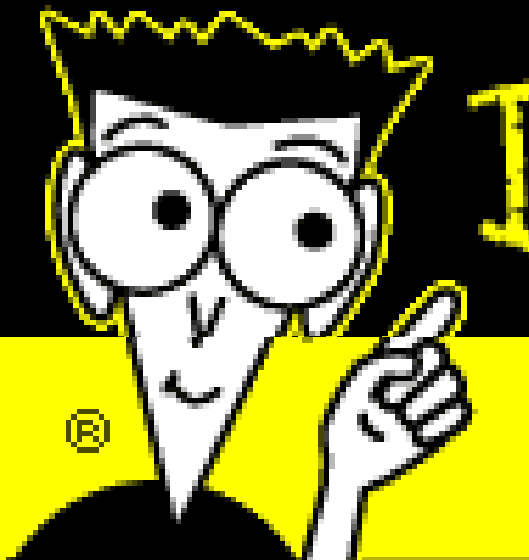DEF for DUMMIES

...and intellectuals.

Topics:
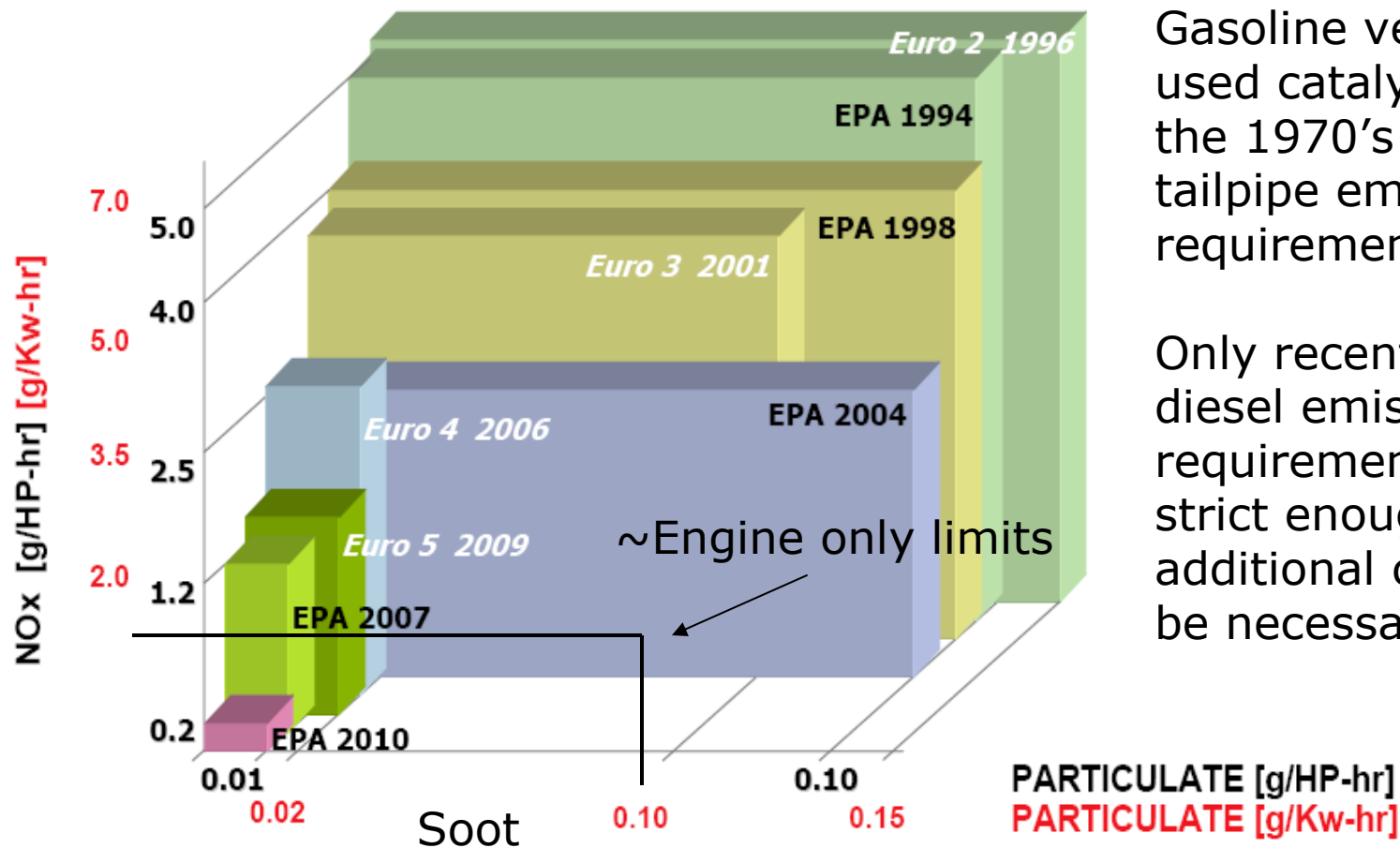
- Why is Diesel Exhaust Aftertreatment Needed?
- What is DEF? (Urea SCR)?
- Why Urea SCR (vs. other technologies)?
- Injection Components – Bosch DeNOx PC-LD
