The Exhaust Emissions Scandal ("Dieselgate")

take a deep breath into pollution trickery

Felix Domke (tmbinc)

Daniel Lange (DLange)

Who are we?

- Felix Domke
- tmbinc@elitedvb.net
- “Independent Security Researcher”, aka. “I was curious”.
- Self-funded, non-commercial research.

- Daniel Lange
- DLange@faster-it.de
- Head of IT strategy, IT Innovation, Chief architect for process chain electrics / electronics at BMW.
- Now runs his own company, Faster IT GmbH.

None of the ideas expressed in this presentation are shared, supported or endorsed in any manner by Felix' employer. Daniel is his own boss, his life is easier.


JCDecaux
We're sorry that we got caught.
Now that we've been caught, we're trying to make you think we care about the environment. But we're not the only ones. #redlines #D12 #ClimateGames
Das Auto.
Brandalism

Challenges

- Saturated market in the developed countries
- Growth only in BRIC
- Overcapacity / Segment explosion (niches)
- Social shifts ("freedom", status symbol)
- Urbanization ("Megacities")
- Technological shifts (electric mobility, self-driving cars, downsizing)

Strategy

- Reach a target ROCE
- Outperform the competition

11 million

11 million
VW group cars affected world-wide

1500

1500
hard disks and USB sticks collected
from 380 associates at VW

6.7 billion

6.7 billion €
reserve for recall / legal cost

”

- Individuelles Fehlverhalten und persönliche Versäumnisse einzelner Mitarbeiter
- Schwachstellen in einigen Prozessen
- Haltung in einigen Teilbereichen des Unternehmens, Regelverstöße zu tolerieren

“

“

- Individual misbehavior and personal neglect of particular associates.
- Weaknesses in particular processes
- Attitude in particular sub-partitions of the company to tolerate rule violations

”

Hans Dieter Pötsch, President of the VW supervisory board

https://www.volkswagen-media-services.com/detailpage/-/detail/.../view/2973811

Jones Day
& Deloitte

„Wir haben keine Erkenntnisse über die Involvierung von Aufsichtsrat oder Vorstand vorliegen.“

“We have no findings on the involvement of the supervisory board or the board of management presented.”

