EPA's Newest Draft Nonroad Emission Inventory Model (NONROAD)

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Craig A. Harvey

US Environmental Protection Agency

Outline

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- Questions and Answers

NONROAD Team

- Office of Transportation and Air Quality (Assessment and Standards Division)
  - Penny Carey
  - Craig Harvey
  - Greg Janssen
  - Jim Warila
  - Rich Wilcox

nonroad@epa.gov

Model Overview

- Stand Alone *(No User Data Necessary)*
- All Nonroad Sources (*except locomotives, aircraft and commercial marine*)
- Differentiated by Equipment Type and Other Characteristics
- HC, CO, NO_x, PM, SO_x, CO_2
- Fuel Consumption

NONROAD Model Versions

* **June 1998**: Original Draft Release

  April 1999: highway tier-2/gasoline sulfur rule

* **June 2000**: 2007 HD Diesel Highway Rule & 1999 NEI/Trends v1.0. 1996 Diesel PM used in NATA.

  Nov 2000: final finding & rec vehicle/large SI ANPRM & 2000 NEI & 1999 NTI. 1999 NEI v1.5 & draft v2.

  July 2001: rec vehicle & large SI NPRM

  May 2002: Draft NONROAD2002, NEI 1970-2001 various years (1999 final v2). NTI for 1990, 96, 99. (and basis for RV/LgSI FRM & nonroad diesel NPRM)

* = publicly released model

Model Overview

Exhaust Emissions Calculation

$$I = EF \cdot DF \cdot Act \cdot LF \cdot RP \cdot Pop$$

I = Exhaust Emissions Inventory (ton/year)
EF = Emission Factor (g/hp-hr)
DF = Deterioration Factor
Act = Activity (hours/year)
LF = Load Factor
RP = average rated power (hp)
Pop = Equipment population (units)

Default Inputs for Diesel Engines in the NONROAD model

Diesel Engines:
Variables modified for NONROAD2002

- Load Factors (LF)
- Zero-hour Steady-state Emission Factors (EF)
- Transient Adjustment Factors (TAFs)
- Deterioration Factors (DFs)
- Median Life
- Base-Year Populations

Diesel Exhaust Emission Inputs: Load Factor

- In NONROAD HDD 2007
  - Load Factors from 1998 PSR *Partslink*
  - assigned individual LF to specific applications
- In NONROAD2002
  - load factors developed from transient-cycle development project
  - Seven cycles developed, designed to mimic equipment operation

Agricultural Tractor	Rubber-Tire Loader	Arc Welder
Backhoe loader	Skid-steer loader	
Crawler Dozer	Excavator	

Diesel Exhaust Emission Inputs: Transient-cycle Load Factors

Cycle	Load Factor	Assignment	Avg
Agricultural Tractor	0.78	high	0.59
Crawler Dozer	0.58	high	
Excavator	0.53	high	
Rubber-tire Loader	0.48	high	
Skid-steer Loader	0.23	low	0.21
Backhoe-Loader	0.21	low	
Arc Welder	0.19	low	
None (steady-state)	---	average 7-cycle	0.43

Diesel Exhaust Emission Inputs:
Emission Factors

Three key components*:*

EF = ZHL x TAF x DF

ZHL = "zero hour" levels -- *from new engine test data*

TAF = transient adjustment factor -- *adjusts the ZHLs that are derived from steady-state lab testing, to account for how engine speed and load variations in the field affect emissions.*

DF = deterioration factor -- *adjusts for age-related deterioration and malmaintenance*

The model also adjusts the PM EF for differences between test fuel sulfur level and in-use sulfur level

Diesel Exhaust Emission Inputs:
Comparison of PM ZHLs

	PM ZMLs, g/hp-hr								
	Tier 1			Tier 2			Tier 3		
Max HP	Tier 1	HD07 T1	ratio:HD07	Tier 2	HD07 T2	ratio:HD07	Tier 3	HD07 T3	ratio:HD07
11	0.4474	0.52	**0.9**	0.50	0.44	**1.1**	na	na	na
16	0.2665	0.52	**0.5**	0.2665	0.36	**0.7**	na	na	na
25	0.2665	0.36	**0.7**	0.2665	0.36	**0.7**	na	na	na
50	0.3389	0.38	**0.9**	0.3389	0.32	**1.1**	na	na	na
100	0.4730	0.37	**1.3**	0.24	0.24	**1.0**	0.30	0.24	**1.3**
175	0.2799	0.22	**1.3**	0.18	0.18	**1.0**	0.22	0.18	**1.2**
300	0.2521	0.19	**1.3**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
600	0.2008	0.12	**1.7**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
750	0.2201	0.14	**1.6**	0.1316	0.12	**1.1**	0.15	0.12	**1.3**
>750	0.1934	0.13	**1.5**	0.1316	0.12	**1.1**	na	na	na

- No changes to BSFCs

Diesel Exhaust Emission Inputs:
Transient Adjustment Factors

- Still based on cycle test data, BUT
  - Added data for excavator cycle (7 cycles in all)
  - Combined Tier 0 and Tier 1 data (not statistically different based on Student's *t*-test)
  - Average of ratios used vs ratio of averages
  - Binned cycle data by load factor category
- TAF assignments to equipment type no longer vary by tier

Diesel Exhaust Emission Inputs:

Transient Adjustment Factors

Cycle	Load Factor	Assignment	HC		CO		NOx	
			Cycle TAFs	Average	Cycle TAFs	Average	Cycle TAFs	Average
Agricultural Tractor	0.78	**High**	0.83	**1.05**	0.50	**1.53**	0.98	**0.95**
Crawler Dozer	0.58		0.88		1.50		0.98	
Rubber-Tire Loader	0.48		1.07		3.68		0.96	
Excavator	0.53		1.40		0.44		0.87	
Backhoe Loader	0.21	**Low**	2.23	**2.29**	2.66	**2.57**	1.05	**1.10**
Skid-Steer Loader	0.23		1.49		1.83		0.95	
Arc Welder	0.19		3.16		3.22		1.31	

Cycle	Load Factor	Assignment	PM		BSFC	
			Cycle TAFs	Average	Cycle TAFs	Average
Agricultural Tractor	0.78	**High**	0.71	**1.23**	0.98	**1.01**
Crawler Dozer	0.58		1.29		0.99	
Rubber-Tire Loader	0.48		2.02		1.04	
Excavator	0.53		0.89		1.03	
Backhoe Loader	0.21	**Low**	2.07	**1.97**	1.16	**1.18**
Skid-Steer Loader	0.23		1.74		1.09	
Arc Welder	0.19		2.11		1.29	