- Functional Description
- Diagnostics
- Customer Interfaces
  - Vehicle Tank Filler
  - Filling Options
  - Low Urea Warning System – Instrument Cluster Info
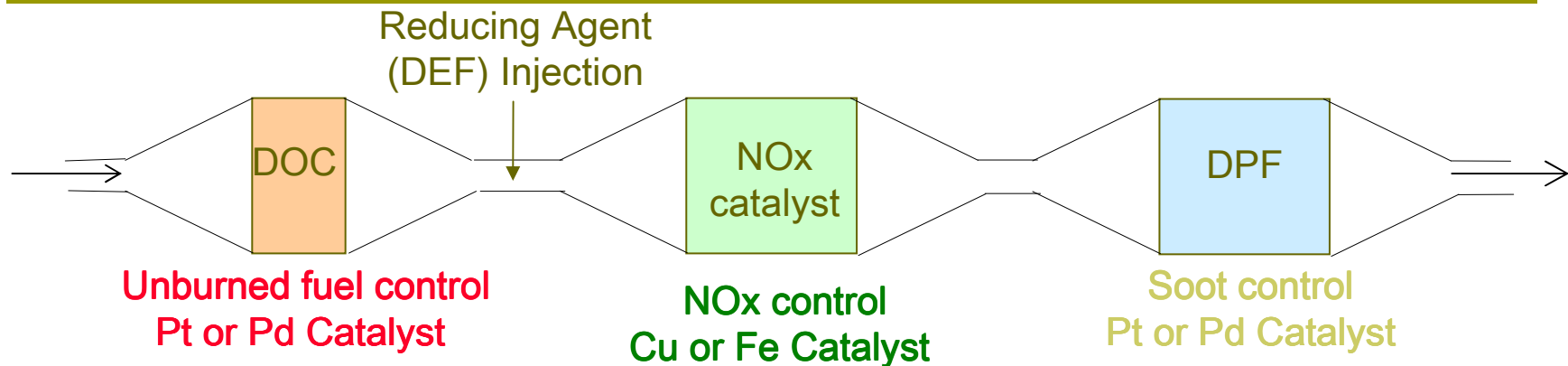
Why Diesel Aftertreatment?
Emission Standard Changes