Hans Dieter Pötsch, President of the VW supervisory board

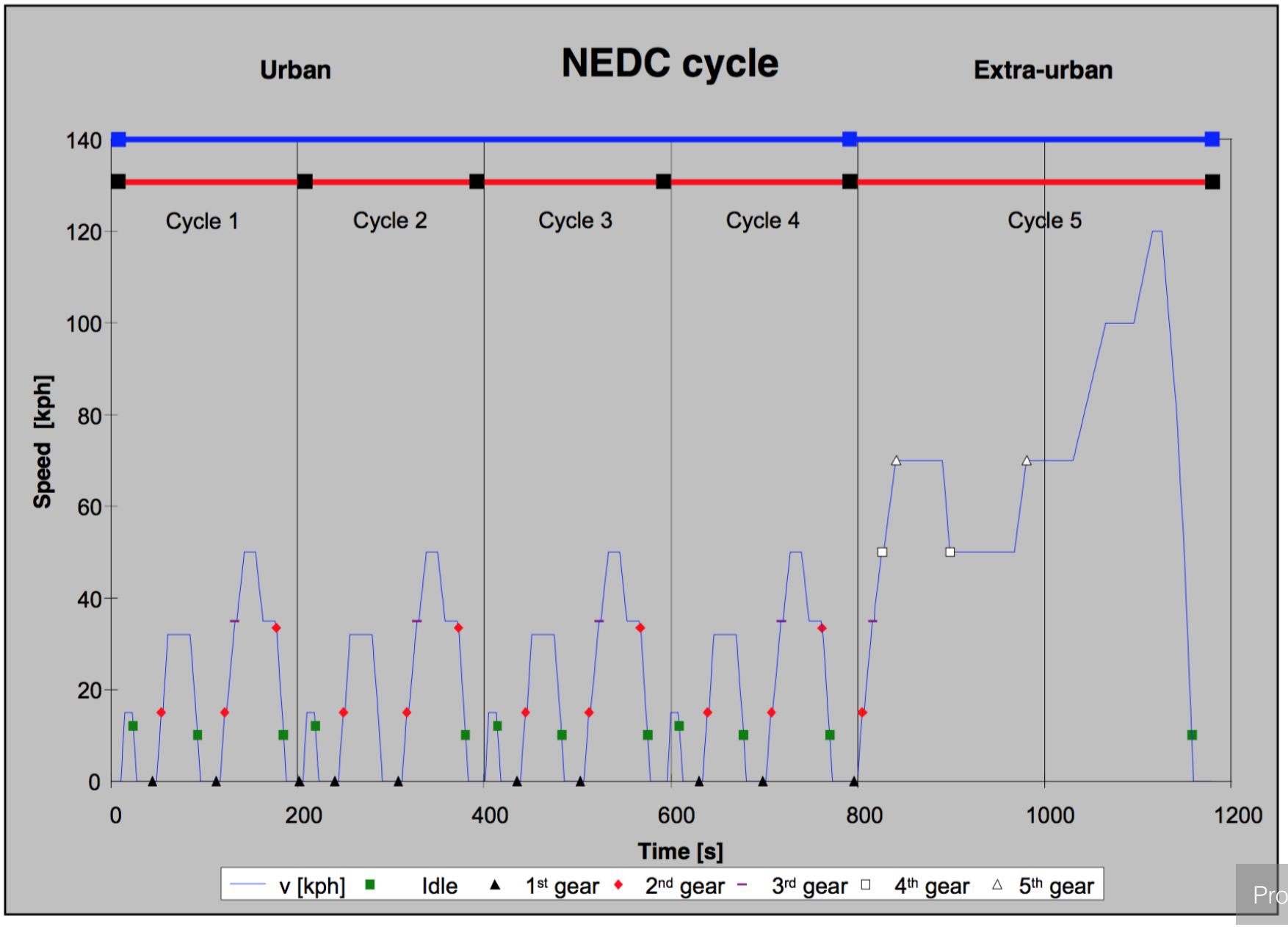
http://www.spiegel.de/wirtschaft/unternehmen/volkswagen-kuendigt-neuausrichtung-und-kulturwandel-an-a-1067111.html

