ECT 2016: Emission Control Technology for Sustainable Growth
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BS VI Solutions for LD, LDD and HDD

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EMISSION CONTROL TECHNOLOGIES

Gasoline

Gasoline

- Global Trend

1. TWC （Three Way Catalyst)
   - Still mainstream of aftertreatment system.
   - Continuous development is required to meet stringent emission legislations with optimized PGM usage.
   - Activities at low temperature, both light-off and steady state conversion, are needed.
   - Meeting tight OBD requirements is a key development target
   - TWC for HEV (Hybrid Electric Vehicle) is an interesting area and Japanese OEs prefer gasoline hybrid at this moment.
   - RDE (Real Driving Emission) will require high conversion efficiencies across a larger part of the engine map, so better systems will be needed – more TWC activity and amended calibrations

2. GPF (gasoline Particulate Filter)
   - The technology is required for EU and China from 2017 to meet the PN legislation, so the activities in customers are increasing. US market will follow because a stringent PM legislation will be implemented.
   - TWC advances can apply to GPF washcoats and lower backpressure is a key aim.

Gasoline

- Global Trend

3. Lean burn engine after treatment
   - NSC (NOx Storage Catalyst) is a possible technology. But PGM cost is high and it has calibration complexity.
   - Reduction of N_2O emission and improvement of S tolerance are challenging.

4. Others
   - Hydrocarbon trap: Can be applied with advanced TWC technology.
   - Developing gCSC technology.

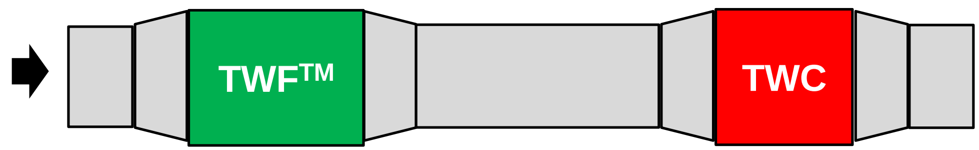
Gasoline

- BS VI solutions

Solution to control gasoline PN emissions

TWC + coated gasoline particulate filter

Three way filter + downstream TWC



- Development partnership with OEMs
- Some application to meet Euro 6c PN limit through improved engine technology or use of uncoated GPF
- Expect TWF™ / cGPF uptake to increase with RDE PN limit

Light Duty Diesel (LDD)

Real World Emission

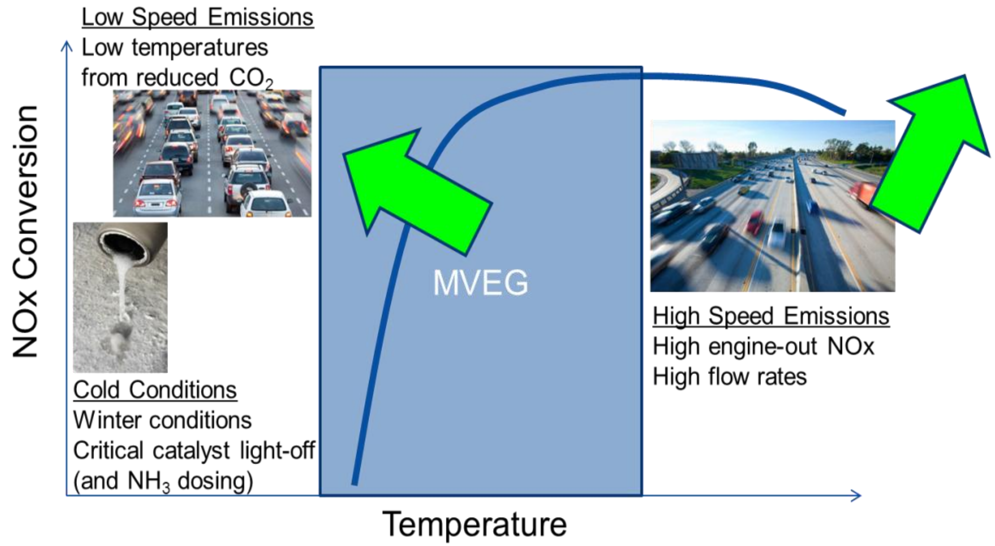
Widen NOx window (Real driving Emission)