Gasoline vehicles have used catalyst since the 1970's to meet tailpipe emission requirements.

Only recently has diesel emission requirements been strict enough for additional catalyst to be necessary.

What is Diesel Aftertreatment?

Reducing Agent
(DEF) Injection

| DOC | NOx catalyst | DPF |

Unburned fuel control
Pt or Pd Catalyst

NOx control
Cu or Fe Catalyst

Soot control
Pt or Pd Catalyst

DOC Functions:
- Diesel Oxidation Catalyst
- Fast HC/CO light-off
- Exotherm for DPF regeneration and SCR heating.

Nox Reduction Functions:
- Selective Catalytic Reduction or Lean Nox Trap (SCR or LNT)
- NOx conversion ONLY

DPF Functions:
- Soot trapping
- Final clean up HC, CO, & NH_3

- Pt or Pd can be traded for cost savings

❑ High NOX conversion depends on:
- Rapid exhaust gas warm-up.
- Highly active and durable SCR catalyst.
- Reliable urea delivery, evaporation and mixing.
- Predictable NH_3 storage within the catalyst.

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Why SCR Aftertreatment?

- Highly Effective Conversion of Nox (NO and NO2)
  - Used widely since the 1960's for stationary emission control
  - AKA - "smoke stack scrubber"
- Urea is stable and non-toxic fertilizer vs. Liquid Ammonia - hazardous
- Urea SCR is a large fixed cost (hardware intensive) but a small variable cost
  - Copper or Iron catalyst metals (very inexpensive)
  - SCR brick size = ~ 1.5 - 2 X engine displacement (6L eng ~ 10L catalyst).
  - May be up to 5% gain in fuel economy over 2008 (less EGR needed)

- Alternative to Lean NOx Trap (LNT)
  - LNT's use diesel fuel to create the reductant for Nox (CO).
  - Requires complex purge management strategy
  - Fuel economy penalty of 5-7% over 2008.
  - May be more cost effective on small light duty diesels where precious metal costs would be lower.
  - Platinum, Palladium & Rhodium catalyst metals (expensive).
  - LNT brick size = ~ 1.5 - 2 X engine displacement depending on engine NOx level and certification standard

What is Urea SCR? (or Chem101)

- Urea SCR
  - Injection of a "Reductant" to convert Engine out NOx (NO and NO2) into harmless N2 and H20
  - Urea is a compound that when heated, splits into 2 molecules of ammonia (NH3) and carbon dioxide (CO2)
  - $CO(NH_2)_2 \rightarrow NH_3 + HNCO$
  - $(16)HNCO + H_2O \rightarrow NH_3 + CO_2$

- Catalyst Reduction of Nox with Ammonia
  - $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

- Other "Reductants" are possible.
  - E85
  - Diesel (or HC's)

What is DEF?

- DEF – Diesel Exhaust Fluid
  - Reducing Agent for Nox in Urea SCR
  - Defined by USCar for North America
  - ISO Standard / API certified (ISO22241)
  - 32.5% Urea dissolved in deionized water.
  - Common fluid between all vehicles – Mercedes, BMW, Audi, Ford, GM and Dodge as well as HD truck engines (semi's).
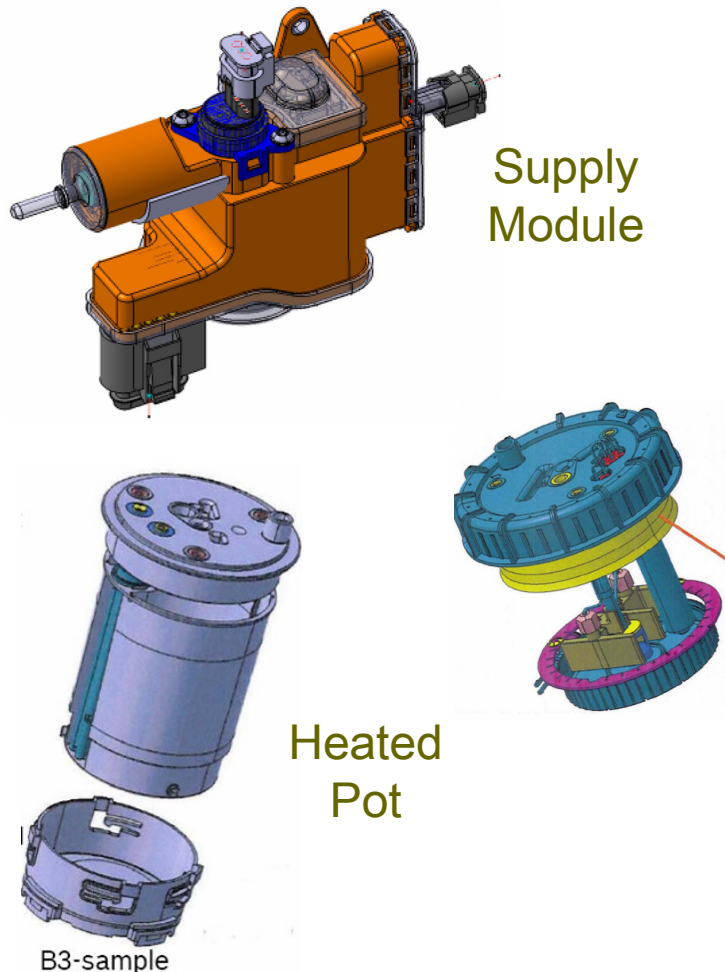 - Also known as AdBlue (trademarked) in Europe

