Emission Control Policies and Solutions for Large Off-Road Diesel Engines

ECT-2015

September 2015

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Manufacturers of Emission Controls Association

www.meca.org

Clean Diesel Technology Driven By a Decade of U.S. EPA Mobile Source Emission Regulations

Average Benefit:Cost = 20:1

Tier 3 Light-Duty
final rule 2014
fully phased in 2025
Diesels held to same standards as gasoline vehicles
Diesel sulfur now < 15 ppm

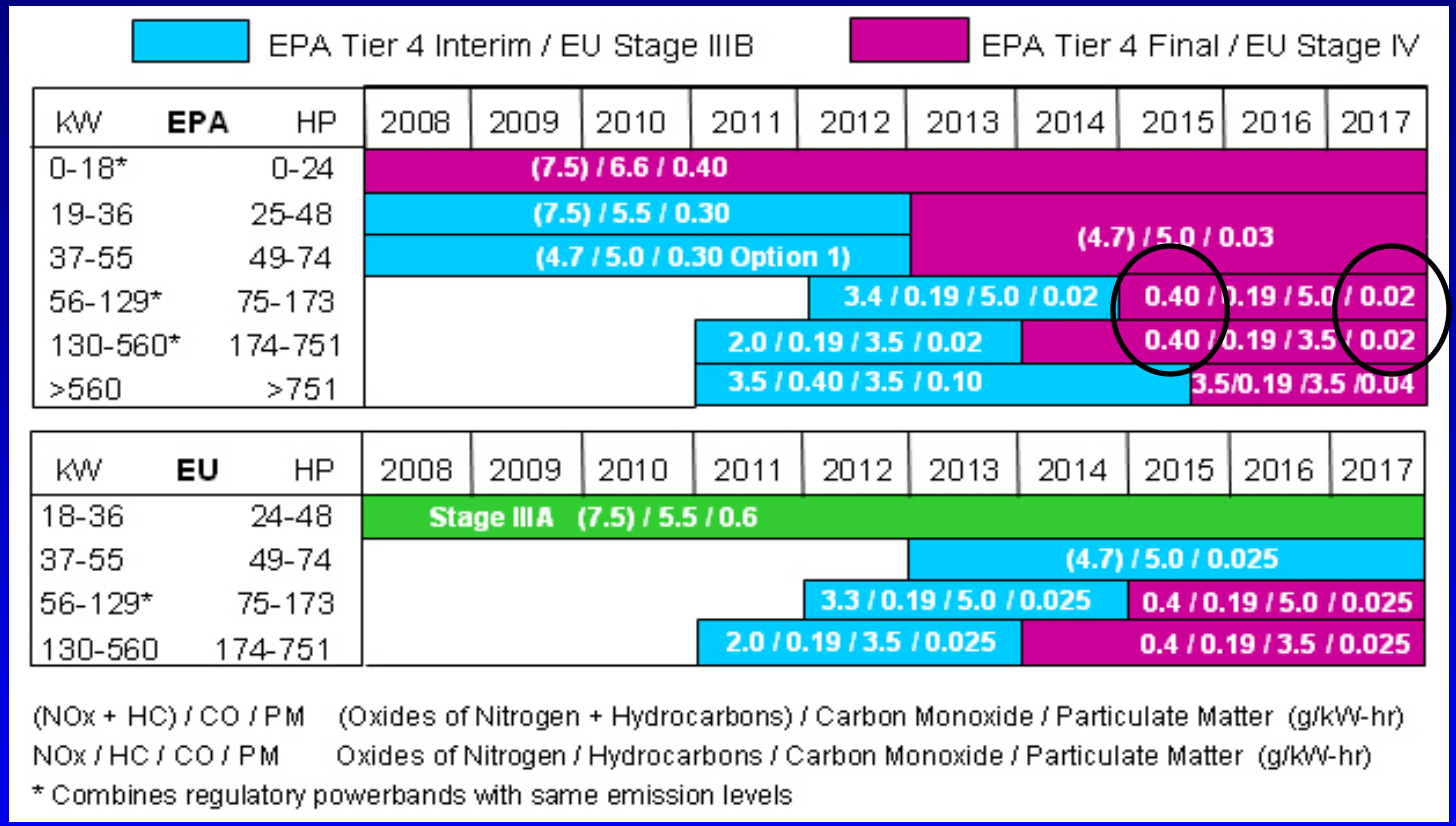
Ocean-going Vessels
final rule 2009; IMO ECA in 2010
ECA: 1000 ppm Sulfur in 2015; 80% lower NOx by 2016