Low Speed Emissions

- Low temperatures especially from CO_2 improvements

High Speed Emissions

- Higher engine-out NOx emissions
- High flow rates



Impact of Compliance Factors on System Choice

Scenario 1 : Most demanding RDE conditions

Compliance factors up to 1.5 (80 – 120 mg/km NOx)

NSC : Challenging and low engine NOx at high load

Urea SCR : NSC + SCRF® for low speed and high speed NOx

DOC + SCRF® is also available

Scenario 2 : Less demanding RDE conditions

Compliance factors > 1.5 (> 120 mg/km NOx)

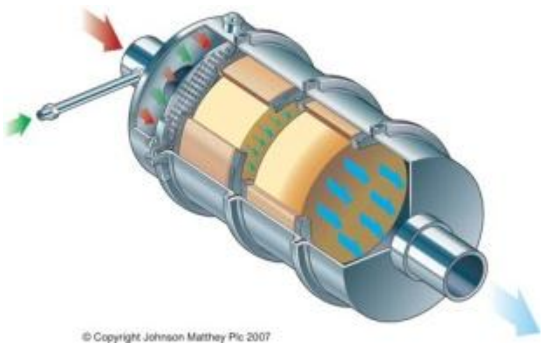
NSC : + passive SCR/F and low engine NOx at high load

Urea SCR : DOC + SCRF® and low engine NOx at low load

NSC + SCRF®

LDD

- BS VI Solutions : Introduction of NOx Control Catalysts



Selective Catalytic Reduction (SCR)

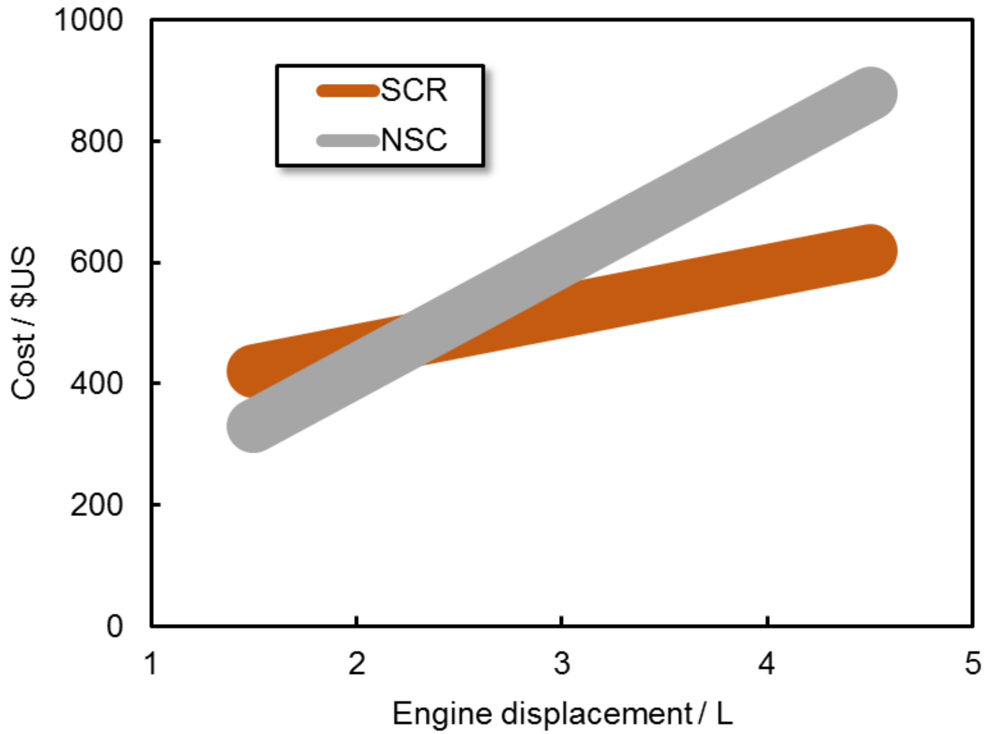
- Metal-zeolite based catalyst
- Low PGM loading (slip catalyst only)
- Requires urea injection system, with tank, doser and injector systems
- Favoured on larger vehicles