Transient Adjustment Factors:
Key Issue for Tier 3 Engines

Lacking a transient certification test, Tier 3 engine designs with EGR are likely to have higher transient emissions

PM for Tier 3 Engines*:* **TAF increase: 20%**

- assume EGR increases transient PM
  due to the time lag for clearance of the intake system

NOx for Tier 3 Engines*:* **TAF increase: 10%**

- assume EGR increases transient NOx
  due to EGR being turned off during transients

Diesel Exhaust Emission Inputs:
Deterioration Factors

The HDD 2007 version uses very low DFs for all pollutants based on highway engine data in MOBILE6

HC, CO, and NOx (all tiers):

- no clear trend from new (highway-only) data
- so stick with existing DFs, BUT
- now using simple unweighted averages of DFs by hp category

PM (all tiers):

- **new approach**: use ARB OFFROAD DF: 47% over the median life (DF=1.47)

All DF's still capped at one median life

Diesel Exhaust Emission Inputs:
Comparison of DFs

Pollutant	Model Version	Deterioration Factor (% increase/ % useful life)* Tier 0	Tier 1	Tier 2	Tier 3
HC	HD07	0.059	0.014	0.013	0.007
	2002	0.047	0.036	0.034	0.027
	ratio:HD07	**0.8**	**2.6**	**2.6**	**3.9**
CO	HD07	0.190	0.144	0.144	0.175
	2002	0.185	0.101	0.101	0.151
	ratio:HD07	**1.0**	**0.7**	**0.7**	**0.9**
NOx	HD07	0.026	0.026	0.012	0.007
	2002	0.024	0.024	0.009	0.008
	ratio:HD07	**0.9**	**0.9**	**0.8**	**1.1**
PM	HD07	0.058	0.058	0.032	0.035
	2002	0.473	0.473	0.473	0.473
	ratio:HD07	**8.2**	**8.2**	**14.8**	**13.5**

* These are values for A in the equation: DF = 1 + A*(fraction of useful life expended)

Diesel Engine Scrappage: *Median Life*

We adjusted the median life for <16 hp engines to match that for 16-50 hp engines, to avoid median lives shorter than the regulatory useful lives; 2500 hrs at full load equates to 5000 hrs at a 50% typical average load factor (the regulatory useful life for these engines is 3000 hr).

Power Category	Source: PSR	Source: EEA	Modified EEA
<16 hp	13,000 hrs	1,250 hrs	2,500 hrs
16-50 hp	10,000 hrs	2,500 hrs	2,500 hrs
50-300 hp	11,500 hrs	4,000 hrs	4,667 hrs
300-1000 hp	9,000 hrs	6,000 hrs	7,000 hrs
>1000 hp	7,500 hrs	6,000 hrs	7,000 hrs

We removed EEA's "rugged life" adjustment:
EEA shortened the highway-derived median lives by 15% to account for the more severe operating conditions of nonroad engines. However, nonroad engine designs typically already account for this (mainly by use of de-rated bigger engines); so we removed the 15% adjustment.

Inputs: Equipment Population

- Population = f(sales, activity, load factor, median life)
- For diesel equipment, we now use PSR sales data to calculate populations, rather than using PSR populations directly.
  - Allows consistent median life and LFs
  - Decreased diesel Pops by ~25%

Default Inputs in the NONROAD model: Recreational Equipment and Large Spark-Ignition Engines

Recreational Equipment

- Applications
  - Snowmobiles
  - All-terrain vehicles (ATVs)
  - Off-Highway Motorcycles (OHMCs)
- Include two-stroke and four-stroke engines
- Substantial changes in most inputs since release of HDD 2007 NONROAD

Emission factors	*Load factor*
Deterioration factors	*Median Life*
Activity	

Large Spark-Ignition Equipment
(SI Engines Rated @ 19 kW)

- Commercial/Industrial
  - Forklifts
  - Generators
  - Commercial Turf
  - Aerial Lifts
  - Pumps
- Marine Engines
  - Stern drive
  - Inboard
- Include 2-stroke and 4-stroke engines
- Multiple fuels
  - Gasoline
  - LPG
  - CNG

Large Spark-Ignition Equipment: Changes to NONROAD Inputs

- Emission factors
- Add Transient Adjustment Factor (TAF) for HC, CO (large-SI only)
- Deterioration factors, all engines
- Stern-drive and Inboard marine engines
  - Emission Factors
  - Technology mix (carbureted vs. fuel-injected)
  - Median Life
- Activity and base-year population, forklifts

Large Spark-Ignition Equipment:
Transient-Adjustment Factor

- Definition: coefficient representing the difference between steady-state cycle results and in-use transient operation

$$TAF = \frac{E_{transient}}{E_{steady-state}}$$

- Results: HC TAF = 1.30
  CO TAF = 1.45

- Application: $E_{base} = E_{ss} \times TAF$
  - TAF applied outside of model

Large Spark-Ignition Equipment:
Deterioration Factors

- Previous assumption: Large-SI engines deteriorate similarly to small-SI engines

- Revised assumption: Large-SI engines deteriorate similarly to pre-controlled highway engines (MY 1960-79)

$$d = \left(\frac{E_{det,100,000}}{E_{base}} \right) - 1$$

Large Spark-Ignition Equipment:
Deterioration Factors

Results: (value in table = 1+*d*)

Pollutant	HDD07	NR2002
THC	2.1	1.26
CO	1.9	1.35
NOx	1.0	1.03
PM	2.1	1.26

Marine SD/I Engines:

- EFs revised based on tests of 10 SD/I engines
  - Carbureted and Fuel Injected
- Technology phase-in revised for FI engines
- Median Life now capped at 20 years
  - More reasonable than default of 3,000 hours at full load ≈ 300 years

Technical Developments in the NONROAD Model: Code Modifications

Code Modifications/Corrections

PM Calculation Equation

The equation was:

$$PM = PM_{base} - [BSFC \times 453.6 \times 0.157 \times 0.01 \times (0.0033 - S_{fuel})]$$

g/hr

g/lb

Converts S percent to weight fraction

In-use S level (%)

Fraction of fuel sulfur converted to PM for engines without traps

Add rated power and load factor

Correct base fuel sulfur (3300 ppm)

Now corrected to:

$$PM = PM_{base} - [BSFC \times 453.6 \times P \times L \times 0.157 \times 0.01 \times (0.33 - S_{fuel})]$$

Code Modifications/Corrections

- **PM** Calculation Equation -- Effect of Corrections:
  - Depends on equipment Hp
  - Net fleet inventory effect is substantial decrease in PM