Bosch DeNOx PC-LD
Liquid "DEF" Injection System

5 Gallon Urea Tank with pump installed

Bosch DeNOx PC-LD - Pump

Supply
Module

Heated
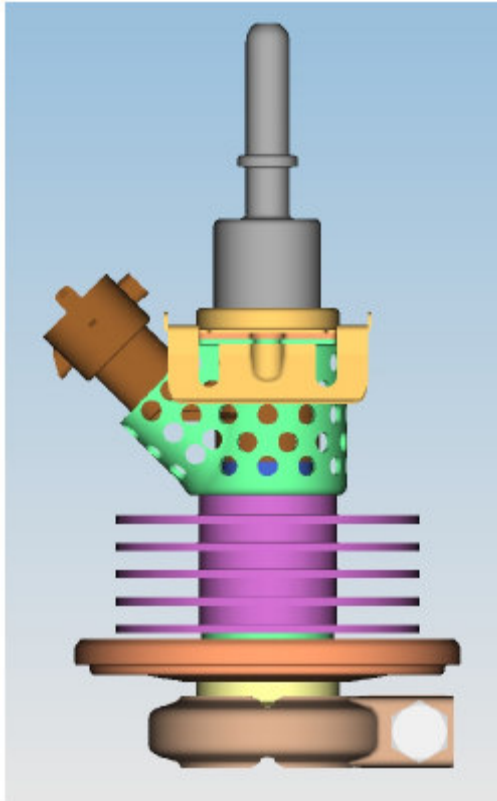Pot

B3-sample

- **Supply Module contains:**
  - Pump (72 psi closed loop control)
  - Pressure sensor
  - Reverting Valve (4-2way)
  - DEF Filter
  - Heater

- **Heated Pot**
  - Tank inlet filter–Pickup Tube
  - Tank Heater
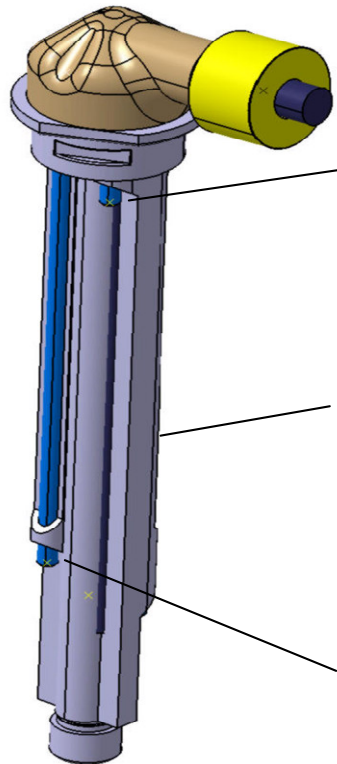 - 3 Height Level Sensor
  - Temperature Sensor

Bosch DeNOx PC-LD - Injector

□ Dosing Module

- Compatible with Urea
- Must be capable of withstanding exhaust gas temps during regeneration
- Must keep urea from boiling (active and passive cooling)

Bosch DeNOx PC-LD – Level Sensor
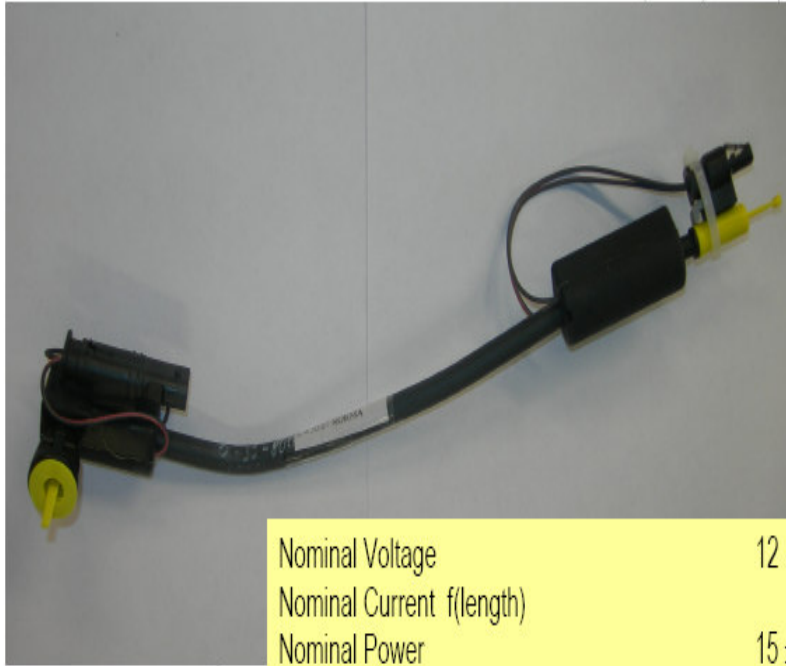
Location of "Pins" based on tank volume