NOx Storage Catalysts (NSC)

- PGM based catalyst
- Requires fuel addition, hence penalty on fuel consumption
- Favoured on smaller vehicles

LDD
- BS VI Solutions

Economical comparison between SCR and NSC based system



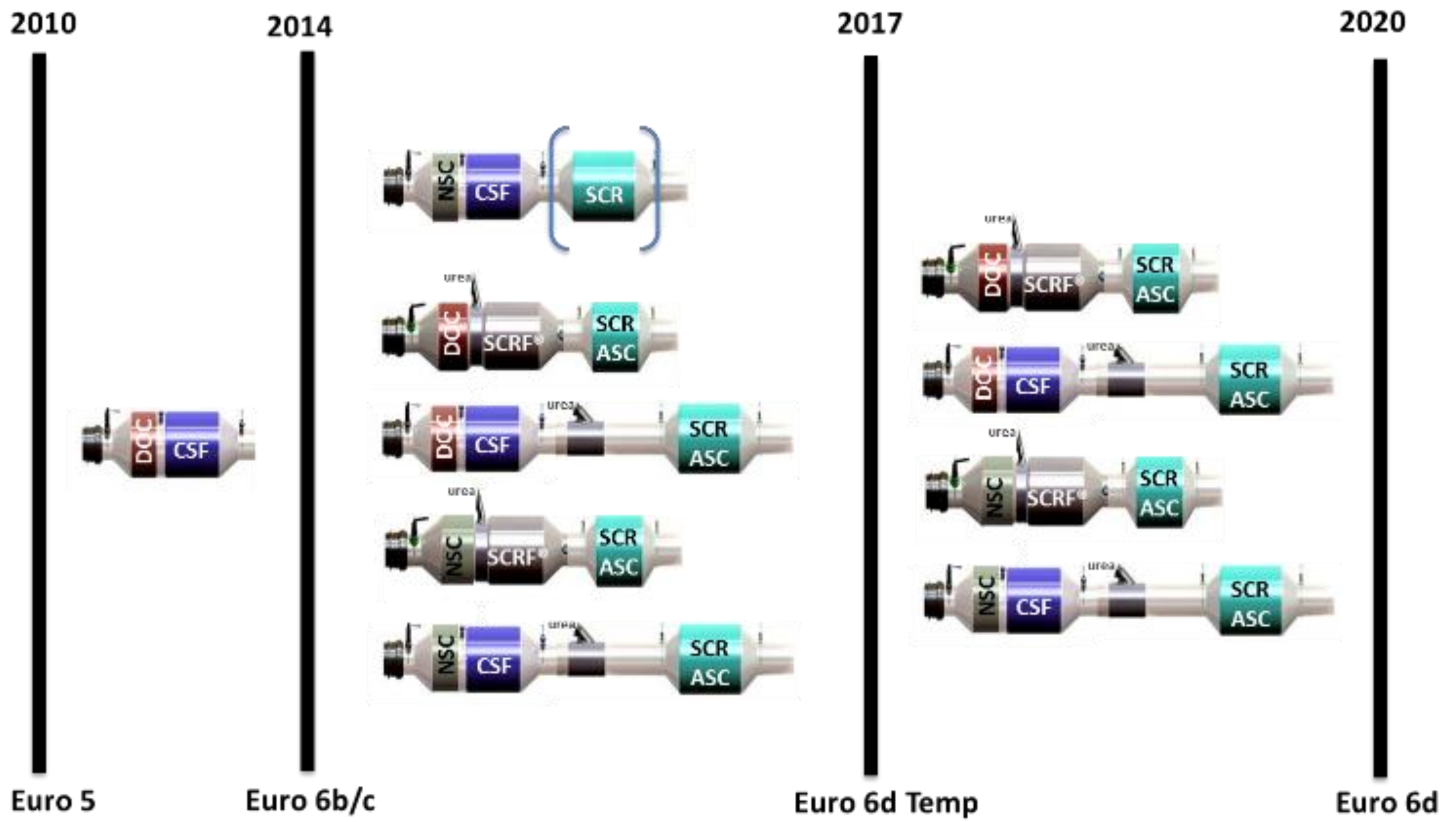
Source :Francois Posada, Anup Bandivadekar and John German, “Estimated Cost of Emission Control Technologies for Light-Duty Vehicles Part 2 – Diesel”, SAE Paper 2013-01-0539, 2013

- Both system costs proportionally increase as a function of engine displacement.
- Cost estimates are almost equal for the engines with displacement around 2.4 L. (this cost balance point could be moved by costs of considered items.