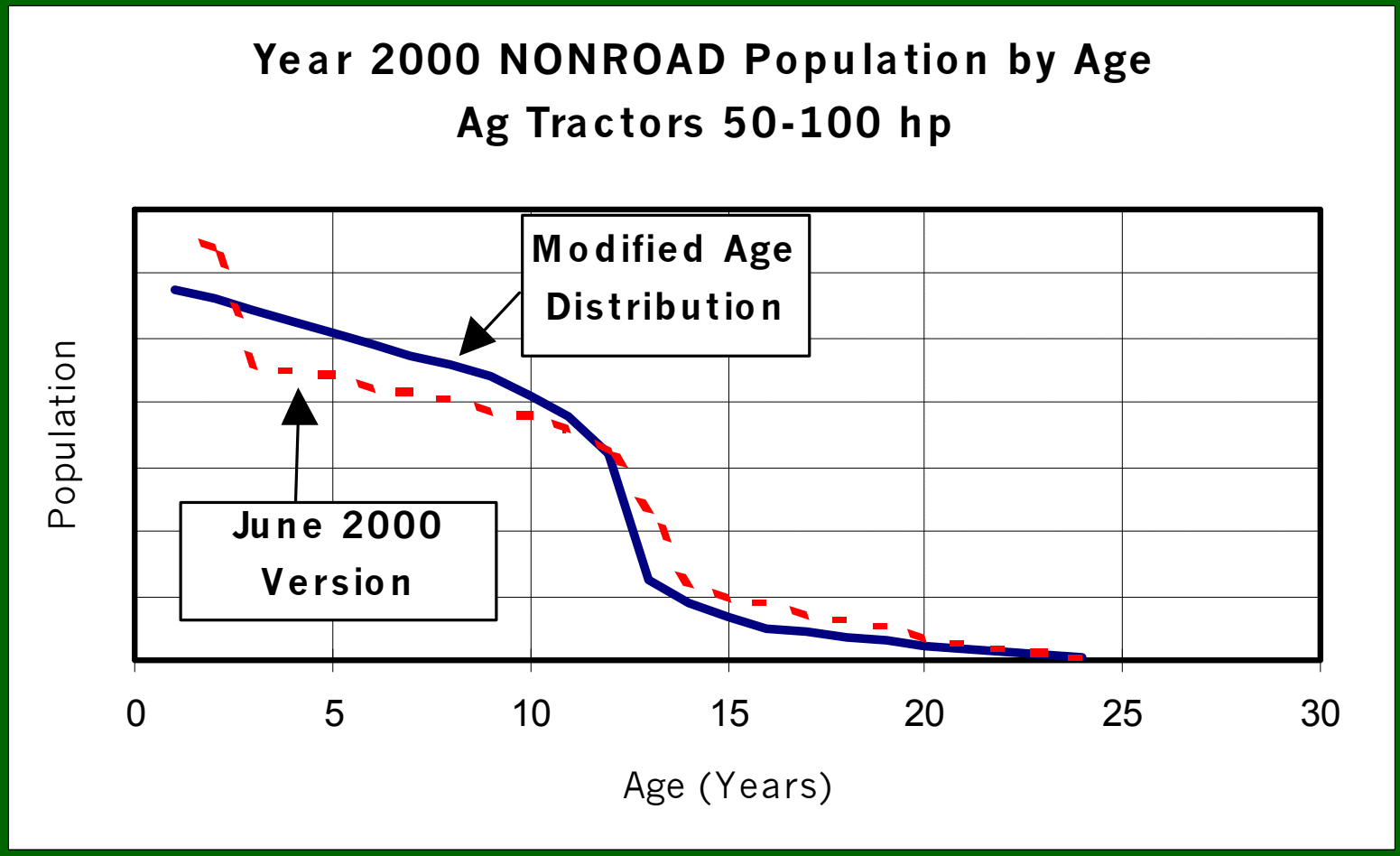
Code Modifications/Corrections

- **SO_2** Calculation Equation
  - Was missing Load Factor
  - Net effect of correction is to decrease SO_2 by roughly 40%

Code Modifications/Corrections

- Scrappage & Age Distribution
  - New simplified method:
    1. Use growth to determine target calendar year population
    2. Apply default age distribution based on scrappage curve shape and no growth
    3. Adjust for assumed growth rate

Scrappage / Age Distribution



Geographic Allocation in Draft NONROAD2002

Geographic Allocation: Overview

- Geographic allocation of engine populations accounts for how many and what types of equipment are being used in a certain location
  - Default data allocates to the county level
- National populations allocated outside NONROAD to county level using county-specific surrogate indicators
- County populations are then aggregated to produce default state population input files

Geographic Allocation: Overview

- NONROAD allocates state-level default populations (N_{state}) for each equipment type to the county level using the surrogate indicators (A)

$$N_{county} = N_{state}\left(\frac{A_{county}}{A_{state}}\right)$$

- Allocating equipment populations represents geographic differences in total population·activity
  - NONROAD uses a single default activity (hours/year) for each equipment type for all of U.S.

Geographic Allocation: Overview

- Users may specify local state/county surrogates or substitute local population data
  - For broad equipment categories or for individual equipment types
  - Local activity data needs to be used with local population data in order to avoid strange results
- Allocation surrogates based on publicly available data as much as possible
  - U.S. Census population/housing, business, and geographic data.
  - Exception for construction which was based on proprietary data from F.W. Dodge, Inc.

Geographic Allocation: Construction Equipment

- Allocated on basis of weighted-average dollar value of different types of construction activity
  - Road and infrastructure construction account for much larger share of actual equipment activity per dollar valuation than residential and commercial construction
  - Based on 1998 survey of construction in Houston (for purposes of SIP)
  - Compares well to 1993 study of construction
    - Equipment activity based on fuel cost per project
    - Dollar valuation derived from 1987 Census data

Geographic Allocation:
Snowblowers

- Two allocation surrogates used to derive state population estimates
  - Residential: single and duplex housing
  - Commercial: number of employees in landscaping/horticultural services
- Apply surrogates in states/counties with minimum snowfall
  - NOAA long-term average snowfall map combined with U.S. counties map
  - 15 inches minimum snowfall

Geographic Allocation: Snowmobiles

- State populations derived from registration data
  - Oakridge National Laboratory (ORNL) study
    - ORNL also attempted to account for unregistered snowmobiles
- Allocation to states/counties with minimum annual average snowfall of 40 inches
  - Average snowfall data from NOAA
  - Inverse human population used to allocate snowmobiles to counties
    - Majority allocated to rural counties
    - Except Alaska (which is almost all rural), for which human population is used directly