½ tank

~ 1 gallon

~ 1 quart

- Measurement principle based on conductivity of Urea across the electrodes
- electrodes 1-3:
  insulation of electrode to be removed at desired level sensing position

- electrode 4:
  insulation is removed

Bosch DeNOx PC-LD - Line

Nominal Voltage	12	VDC
Nominal Current f(length)		ADC
Nominal Power	15 ± 15%	W/m DC
Operating Voltage	9 to 16	VDC
Operating Current at –40°C and 16V f(length)		ADC
Start Current f(length)		ADC
Testing Voltage	14 ± 0,2	VDC

Heated Hydraulic Supply Line

- Connects Pump Outlet to Urea Dosing Module
- Keeps urea liquid at cold ambient temperatures (below -11C)
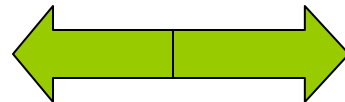
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Hardware Connections for P473

- Engine Control Unit
  - Low Power drivers
    - DEF Injector
    - DEF Pump Control
    - Reverting Valve
  - Pressure Transducer
  - Diagnostics
    - Functional
    - Rationality

- Glow Plug Control Module
  - High Current Drivers
    - Pump Heater
    - Line Heater
    - Tank Heater
    - High Side Power Relay
  - Diagnostics
    - Open Load
    - Short Circuit detection
    - Over current protection

High Speed CAN Communication

Functional Description (System Fill)

Fill and Run

- System starts from "Empty"
- Pump runs with injector open to fill system with liquid
- Injector closes and system builds pressure.
- 5000 HPa is target pressure – ready for injection (72 psi)

When:

- Ignition is on
- Engine is running
- Exhaust at SCR catalyst is >90 C

Functional Description (Fill and Purge)

Emptying
- Starts "Full"
- Drops pressure
- Triggers Reverting Valve (reverses flow)
- Opens Injector
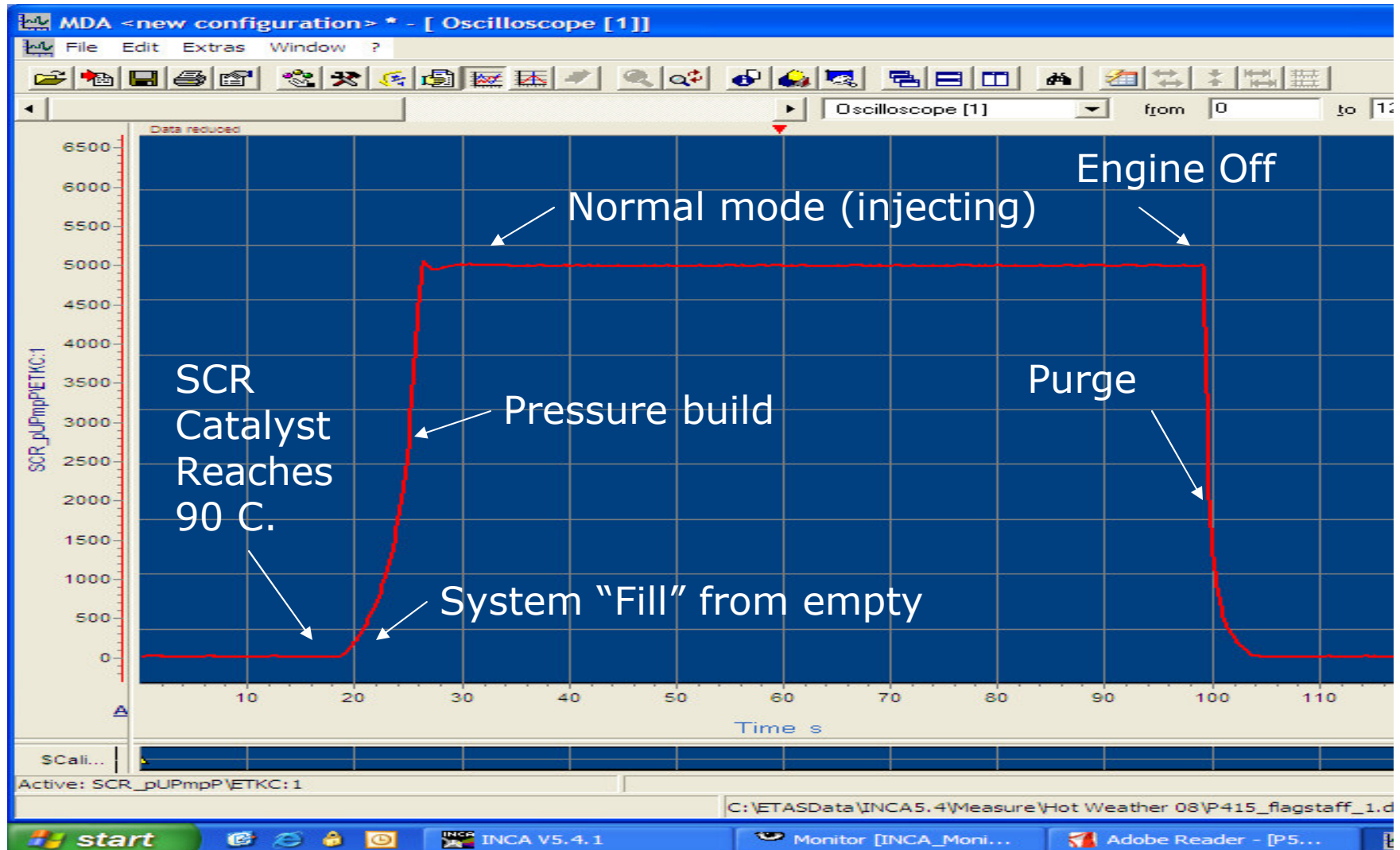- Runs pump until all DEF has returned to tank unit
- ECU shuts down