LDD

- BS VI Solutions

LDD After-Treatment System Road Map in Europe



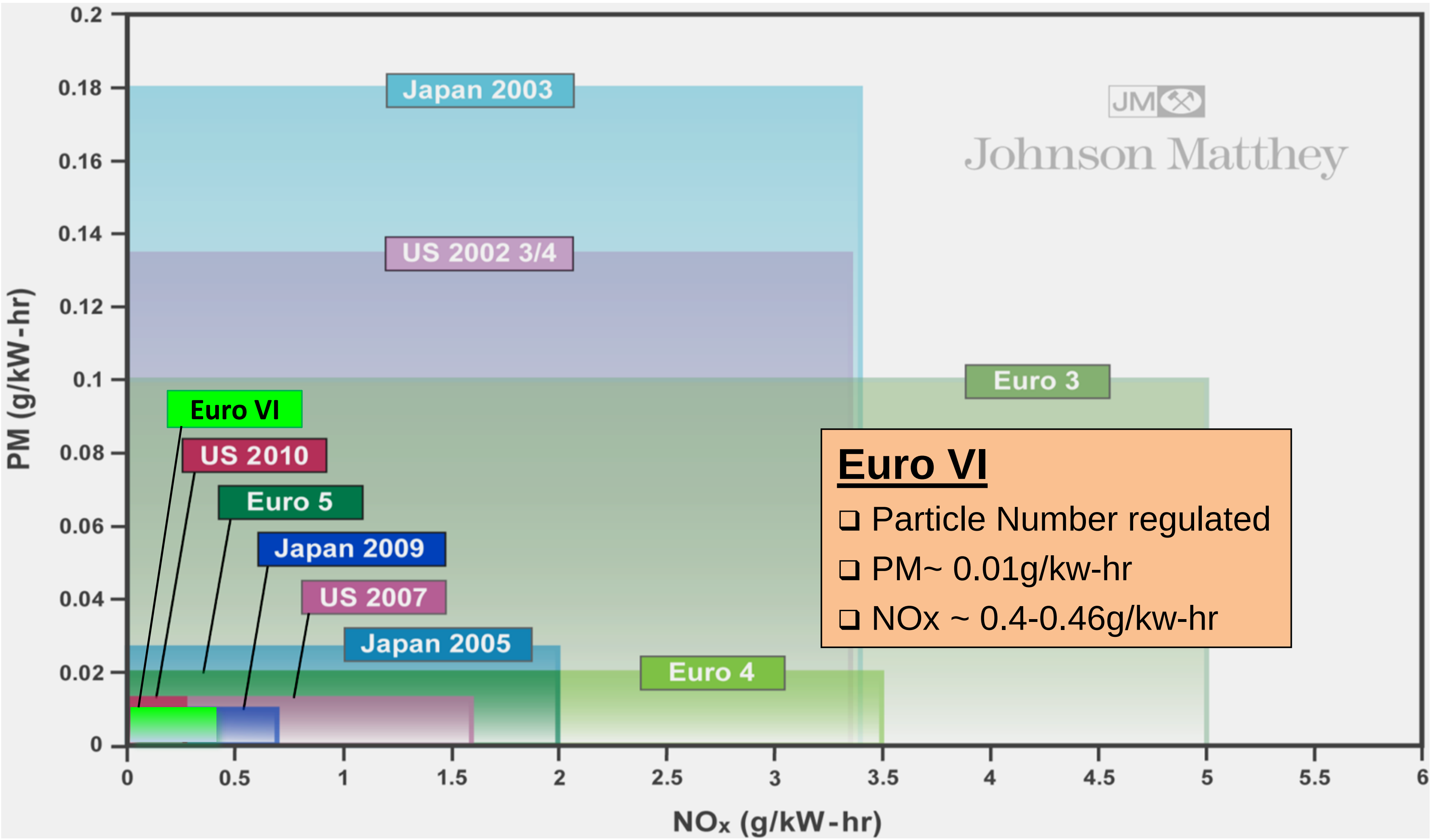
- For Euro 6 b/c, either NSC or SCR are required
- For Euro 6d with RDE, both NSC and SCR function will be required in some applications