Heavy-Duty Highway
final rule 2000
Sulfur now < 15 ppm
fully phased in 2007-2010

Locomotive / Marine Tier 4
final rule 2008
Sulfur now < 15 ppm
fully phased in 2017

Nonroad Diesel Tier 4
final rule 2004
Sulfur now < 15 ppm
fully phased in 2015;
basis for new stationary engines

Tier 4 U.S./Stage IV EU Off-road Diesels Offering a Wider Range of Emission Controls



(NOx + HC) / CO / PM (Oxides of Nitrogen + Hydrocarbons) / Carbon Monoxide / Particulate Matter (g/kW-hr)
NOx / HC / CO / PM Oxides of Nitrogen / Hydrocarbons / Carbon Monoxide / Particulate Matter (g/kW-hr)
* Combines regulatory powerbands with same emission levels

Tier 4 Final includes a variety of emission control solutions including: EGR+DOC, DOC+SCR, EGR+DPF, DPF+SCR

50%+ higher off-road limits:

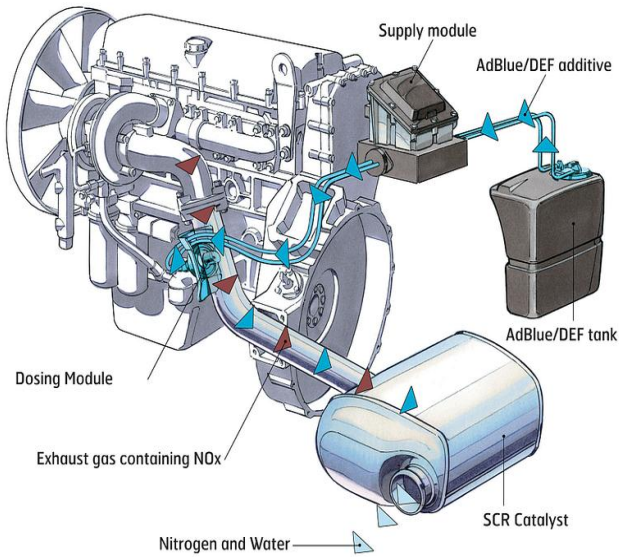
PM (g/kWh)
0.020 off-road
(0.04-0.06 for Tier 4 loco/marine)
vs.
0.013 on-road

NOx (g/kWh)
0.40 off-road
(1.8 for Tier 4 loco/marine)
vs.
0.26 on-road

EU considering a Stage V standard that could be similar to Euro VI, including a PN limit; EU Stage IIIB/IV and U.S. Tier 4 Standards utilize the Nonroad Transient Cycle (NRTC)

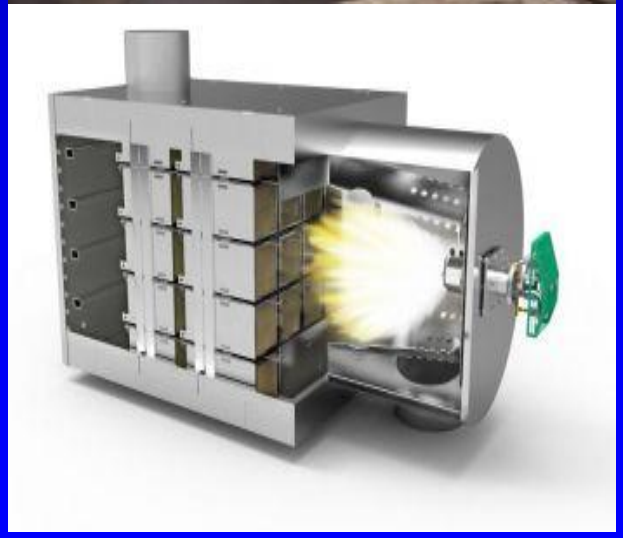
Clean Diesel Technology Expanding into U.S. Off-road Applications with & without DPFs