10

10 jet planes

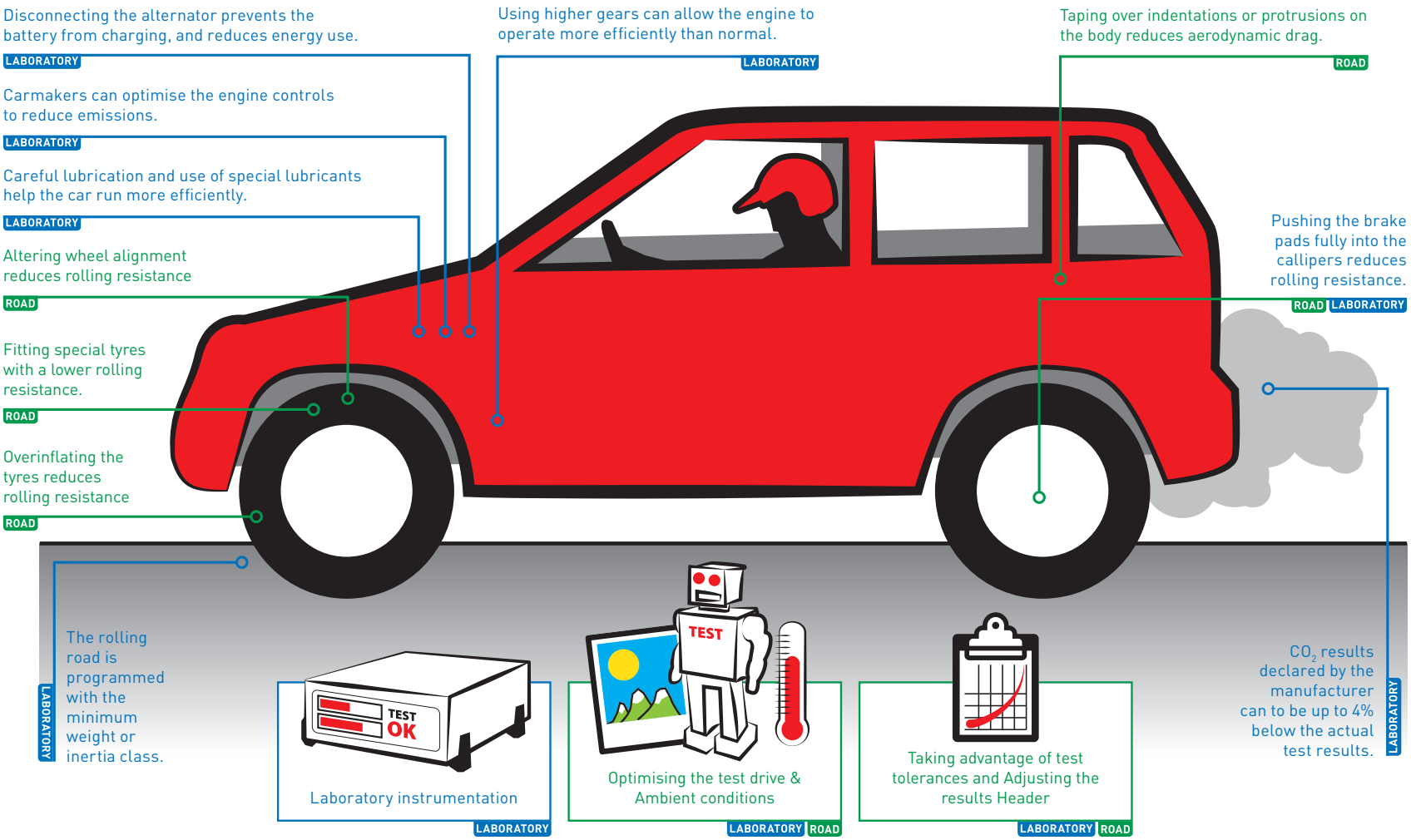
Lion Air Services

George Town, Cayman Islands