Heavy Duty Diesel (HDD)

HDD

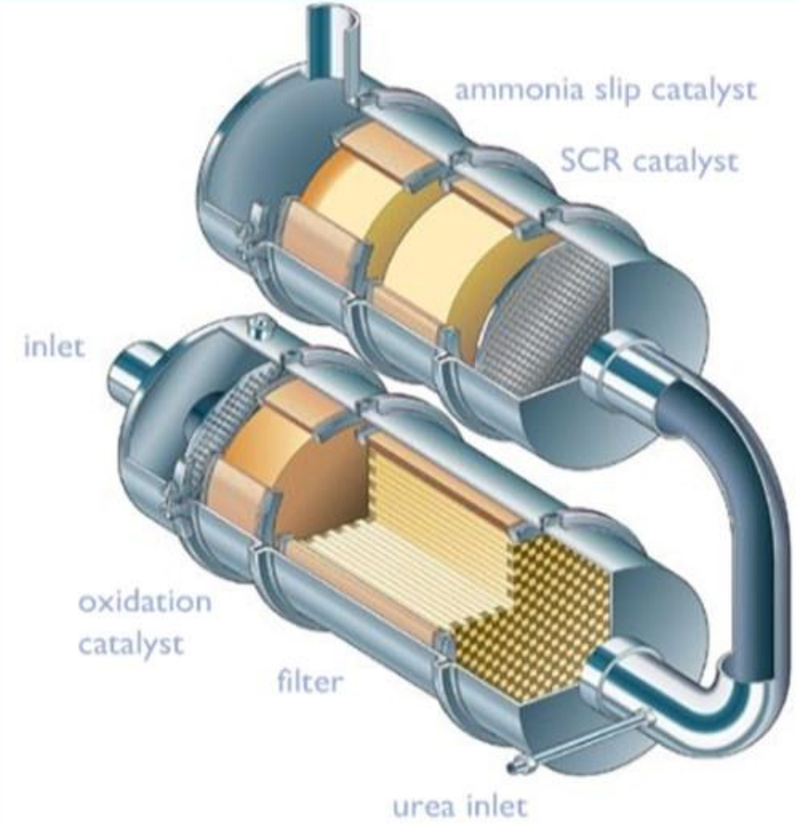
- BS VI Expected to follow Euro VI : Requirement of Euro VI (PN first time required)

❑ **Expected >96% NOx conversion required for most BSVI applications under WHTC transient cycle**



HDD
- General Market Trends For Euro VI

- Euro VI regulates Particle Number, forcing to use high efficiency wall flow filters
- Global system trend:
  - JP'09: DOC + CSF + Fe-SCR + ASC
  - EPA10:
    - ➢ DOC + CSF + Cu-SCR + ASC
    - ➢ DOC + CSF + Fe-SCR + ASC
  - EU VI: DOC + CSF + SCR + ASC
    - ➢ Filter effectively mandated at EU VI
    - ➢ Mixed SCR technologies: V, Cu & Fe
- Key questions to address:
  - DPF/CSF regeneration strategy
    - ➢ Active or passive?
  - SCR catalyst technology
    - ➢ Cu or Fe or V?