Geographic Allocation: Recreational Marine

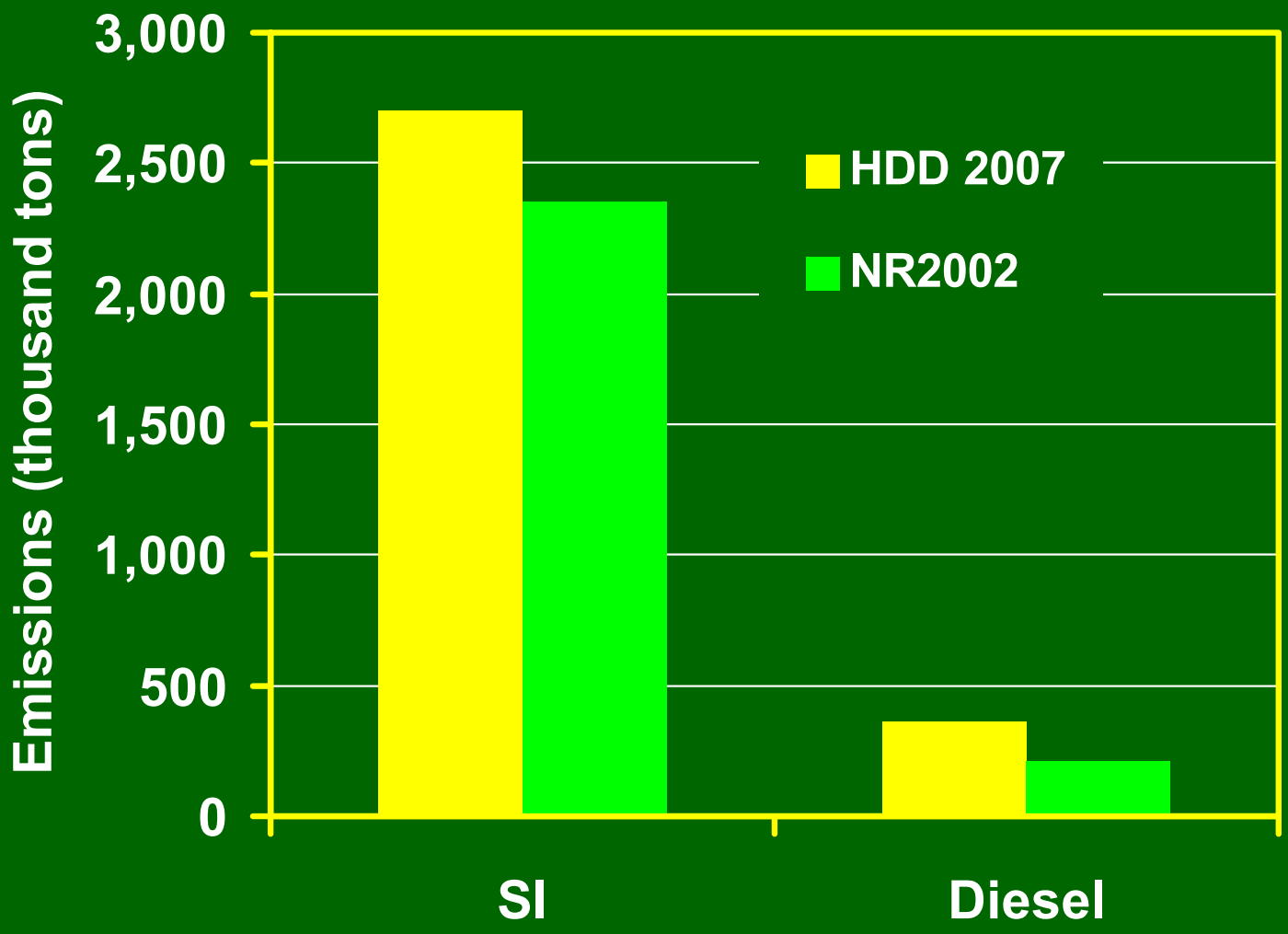
- Nation-State Allocation: population allocated on basis of estimated 1992 gasoline use
  - Results from ORNL Non-highway Gasoline Use Estimator Model
- State-County Allocation: Water surface area
  - Adjustments to water surface area allocation create two separate allocation surrogates for inboards and outboards/PWCs
    - Reflects assumption that inboards operate up to 2 miles offshore; outboards and PWCs operate up to a quarter mile from shore
  - Results in more inboard boats allocated to coastal counties and outboards and PWCs allocated to inland bodies of water

Basis for Comparison

- **Time Period:** Calendar Year 1999
- **HDD 2007:** national estimates using June-2000 version with national defaults
  - current publicly available version
- **NR 2002:** national estimates from 1999 NEI, final version 2
  - sums of county inventories
  - recently released to states