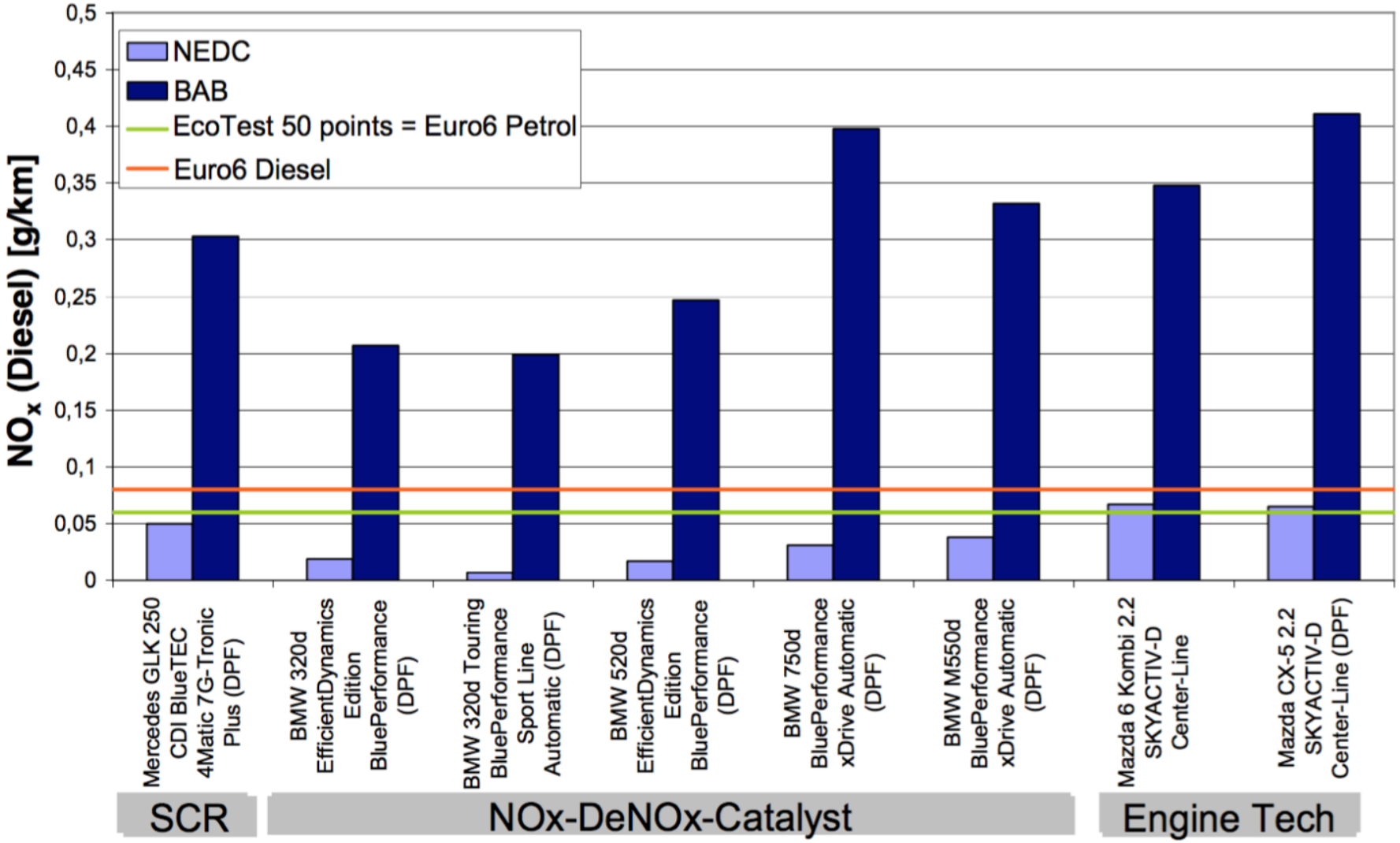
Prof. Kolke, ADAC

Common ways carmakers manipulate tests for CO_2 emissions