Fully Integrated System : SCRT™

HDD

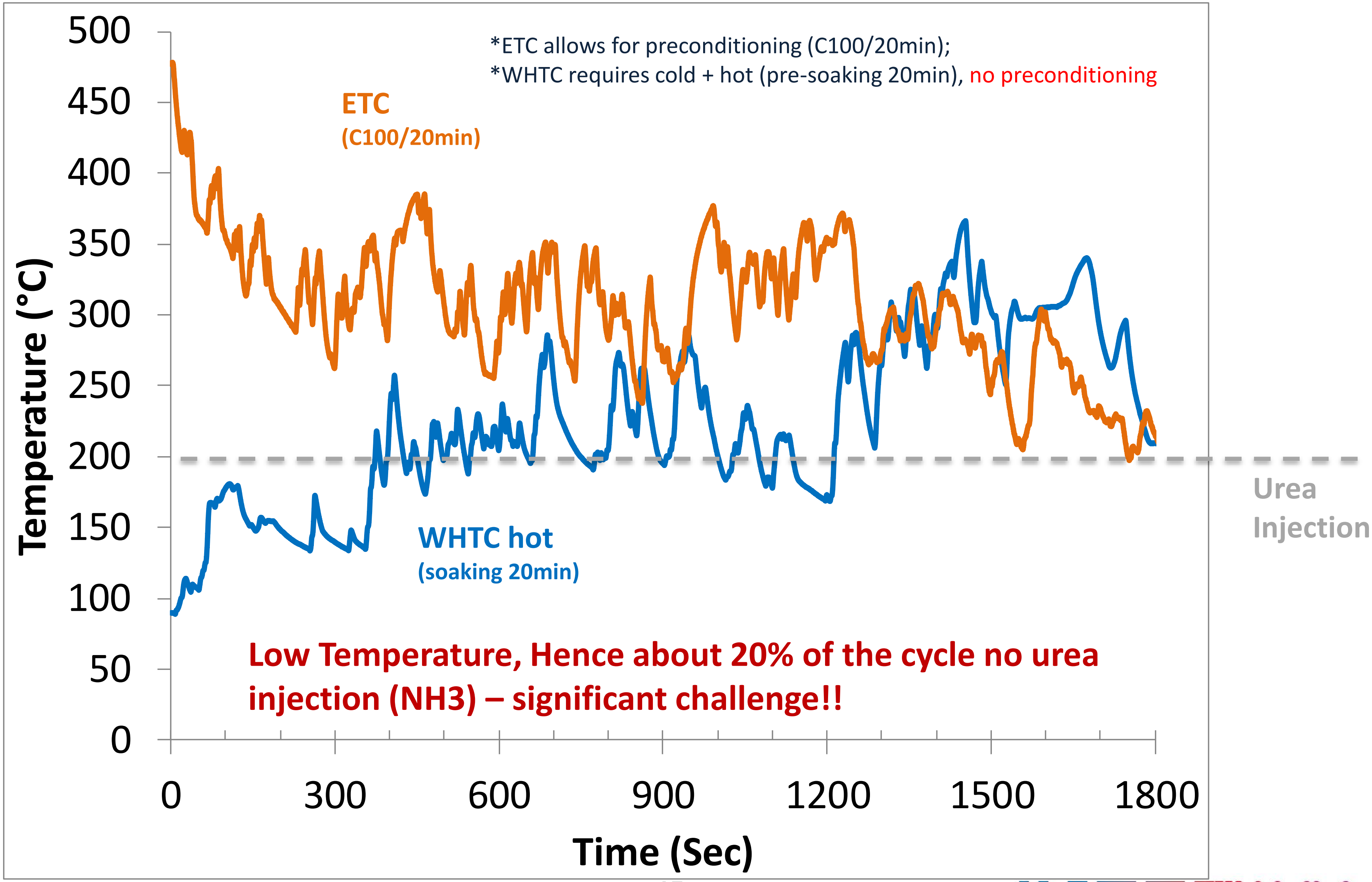
- Indian Engine and Drive Cycle Applications for BS VI

- Engines can have lower power ratings with large displacement (e.g., 6 L with 135 Hp)
  - This can result in cooler exhaust temperature
  - Further problem under WHTC testing
  - May require engine downsizing (use 4 L engine for 135 hp)

- Indian drive cycles can have prolonged low speed operation
  - Low speed operation can create exhaust temperature issue
  - Concern about real world emissions if temperature too low for SCR
  - May require thermal management