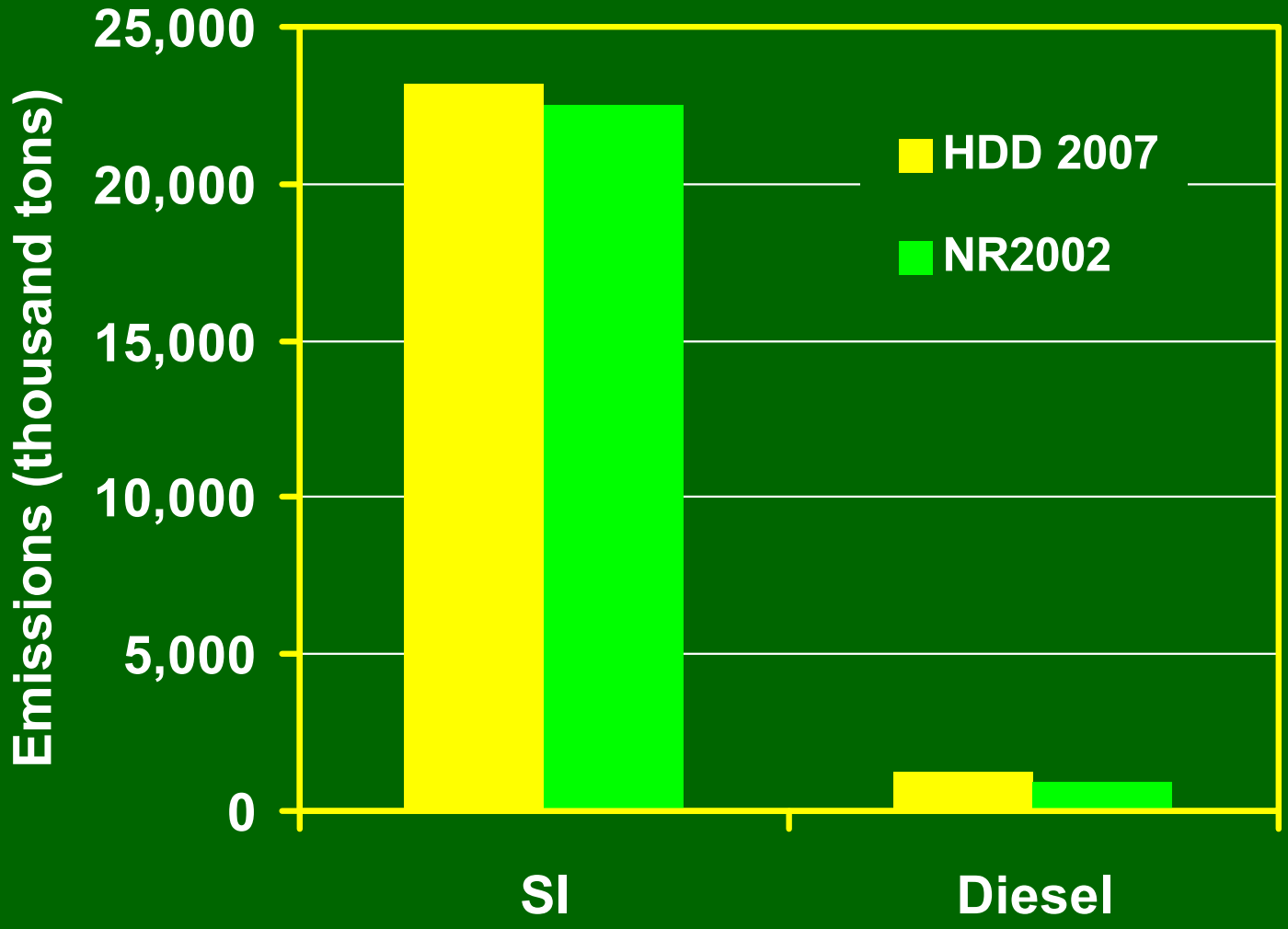
Inventory Comparison: *VOC*

National Estimates for 1999



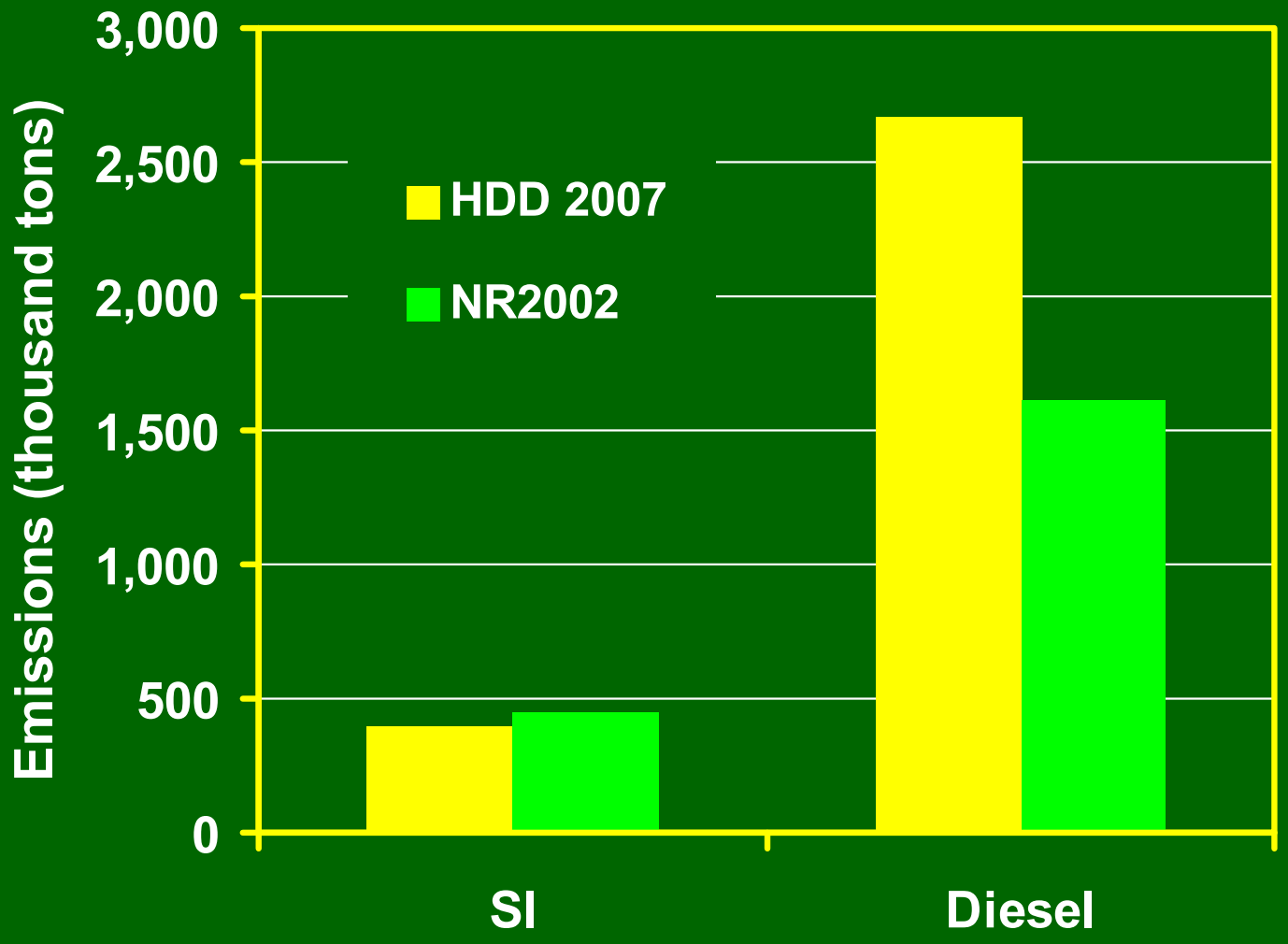
Inventory Comparison: *CO*

National Estimates for 1999