Tier 4 Tractors with SCR



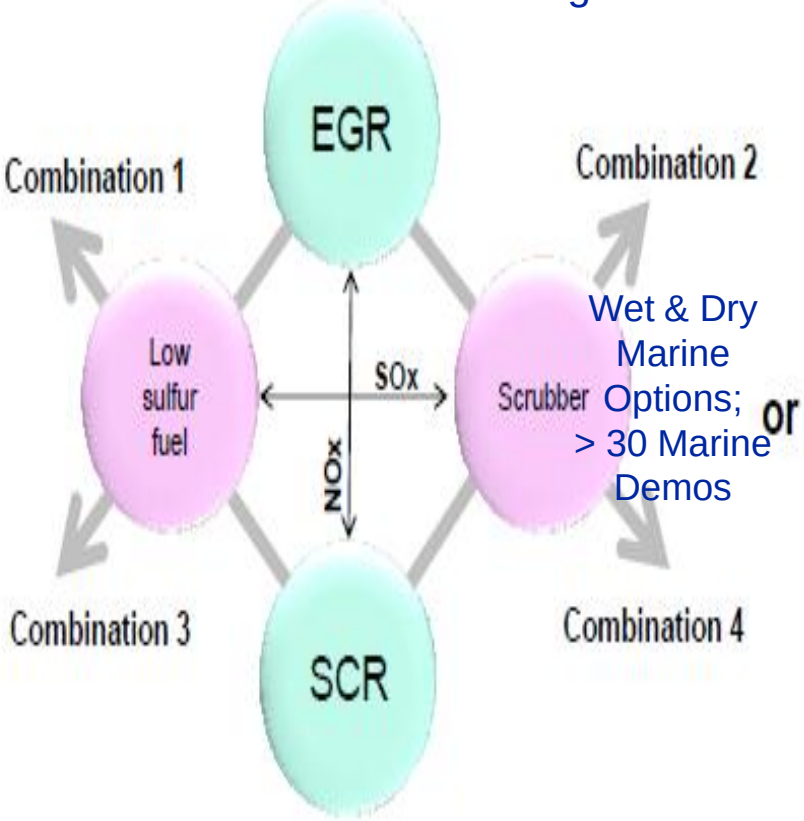
Larger Tier 4 Machines with DPF+SCR

Locomotives with DPFs and/or SCR systems



Growing Experience with Large Diesel Engine Emission Control Options

Emerging for
Marine & Locomotive Engines



Wet & Dry Marine Options; > 30 Marine Demos

or

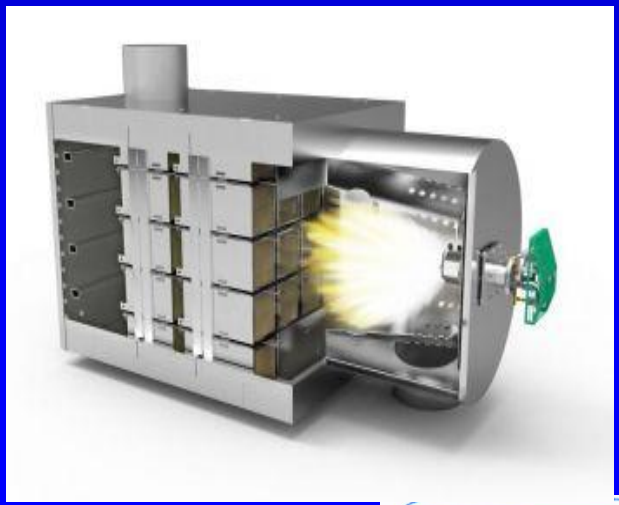
Lean burn gas Otto cycle

LNG/CNG Stationary, Marine, & Loco Engines

- 500 Ship Installations;