and fuel economy



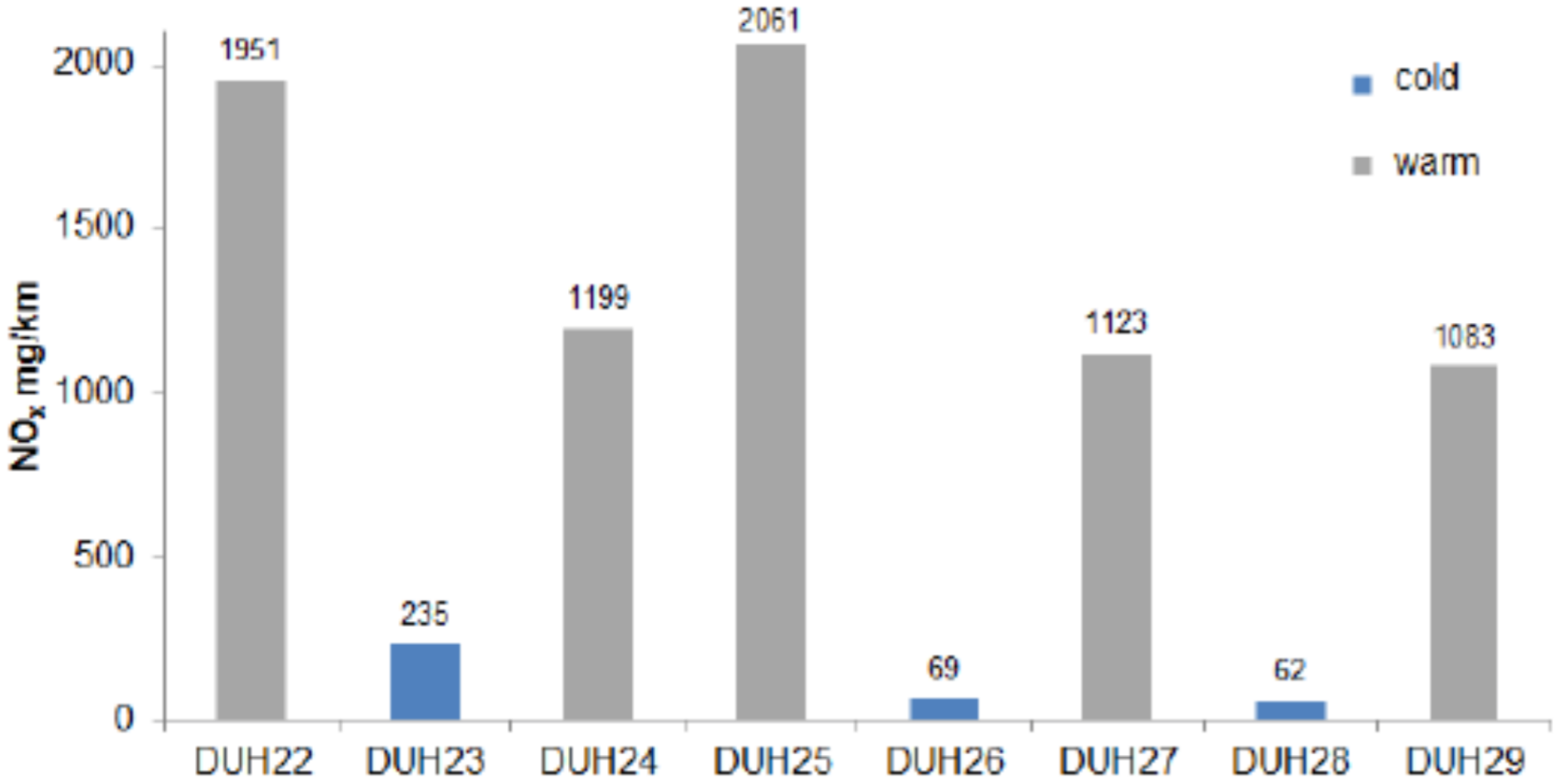
Transport & Environment, Mind the Gap report

