air flow and heat shielding, for thermal management
  - Catalyst chemistry, substrate design, and catalyst volume are key factors for proper catalyst design and to address safety issues
Based on Briggs & Stratton catalyst design currently used in Europe

1st muffler tested was lengthened to accommodate second 20 cc catalyst substrate (~40 cc total)

Subsequent mufflers reconfigured for use with OHV engines, other SV engines, and for various types of catalyst substrates
- metal monoliths
- low-cost metal mesh
Catalyst Technology Can Be Applied Safely

- We have tested more than 20 combinations of catalyst systems and engines
  - Laboratory testing
    - More than 200 A-cycle tests since January 1, 2005
    - More than 500 A-cycle tests since the start of the program
  - Field testing and field operational experience
    - Field aging in SE Michigan
    - Field aging and data-logging in Central Texas
    - Field aging and infrared data collection in Tennessee and Alabama (October – November 2005)
  - Wide range of operating conditions
  - Measurement of surface temperatures via infrared thermal imaging
- Our test program continues, however..
- Data to date demonstrates catalysts can be applied safety to these engines
  - Exhaust system surface temperatures are comparable to today’s products
Class I, Phase 200cc Side valve Engine Tested with Catalyst and Passive Secondary-Air Injection

-A-cycle NOx+HC Emissions @ 10-20 hours
Class I, Phase 200cc Side valve Engine Tested with Catalyst and Passive Secondary-Air Injection
-A-cycle PM Emissions @ 10-20 hours

PM Emissions (g/kW-hr)

- OEM Muffler
- Catalyst muffler with Venturi Secondary Air
Class I, Phase 2, 190cc Side-valve and OHV Engines with Catalysts and Passive Secondary-Air Injection

-A-cycle NOx+HC Emissions @ 10-20 hours

6-mode A-cycle NOx+HC (g/kW-hr)

- Side-valve Engines
- OHV Engines

Graph showing emissions for various engine configurations.
EMS and Catalyst Development for Class II Lawn Tractors
EMS and Catalyst Development using the Class II 500cc Lawn Tractor Engine

**NOx+HC Emissions, g/kW-hr**

Class II, Phase 2: 12.1 g/kW-hr

- OEM
- EFI
- EFI, Catalyst A Configuration
- EFI, Catalyst B
- EFI, Catalyst C
- EFI, Catalyst D

**Legend**

- NOx
- HC
EMS and Catalyst Development using the Class II 490cc Lawn Tractor Engine

Class II, Phase 2: 12.1 g/kW-hr

OEM, EFI, EFI, Catalyst E, EFI, Catalyst F

NOx + HC Emissions, g/kW-hr
Class I, Phase 2 190cc Side valve with and without catalyst at 125+ hours (40 cc cordierite, 5:0:1 30 g/ft³)

Phase II Standard: 16.1 g/kW-hr @ 125 hours
Class I, Phase 2 190cc OHV with and without catalyst at 125+ hours
(40 cc cordierite, 5:0:1 30 g/ft³)

Phase II Standard: 16.1 g/kW-hr @ 125 hours

- OEM Muffler
- Catalyst muffler with Venturi
- Secondary Air
Class I, Phase 2 190cc OHV with and without catalyst at 110-120 hours (32 cc 100 cpsi metal monolith, 5:0:1 50 g/ft³)

Phase II Standard: 16.1 g/kW-hr @ 125 hours

- OEM Muffler
- Catalyst muffler with Venturi-Secondary Air
Class II, Phase 2 OHV 400 cc
- Emissions at 250 hours

Class 2/Phase II OHV with 200 cc Cordierite Catalyst-1

6-mode A-cycle HC+NOx Emissions (g/kW-hr)
Infrared Thermal Imaging

190cc SV Engine at >110 hours

Modified Catalyst Muffler
(5:0:1 30 g/ft³, 40cc, 400 cpsi ceramic-monolith, venturi secondary air)
100% Load – Wide Open Throttle

Maximum surface temperature: 407.0 °C

OEM Muffler
100% Load – Wide Open Throttle

Maximum surface temperature: 483.8 °C
Infrared Thermal Imaging
190cc SV Engine at >110 hours

Modified Catalyst Muffler
75% Load – Mode 2

Maximum surface temperature: 346.7 °C

OEM Muffler
75% Load – Mode 2

Maximum surface temperature: 373.4 °C
Infrared Thermal Imaging
190cc SV Engine at >110 hours

Modified Catalyst Muffler
50% Load – Mode 3

Maximum surface temperature: 318.4 °C

OEM Muffler
50% Load – Mode 3

Maximum surface temperature: 360.9 °C
Infrared Thermal Imaging
190cc SV Engine at >110 hours