Lots of Stationary Engines;
A few Locomotive Demos

Growing Number of DPF Demos on Marine & Locomotive Engines



SCR Applications Moving from Stationary to Mobile Sources: Urea Infrastructure Expanding

Tier 4
Off-Road
Engines

2010+
Heavy Duty
Vehicles

Power Plants

Gas Turbines

Tier 4
Locomotive
Engines
for Pass. Rail

SCR
Products

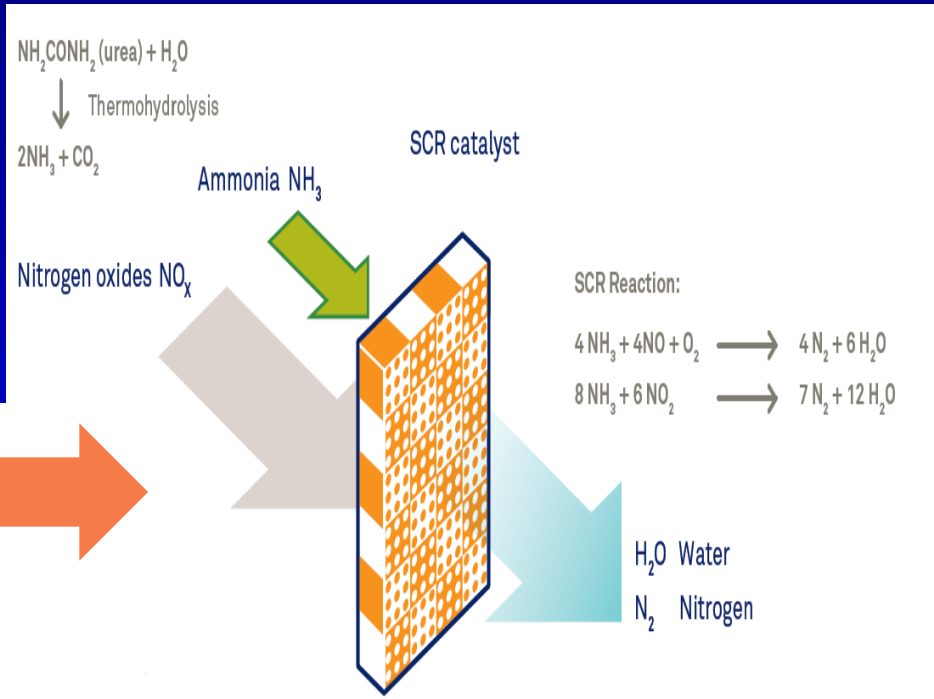
Waste Incineration

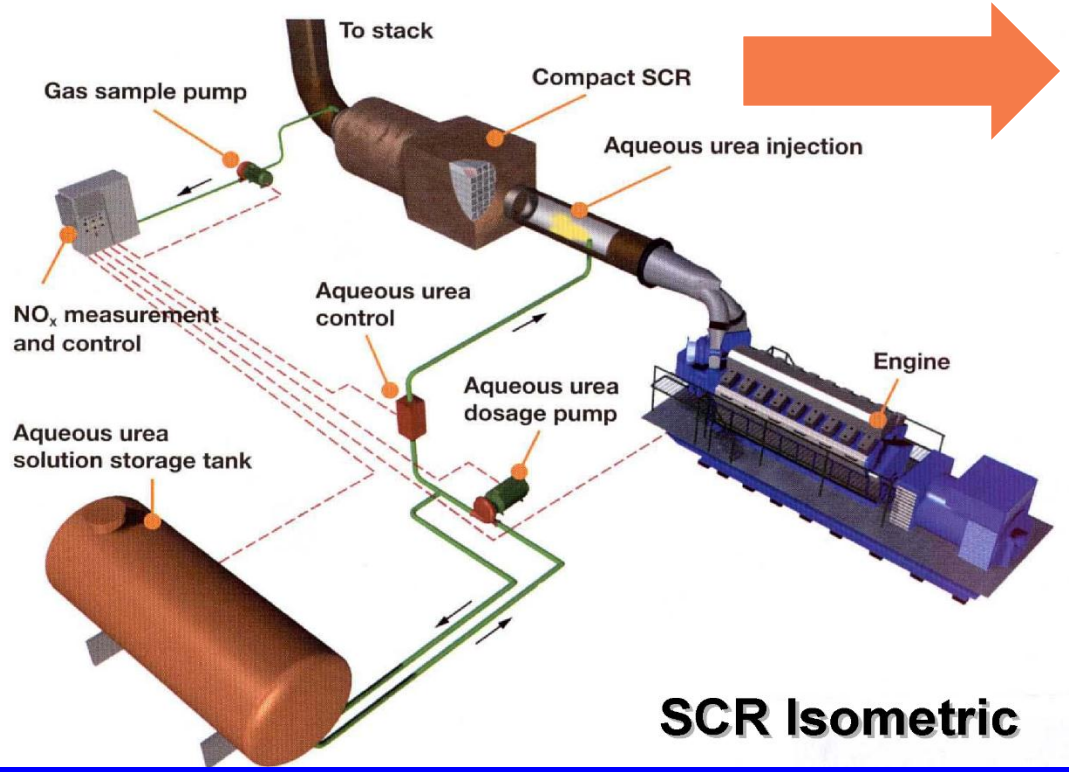
Marine
Engines

Tier 2/3 Diesel Passenger Cars

Stationary
Engines

Selective Catalytic Reduction: High NOx Conversion Emission Control Technology



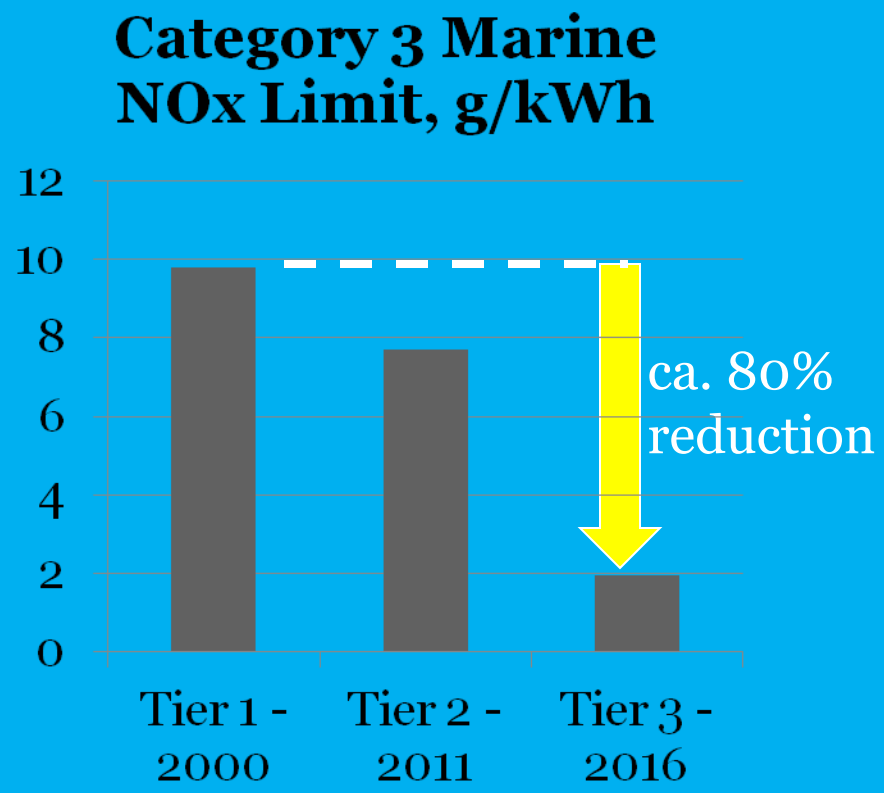


SCR Efficiencies > 90% on Large Diesel Engines Under Full Load