NO_x emissions in EcoTest: Performance of various exhaust after-treatment systems

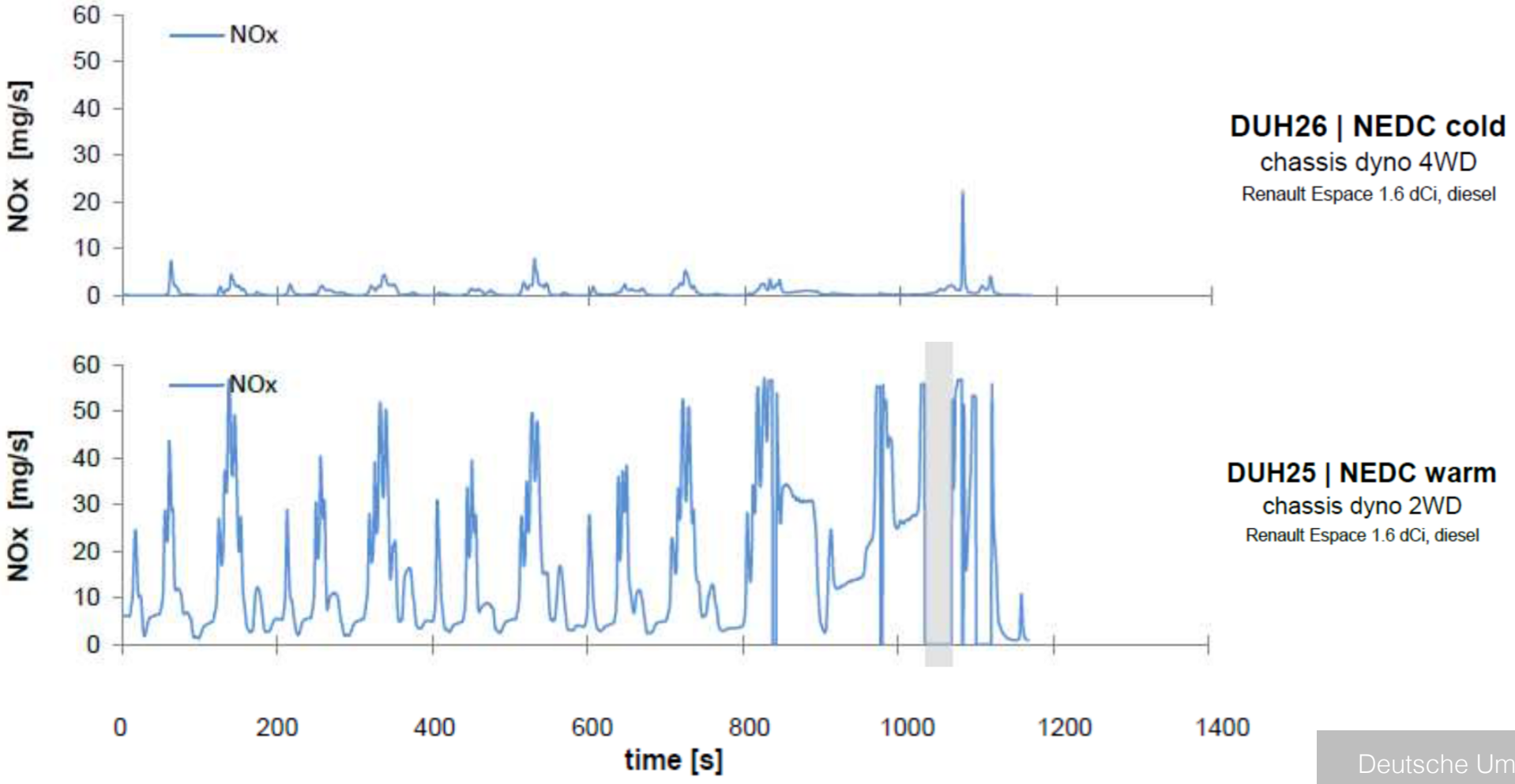



Deutsche Umwelthilfe

NO_x-Ergebnisse im NEFZ



Vergleich zweier NO_x-Messungen



DUH26 | NEDC cold
chassis dyno 4WD
Renault Espace 1.6 dCi, diesel

DUH25 | NEDC warm
chassis dyno 2WD
Renault Espace 1.6 dCi, diesel


California
Prop 65
Warning:
The following products contain chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm: belts, shoes, jewelry, handbags, all products with metal, plastic, zippers, vinyl, and buttons.

Statistics

- 59 (95% CI: 10 to 150) early deaths in the US
- social cost of ~$450m 2009–2015
- recall by the end of 2016 will prevent:
  - ~130 early deaths
  - ~$840m in social costs

Steven R H Barrett et al: Impact of the Volkswagen emissions control defeat device on US public health; Environmental Research Letters, Vol 10, No 11

8. November 2015, 17:57 Uhr Abgas-Skandal

VW-Ingenieure manipulierten aus Angst vor Winterkorn

Der frühere VW-Chef Martin Winterkorn auf der Automesse IAA: Er wollte die [illegible] (Foto: AFP)

VW-Engineers manipulate in fear of Winterkorn

15,9 million

15,9 million €
Annual salary for Martin Winterkorn

Only for VW (Porsche etc. extra)
Also to be paid in FY 2016.
He negotiated well.

18. Dezember 2015, 06:00 Uhr VW-Abgasskandal

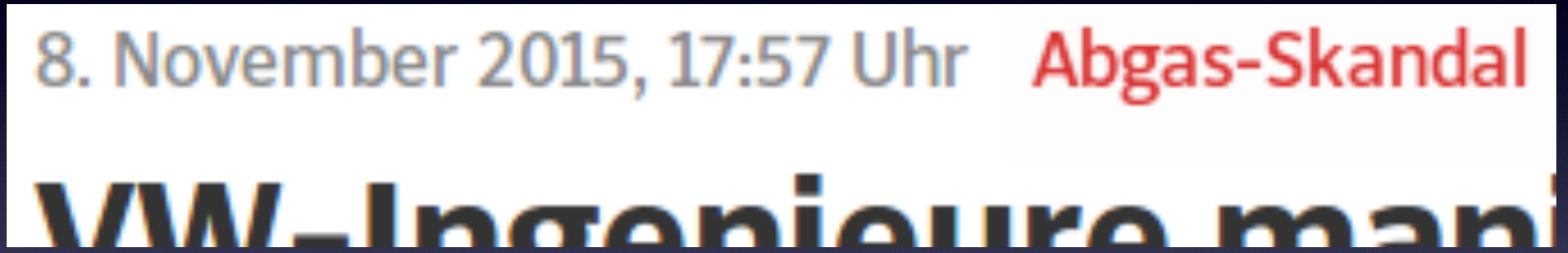
Winterkorn bezieht offenbar weiter ein Millionengehalt