Modified Catalyst Muffler
25% Load – Mode 4

OEM Muffler
25% Load – Mode 4

Maximum surface temperature: 303.9 °C

Maximum surface temperature: 350.0 °C
Infrared Thermal Imaging
190cc SV Engine at >110 hours

Modified Catalyst Muffler
10% Load – Mode 5
Maximum surface temperature: 298.7 °C

OEM Muffler
10% Load – Mode 5
Maximum surface temperature: 332.2 °C
Infrared Thermal Imaging
200cc SV Engine at <25 hours

Modified Catalyst Muffler
(5:0:1 30 g/ft³, 40cc, 200 cpsih metal monolith,
venturi secondary air)
100% Load – Wide Open Throttle

Maximum surface temperature: 494.3 °C

OEM Muffler
100% Load – Wide Open Throttle

Maximum surface temperature: 578.8 °C
Infrared Thermal Imaging

200cc SV Engine at <25 hours

Modified Catalyst Muffler
50% Load – Mode 3

OEM Muffler
50% Load – Mode 3

Maximum surface temperature: 420.6 °C

Maximum surface temperature: 493.3 °C
Infrared Thermal Imaging

200cc SV Engine at <25 hours

Modified Catalyst Muffler
10% Load – Mode 5

OEM Muffler
10% Load – Mode 5

Maximum surface temperature: 433.3 °C

Maximum surface temperature: 497.4 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

Modified Catalyst Muffler
(5:0:1 30 g/ft³, 40cc, 400 cpsi ceramic monolith, venturi secondary air)
100% Load – Wide Open Throttle

Maximum surface temperature: 446.7 °C

OEM Muffler
100% Load – Wide Open Throttle

Maximum surface temperature: 480.5 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

- Modified Catalyst Muffler
  50% Load – Mode 3
  Maximum surface temperature: 361.8 °C

- OEM Muffler
  50% Load – Mode 3
  Maximum surface temperature: 371.1 °C
Infrared Thermal Imaging
190cc OHV Engine at >125 hours

Modified Catalyst Muffler
10% Load – Mode 5

OEM Muffler
10% Load – Mode 5

Maximum surface temperature: 295.7 °C

Maximum surface temperature: 300.4 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

Hot-soak test from 50% load condition

**Modified Catalyst Muffler**

- **0-seconds**
  - Maximum surface temperature: 350.9 °C

- **30-seconds**
  - Maximum surface temperature: 325.3 °C

**OEM Muffler**

- **0-seconds**
  - Maximum surface temperature: 360.4 °C

- **30-seconds**
  - Maximum surface temperature: 317.9 °C
Infrared Thermal Imaging
190cc OHV Engine at >125 hours
Hot-soak test from 50% load condition

Modified Catalyst Muffler
Maximum surface temperature: 290.2 °C
1-minute

OEM Muffler
Maximum surface temperature: 287.8 °C

Maximum surface temperature: 246.9 °C
2-minutes

Maximum surface temperature: 241.6 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

Hot-soak test from 50% load condition

Modified Catalyst Muffler

Maximum surface temperature: 206.8 °C

OEM Muffler

Maximum surface temperature: 206.9 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

Hot-soak test from WOT condition

Modified Catalyst Muffler

Maximum surface temperature: 422.8 °C

OEM Muffler

Maximum surface temperature: 484.6 °C

0-seconds

30-seconds

Maximum surface temperature: 395.8 °C

Maximum surface temperature: 417.8 °C
Infrared Thermal Imaging
190cc OHV Engine at >125 hours
Hot-soak test from WOT condition

Modified Catalyst Muffler
- 1-minute
  - Maximum surface temperature: 384.0 °C
- 2-minutes
  - Maximum surface temperature: 324.4 °C

OEM Muffler
- 1-minute
  - Maximum surface temperature: 372.8 °C
- 2-minutes
  - Maximum surface temperature: 301.4 °C
Infrared Thermal Imaging

190cc OHV Engine at >125 hours

Hot-soak test from WOT condition

Maximum surface temperature: 265.0 °C

Maximum surface temperature: 258.1 °C

Maximum surface temperature: 219.3 °C

Maximum surface temperature: 218.0 °C
Laboratory Failure Mode Simulations

- Simulate rich operation due to
  - Inappropriate choke usage
  - Malfunctioning float or float-valve
  - Malfunctioning air bleed compensation or clogged filter
- Simulate partial ignition misfire
- Induce backfire following high-inertia over-run

<show video footage>
Closing Comments

- EPA will continue its technical development and safety assessments and move forward on safety study and rule development
- Very interested in receiving your input and suggestions on our work and pending safety study
- To better inform our assessments and safety study, EPA is also interested in discussions with engine manufacturers and equipment OEMs on their progress in developing product for 2007/2008 California market.