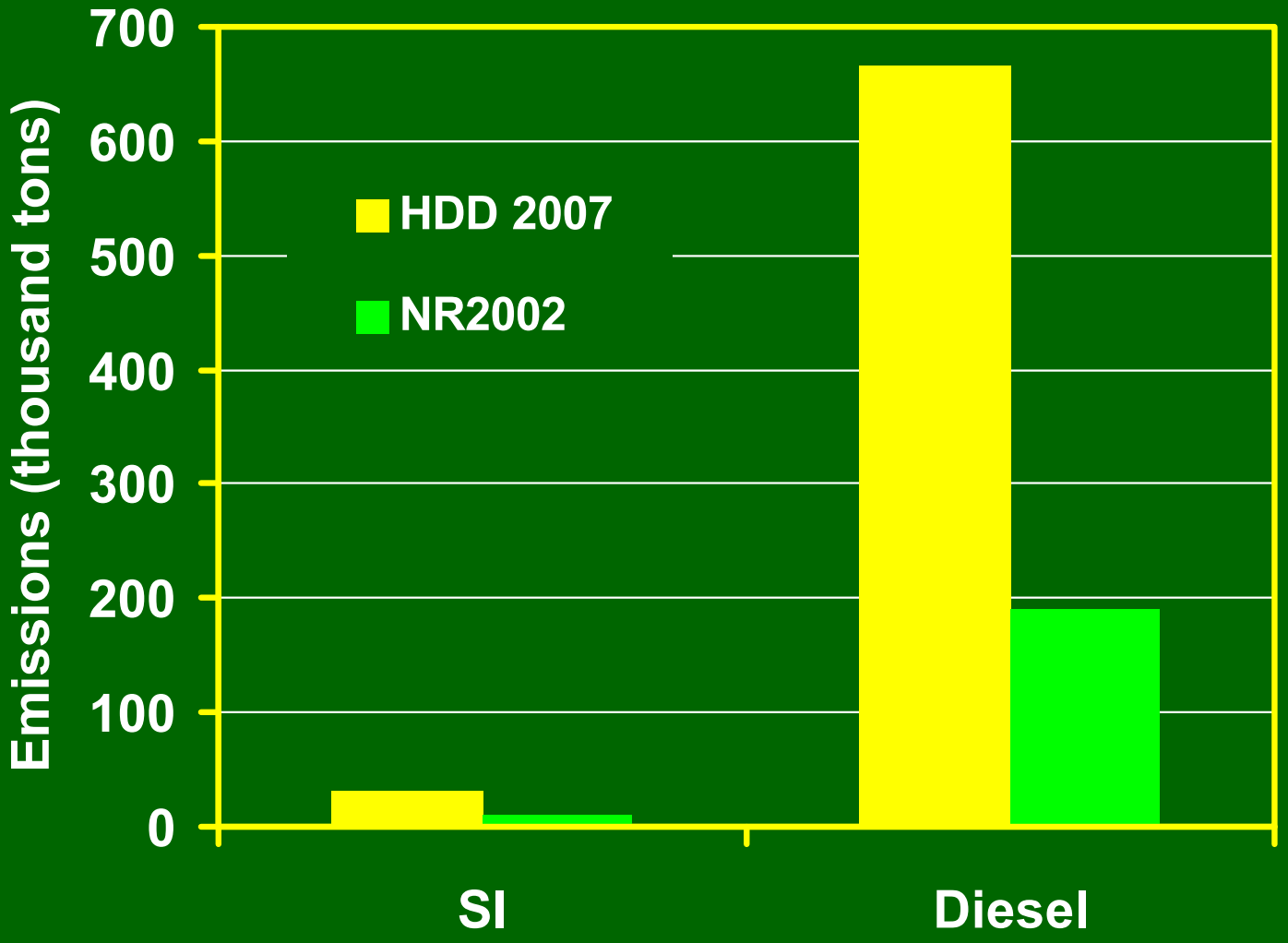
Inventory Comparison: NO_x

National Estimates for 1999



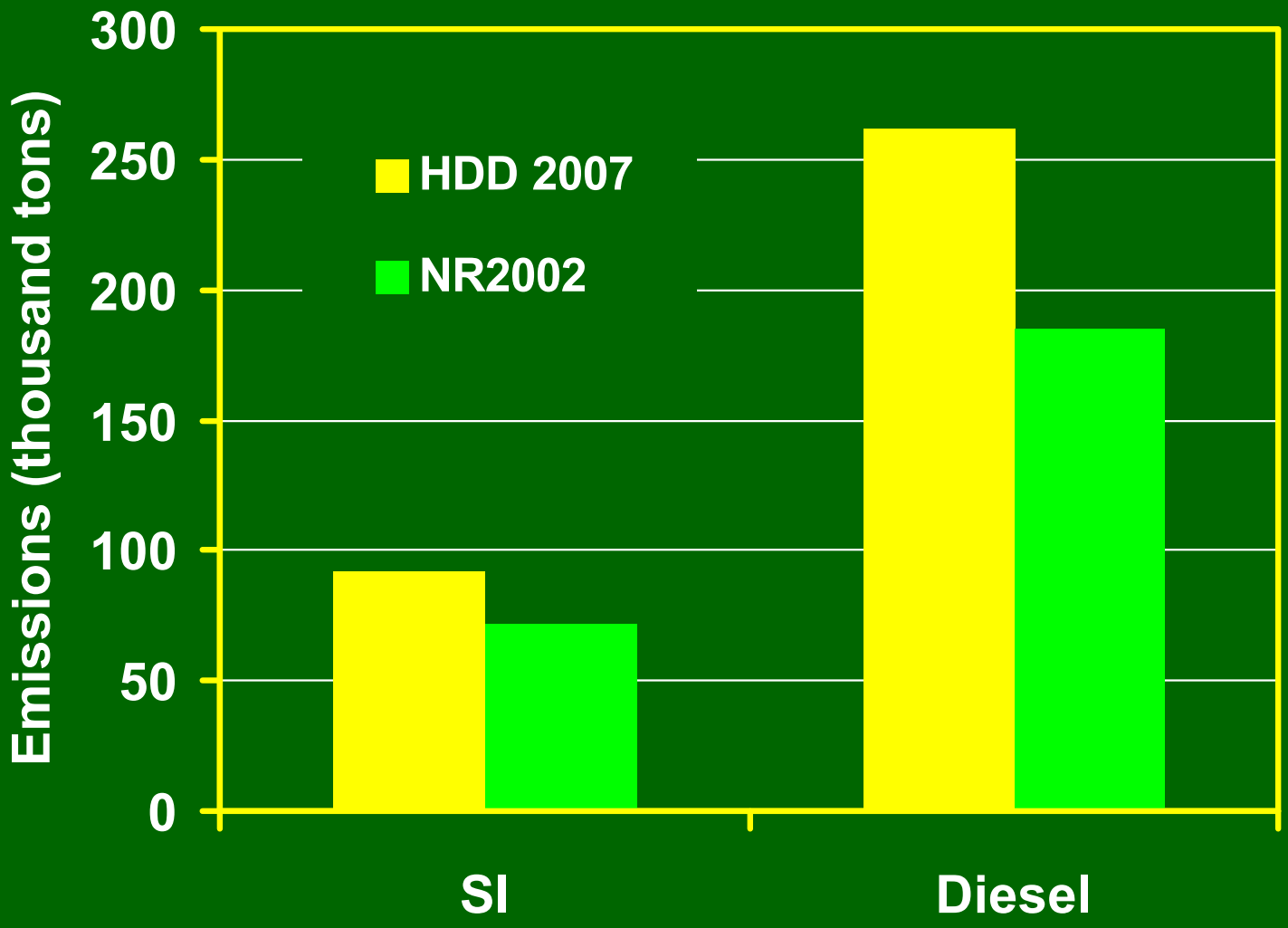
Inventory Comparison: SO_x

National Estimates for 1999