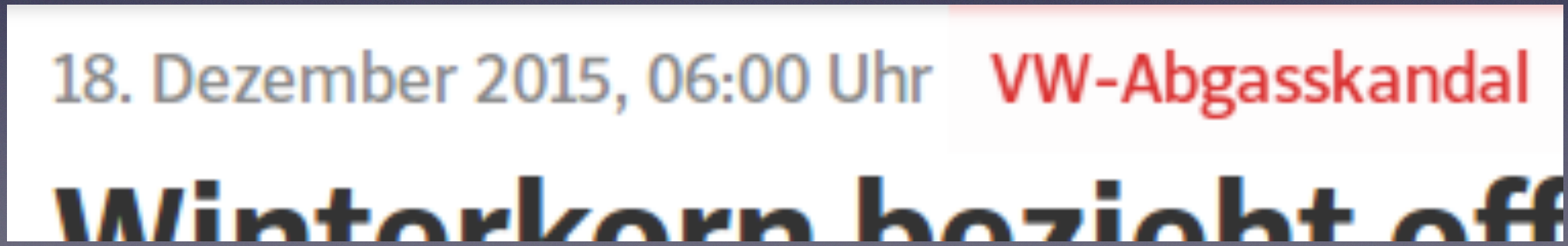
Der damalige VW-Vorstandschef Martin Winterkorn bei der Jahrespressekonferenz 2013 des Konzerns in Wolfsburg (Foto: dpa)

Winterkorn ~~apparently~~ continues to receive millions in salary


„ ‚Dieselgate‘ heißt es immer so schön.
Ich bin der Meinung, man sollte
es ‚VW-Gate‘ nennen.“
“ ‘Dieselgate’ it's called nicely.
I think it should be called
‘VW-Gate’.”
Hildegard Wortmann, SVP product management
http://www.handelsblatt.com/unternehmen/industrie/bmw-managerin-...-ich-finde-es-sollte-vw-gate-heissen/12630786-all.html

SZ - The Court Circular





MOTORRAD 14/2000

BMW F 650 GS with injection and
computer-controlled catalytic converter.

Test cycle ECE 40: lowest emissions of the test.

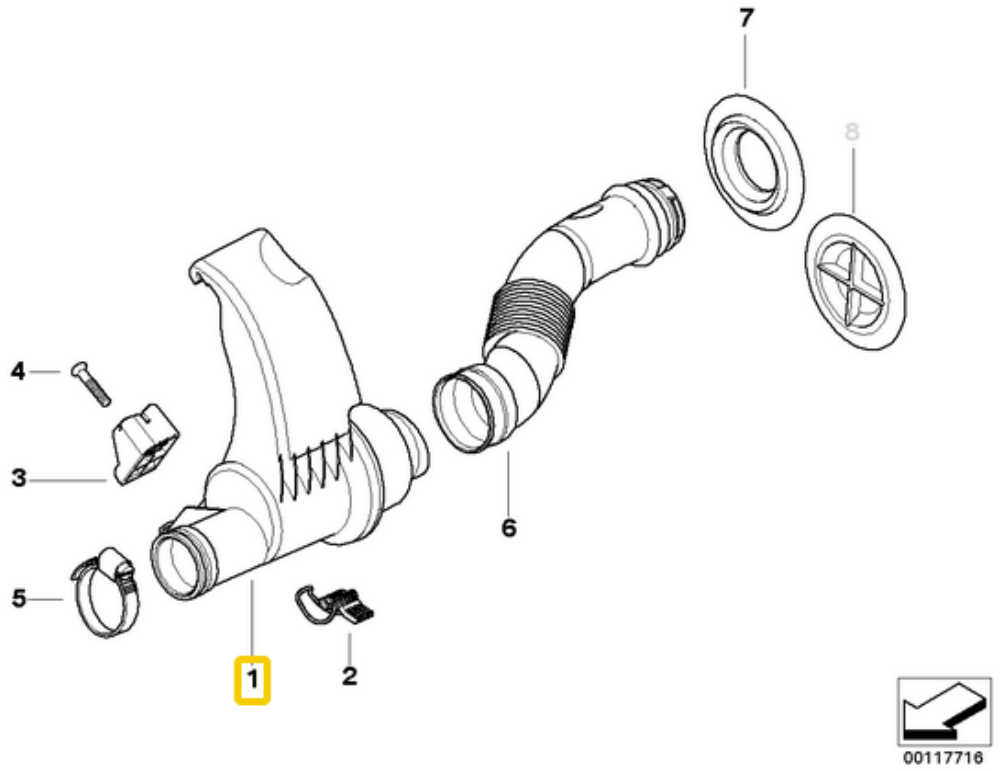
Warm start: every motorbike produces the same result, but the BMW.
It has the 34-fold carbon monoxide emissions against test bench results.