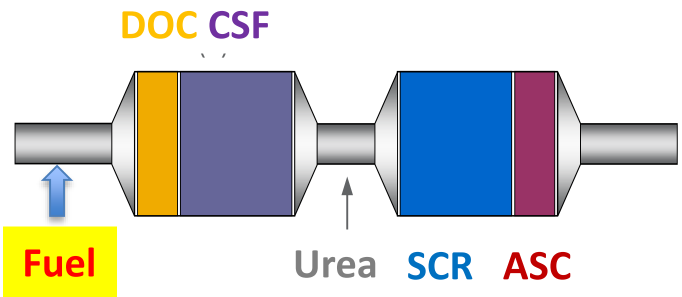
HDD

- Exhaust Temperatures BS IV (ETC) vs BS VI (WHTC) – Much Lower Temperature



HDD
- Expected systems for BS VI: Two Different Options

DPF - Active Regeneration Design



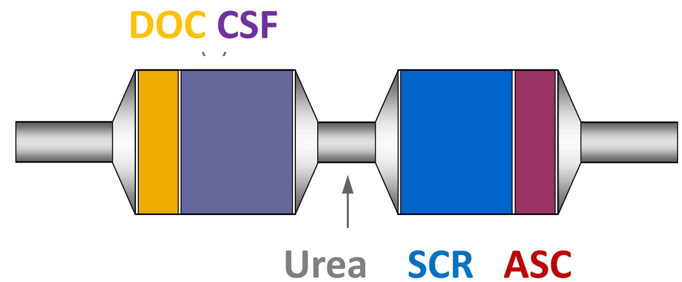
Periodic active regen re-sets the system

Increases fuel consumption and system durability requirement

Key enablers

- ***DOC/CSF with Fuel Light-off at low temperature***
  - Enables high level of active regeneration
- ***SCR with High Temperature Durability***
  - Two options: Fe and Cu SCR
    - Fe is sulfur tolerant, but can be reversibly inhibited by HC/coke
    - Cu is HC/coke tolerant, but is reversibly inhibited by sulfur
- ***ASC with high selectivity to N_2***