When:
- Key is Off
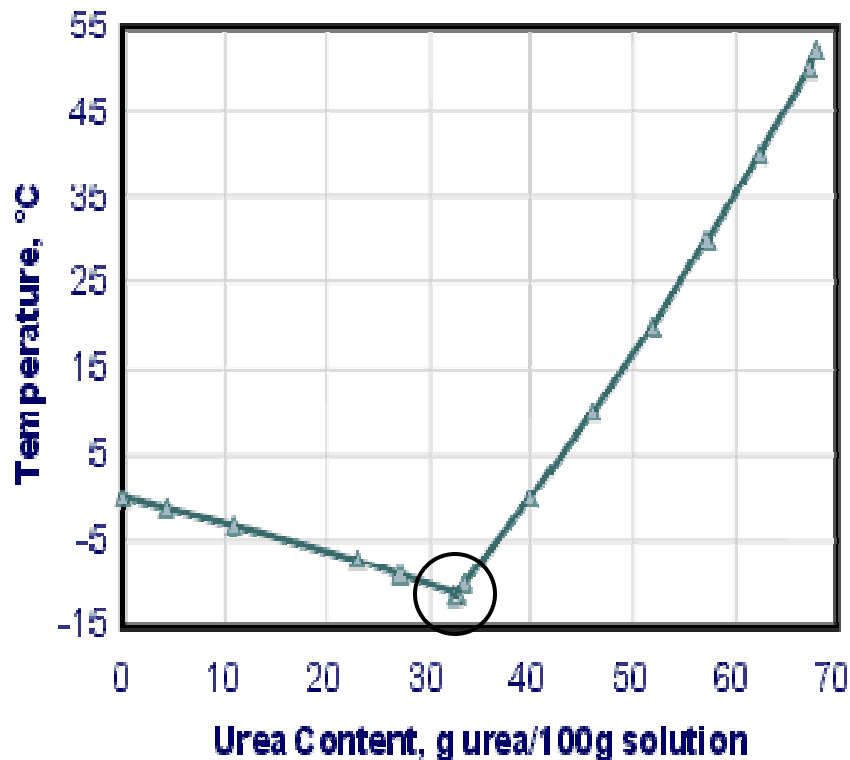- Engine not running
- Delay time expired

How long:
- ~25 seconds total

Functional Description (Pressure Trace)

Urea Freeze - Thaw

- 32.5% Urea freezes at -11 C (13 F)
- Government requirements:
  - Mandate injection to -30C
  - Must deliver urea to the exhaust in less than 30 minutes after start

DEF Freeze - Thaw

Tank contains:

- 100 watt PTC heater
  - Self regulating
  - Internal resistance increases as temperature goes up
  - Maximum of 12 amps

- Heated suction tube

Injected urea quantity must be limited to thawing capability of system. Liquid is required to transfer heat to surrounding "ice" for melting.