Commercial Marine EPA NOx Emission Standards

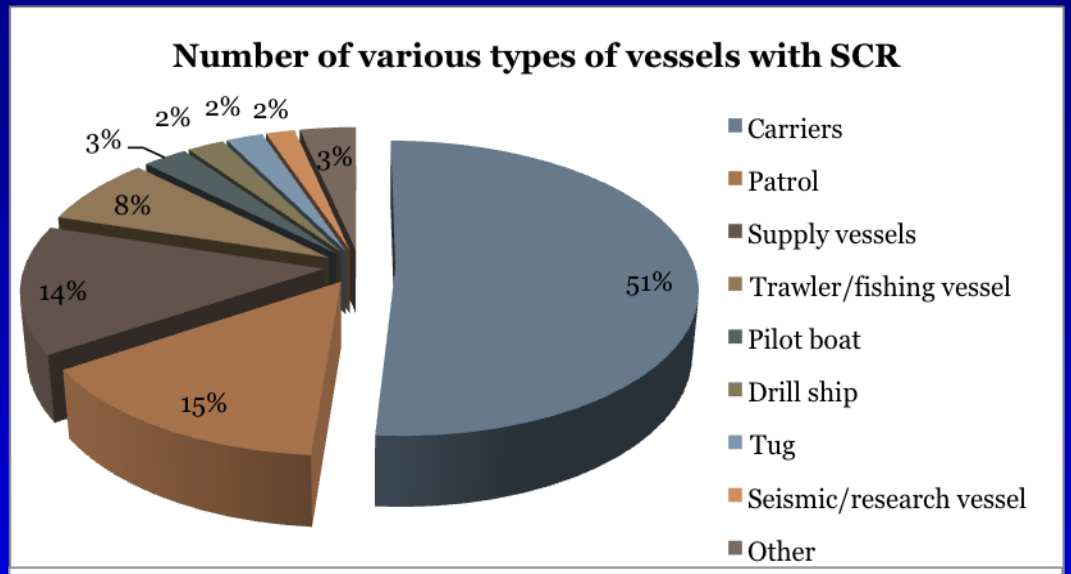
North American ECA:
1% sulfur limit began August 1, 2012
0.1% sulfur limit begins January 1, 2015

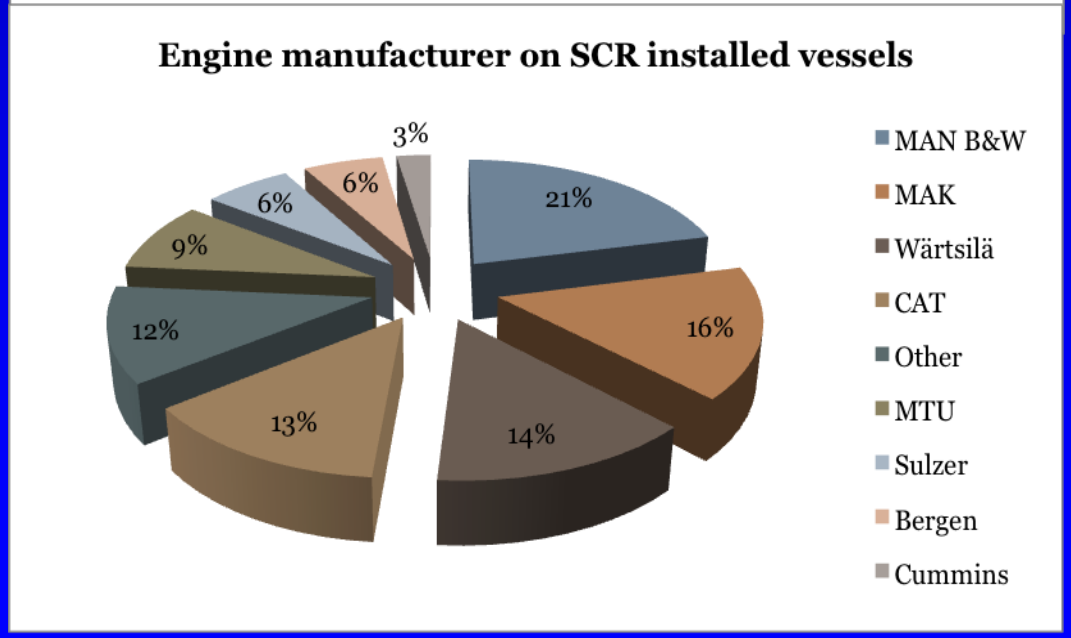
U.S. has also added Puerto Rico & the U.S. Virgin Islands to the North American ECA