DPF - Passive Regeneration Design



DPF regeneration strategies largely passive

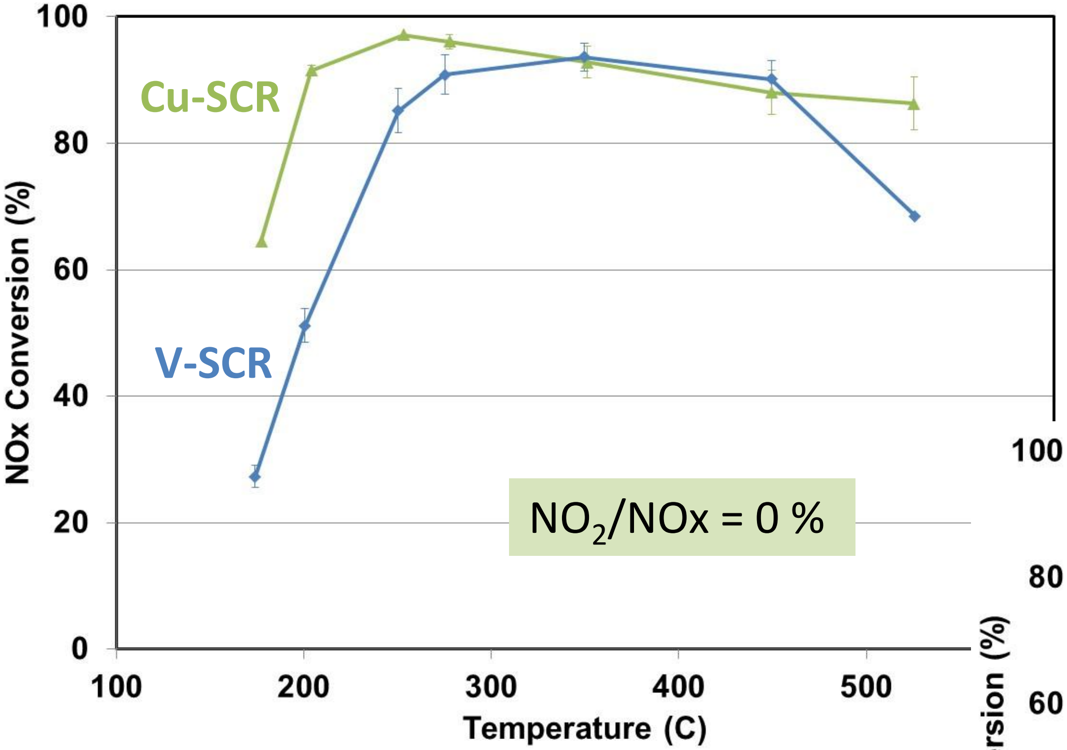
Some Assisted regen

Key enablers

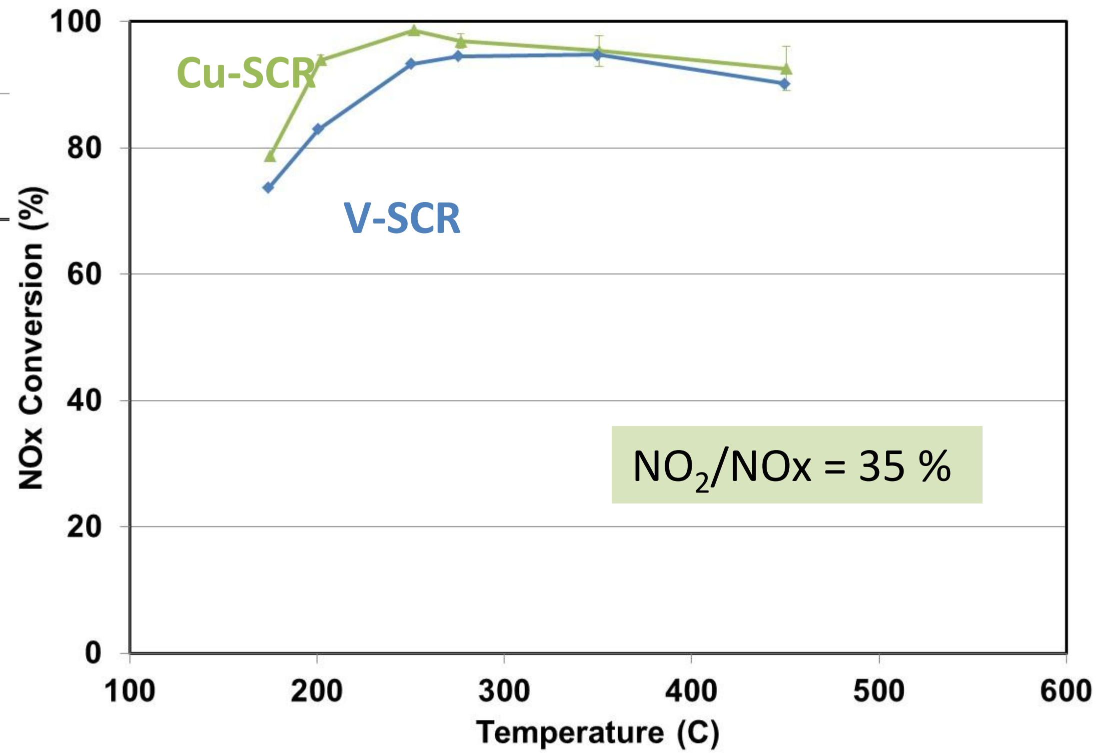
- ***DOC/CSF with High NO_2 Make***
  - Provides limited added heat management
  - Enables passive regeneration
  - Provides more NO_2 for downstream SCR
- ***SCR with Poison Tolerance***
  - Ideally Sulfur and HC/coke tolerant
  - Use of V-SCR
- ***ASC with high selectivity to N_2***

HDD

- SCR Selection for BS VI: Cu-SCR Outperforms V-SCR at Low Temperature



Reactor Testing, SCRs aged at 550C for 200hrs, SV=50K



Performance gap in NO only; significantly less in application when NO_2 present

HDD
- SCR Selection for BS VI

- On Colder exhaust engines, Cu-SCR demonstrates improved performance, no difference on warmer engines