Exhaust Hardware – Urea Mixing

DEF

1mm

Diesel Exhaust Gas

Uniform NH$_3$
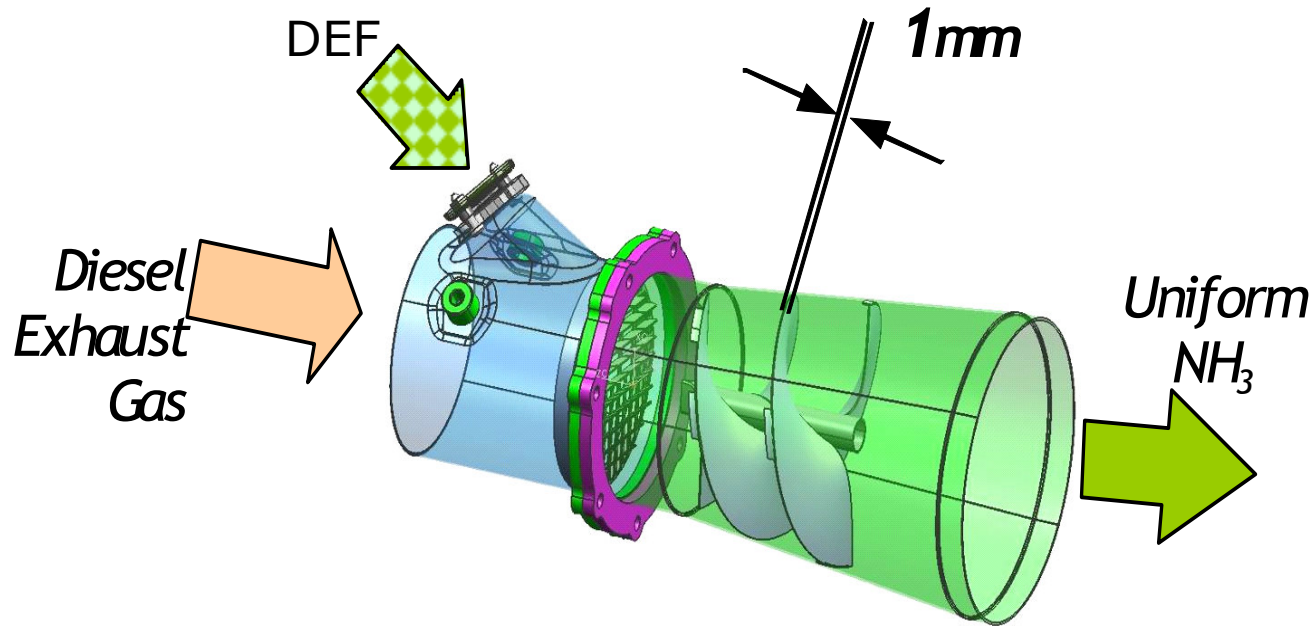
□ Exhaust contains 2 part mixing system

- Atomizer to break up and vaporize droplets
- Twist mixer (fixed, does not rotate) to evenly distribute
- At Peak Engine Power only 19 ms from injector to catalyst face

Diagnostics

- Full OBDII requirements
  - CCM, Functional and Rationality checks for all sensors and actuators

- Done in multiple modules and reported to ECU via CAN

Diagnostics

- CCM
  - Open circuit, short circuit to ground and short circuit to battery for:
    - DEF Pressure sensor
    - DEF Pump
    - Reverting Valve Solenoid
    - Injector (high side and low side drivers)
    - Heaters and relay
    - Tank temperature sensor
    - Tank level sensor

Diagnostics

- Functional / Rational Tests:
  - DEF Pressure sensor
    - Comparison to ambient pressure with motor off
  - DEF Pump
    - Compare to expected DC vs. injection rate
  - Reverting Valve Solenoid
    - Monitors pressure drop when triggered
  - Injector
    - Monitors voltage signal to ensure true opening/closing
  - Heaters and relay
    - Monitors tank temperature rise rate versus time
  - Tank temperature sensor
    - Comparison to ambient temperature
  - Tank level sensor
    - Comparison of "pins" (top pin covered / bottom pin not)

System Diagnostics

- Functional Testing:
  - System must build pressure
  - System must maintain pressure
    - Over pressure errors
    - Under pressure errors
- Fault Detection:
  - 1st – 30% torque derate
  - 2nd – MIL + 30% torque derate
  - Required to "compel" repair or against tampering

SCR Off Board Diagnostics

□ Service Routines Available:

- ■ <u>SCR System Emptying:</u> Used to depressurize the SCR system and empty the DEF from the SCR system hydraulic lines. Also may be requested by other SCR tests in order put the system into a known default state.