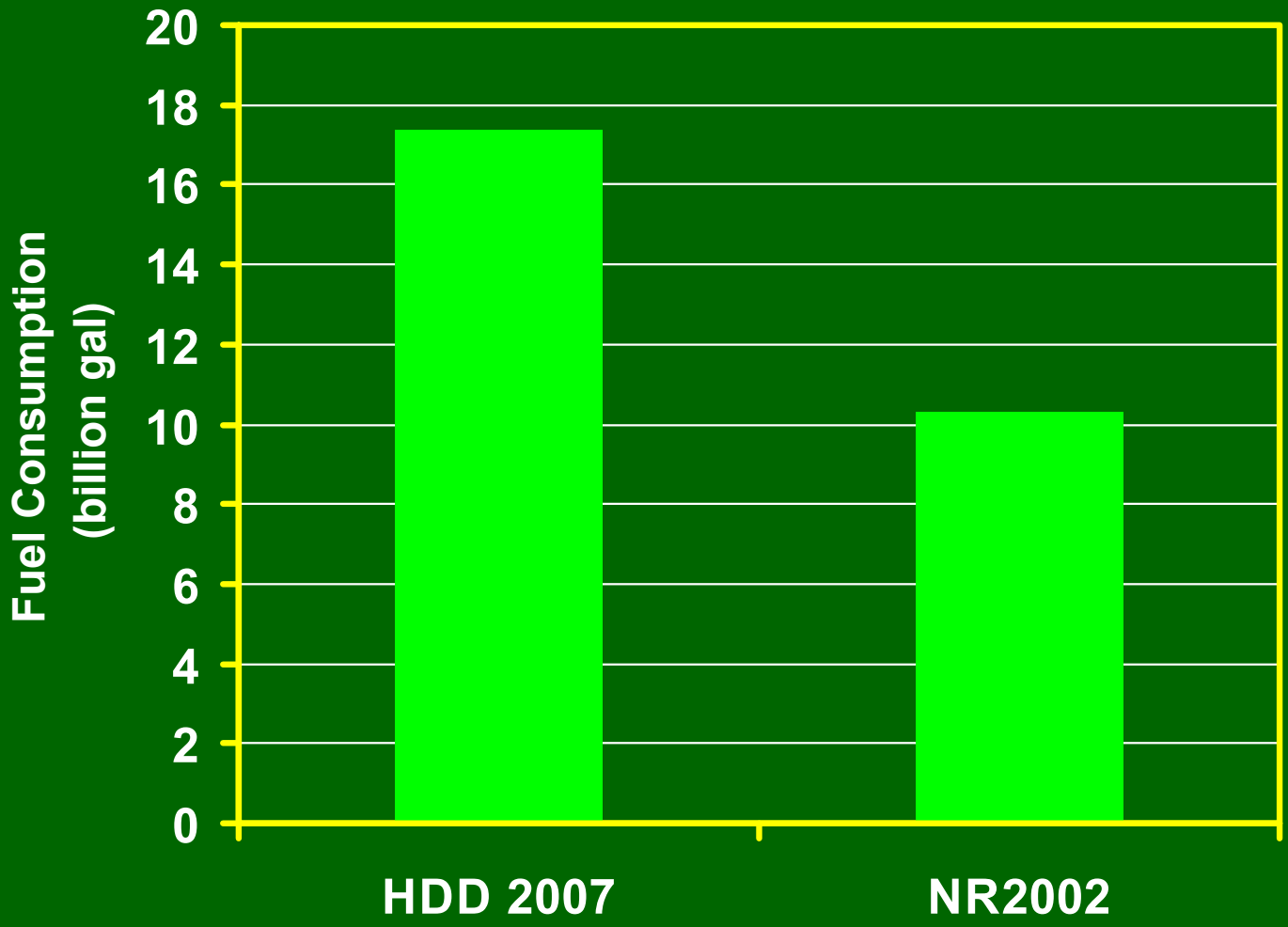
Inventory Comparison: PM_{10}

National Estimates for 1999



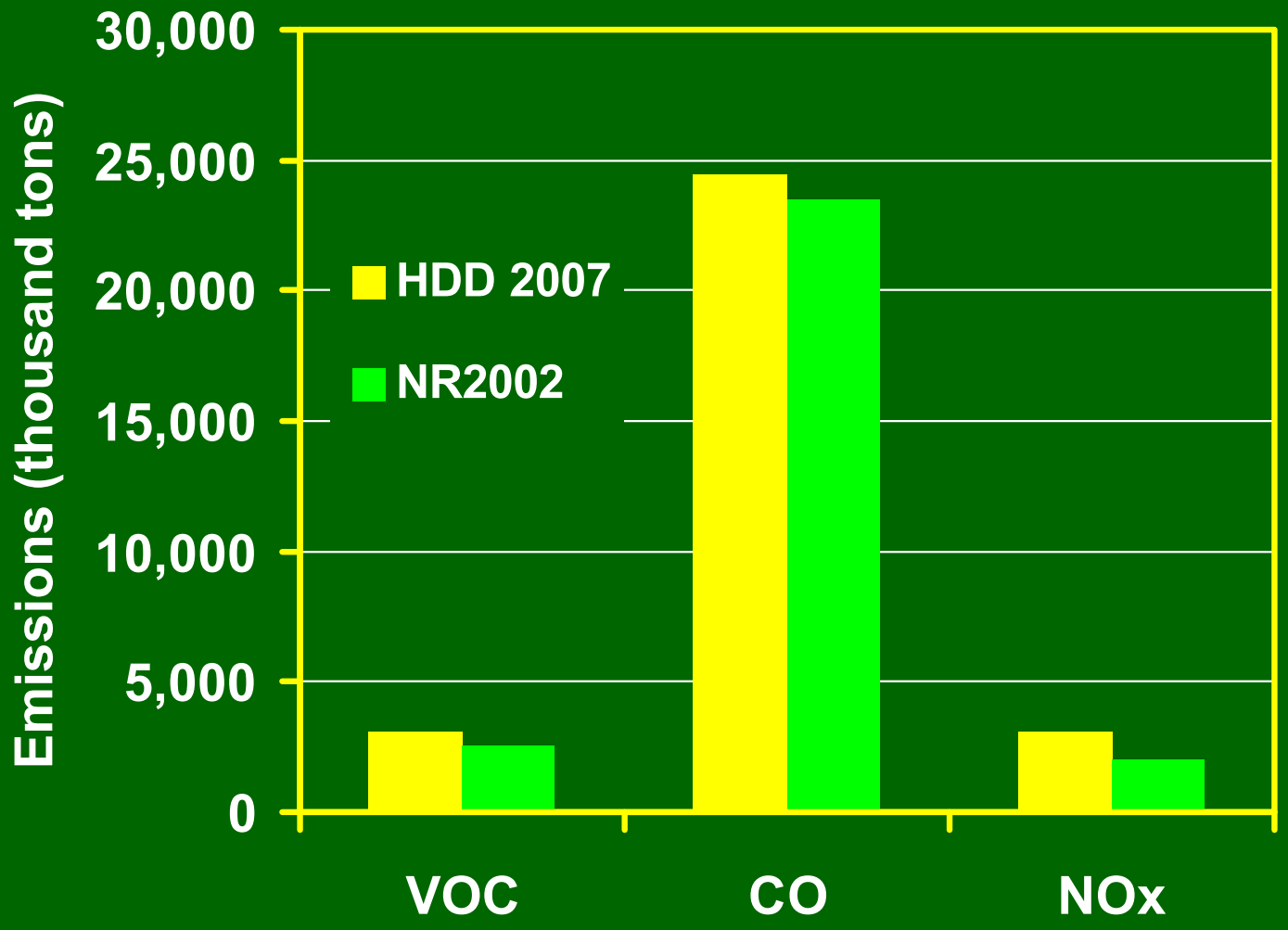
Inventory Comparison:
Diesel Fuel Consumption