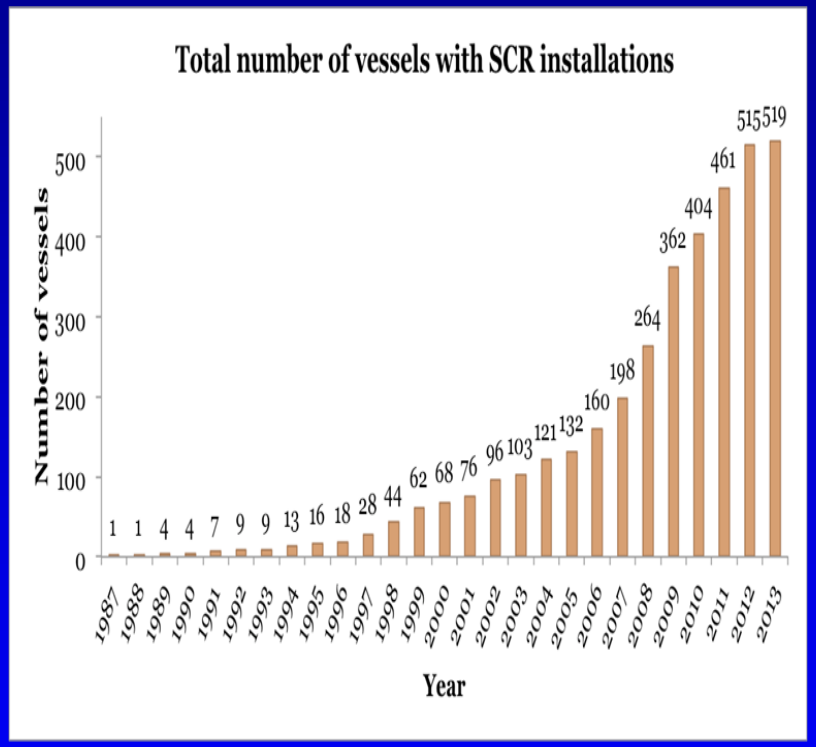


Category 3: 30 liters/cyl. or greater; max. speed 2000 rpm or greater; Tier 3 limits apply in ECA for new vessels starting in 2016