- ■ <u>SCR System Refill Activation:</u> Used to force a quick refill detection strategy if necessary after the DEF tank has been refilled during service.

- ■ <u>SCR Parameter Reset:</u> Used to reset the onboard SCR system related data typically following an SCR catalyst replacement.

- ■ <u>SCR Visual Leak Check:</u> Used to prepare and pressurizes the SCR system so that a visual leak check can be performed.

- ■ <u>SCR Dosing Measurement Test:</u> Used to verify the quantity and flow of DEF from the injector and allows for a visual quality inspection of the fluid.

DEF Storage and Filling

- Customer Interface and Interactions

DEF Tank Size / Consumption

- Size tanks for around Oil change interval of "average" customer vehicle unloaded
- Average consumption of 800 to 1400 miles per gallon of DEF
- Consumption rate can vary greatly with driving style and vehicle loading
- Approximate rate of 1-1.5% of fuel consumed.

  (100 gallons of fuel = 1 gallon of DEF)

Urea Tank Fill – Customer Interface

- ❑ Urea Fill Cap
  - ■ USCAR – US Industry Standard Design
  - ■ Attempts to prevent fills with wrong fluid
  - ■ 19mm vs 21 for gasoline and 23 for diesel
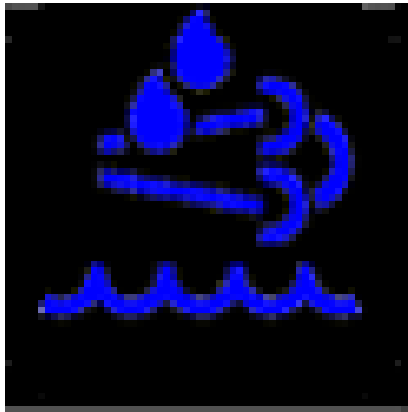
Urea Tank Fill

- **Urea Fill Options**
  - 1, 2 or 2.5 gallon bottles (boxes)
  - 55 to 265 gallon barrels with pumps

Available at:
  - Dealers
  - Fuel Stations
  - Truck stops
  - Oil Change Garages
  - Parts stores
  - http://mercator.nrel.gov/vibe-def/

Low DEF Warning System

Symbol for DEF

- Government requirement to inform and **compel** the driver to refill the DEF tank.
- Inducement of forced idle is preceded by two steps of vehicle speed limiting and a vehicle refueling event.
  - Allows limited mobility to customers in "extreme" cold or "extreme" hot.
  - Also used for fluids detected other than Urea in tank

Ford Low DEF Warning
Customer Interface - Notifications

Miles		Message 1		Message 2		Actions
8500		Exhaust Fluid Level OK	or	Exhaust Fluid Under Half Full		Appears on System Check
1000		Exhaust Fluid Range: 800 miles	🔴	Press Reset or Info Button		Appears on Threshold, Key Cycle Or System Check
500		Exhaust Fluid Range: 300 miles	🔴			Appears on Threshold, Key Cycle Or System Check + DEF Symbol
299		Speed Limited 55 MPH in 99 miles	🔴	Exhaust Fluid Low	🔴	Above + mileage countdown and 1 Chime
200		55 MPH Max Upon Restart	🔴	Exhaust Fluid Empty	🔴	Above + Flashing DEF Symbol
restart		Speed Limited To 55 MPH	🔴	Exhaust Fluid Empty	🔴	Above + repeating Chime Speed Limited 55 MPH
0		50 MPH Max Upon Restart	🔴	Exhaust Fluid Empty	🔴	Same
restart		Speed Limited To 50 MPH	🔴	Exhaust Fluid Empty	🔴	Above + Speed limited 50 MPH
-100		Engine Idled Upon Refuel	🔴	Exhaust Fluid Empty	🔴	Same
Diesel Tank Fill		Engine Idled See Manual	🔴	X Overrides Available	🔴	Above + Engine Idled

Cluster Messages 1

Cluster Messages 2

Cluster Messages 3