National Estimates for 1999



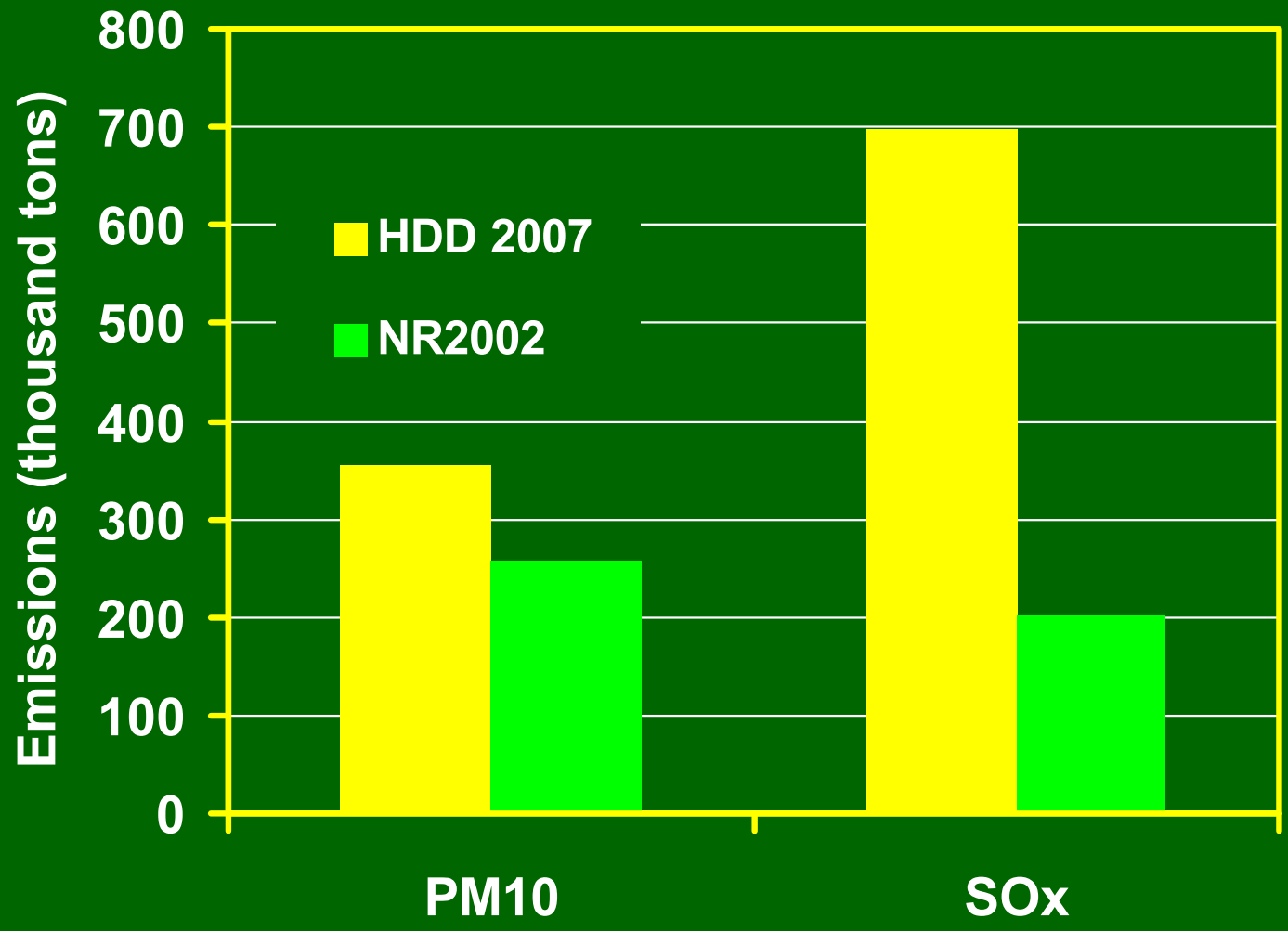
Inventory Comparison: SI + Diesel

National Estimates for 1999



Inventory Comparison: SI + Diesel

National Estimates for 1999



Model Release:
Tied to Nonroad Rulemaking

Milestone	Date
• Draft Release at time of NPRM	• Spring 2003
• Comment Period	• 60 days
• Final Release after FRM	• Spring 2004

Guidance:
NONROAD in SIPs

- Draft NONROAD is currently the best tool available for estimating regional nonroad inventories.
- With the release of the Nonroad NPRM, Draft NONROAD2002 is now publicly available.
- Draft NONROAD can be used in official SIP submissions to EPA.
- States need to be aware that Draft NONROAD is likely to undergo further revisions before it is finalized next year.