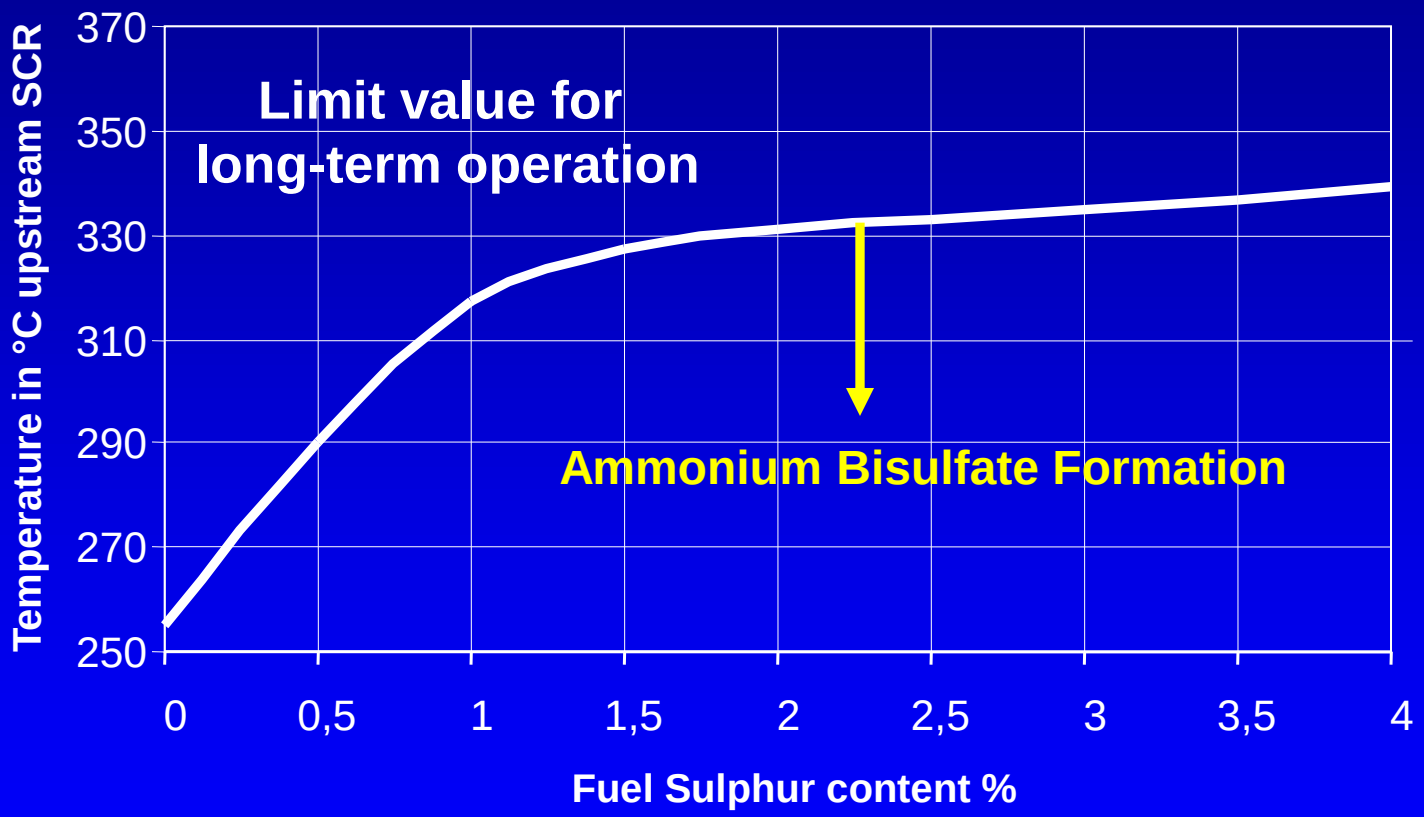
SCR Marine Applications Includes a Variety of Ship Types/Engine Manufacturers/2 & 4 Stroke Engines







SCR Experience / Heavy Fuel Oil / V-SCR



U.S. Clean Diesel Marine Demonstrations

SCR Retrofits on 2 Staten Island Ferries

DOC + Crankcase Filter Retrofits On Mississippi Barge Tugs

DPF+SCR Retrofit on LA Port Tug

Long Beach Hybrid Tug Retrofit

U.S. Clean Diesel Locomotive Demonstrations

Passive DPF Retrofits on Tier 2 Gen-Set Switcher Loco

Tier 4 Gen-Set Switcher with DPFs

Tier 2 Loco Retrofit with EGR and DOCs/DPFs

GE Tier 4 Line Haul Loco with EGR

Conclusions

- U.S. regulations have driven the development and introduction of clean diesel emission technologies in both on-road and off-road diesel engines
- Use of ULSD allows for the opportunity to employ best available technologies for controlling PM and NOx
- U.S. emission regulations for large diesel engines (stationary, marine, locomotive) are less stringent than in the heavy-duty highway sector allowing for engine-based controls for PM (no DPFs), and solutions including EGR or SCR for controlling NOx
- Interest in low cost natural gas engines for stationary, marine, and locomotive engines; fueling infrastructure not yet well developed