BMW detects the test cycle and switches to a different parameter set.

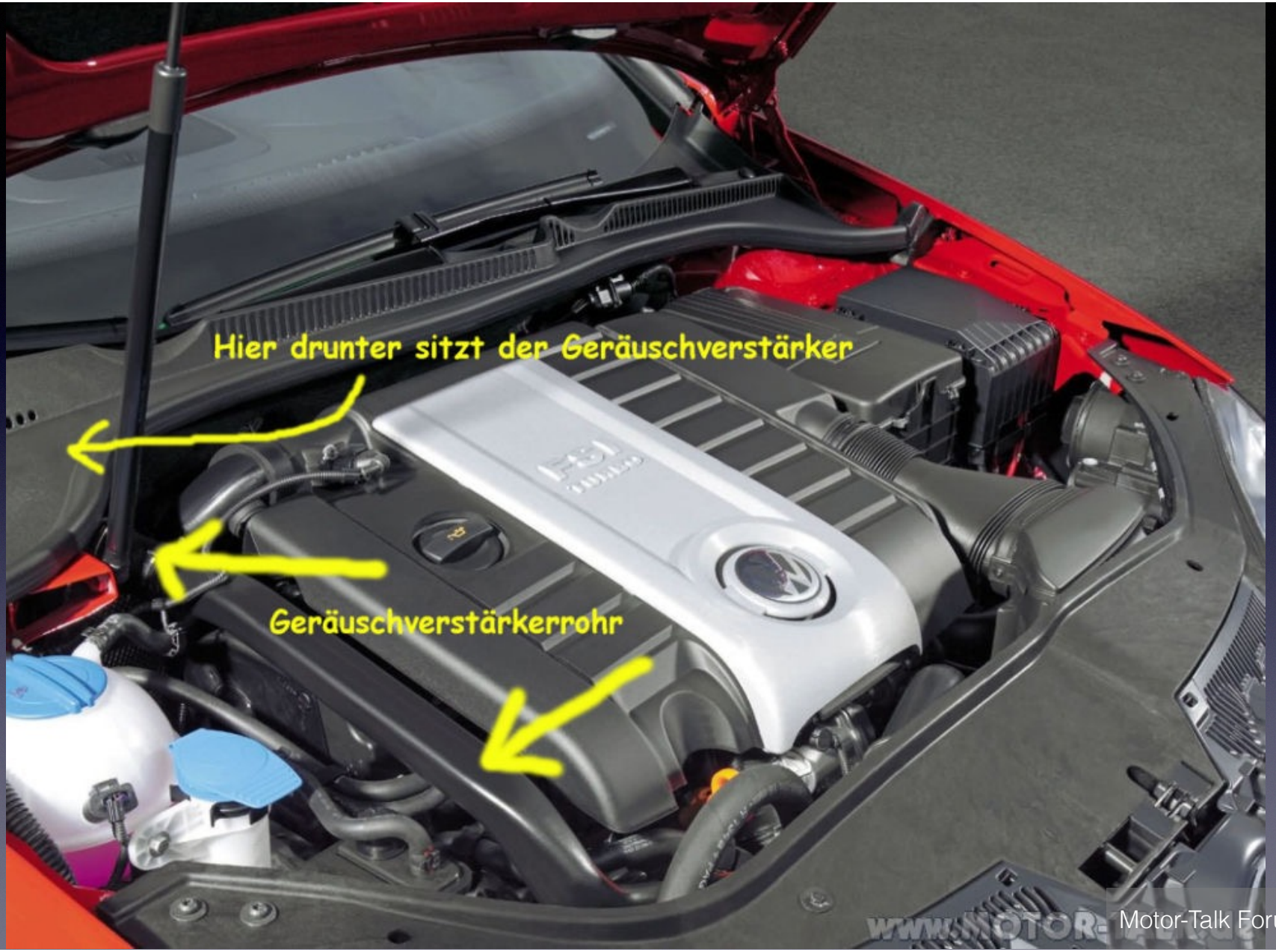
BMW argument: Testing has not much to do with real-life use. Also the engine runs more agile with the other parameter set.

http://www.motorradonline.de/vergleichstest/technik-abgasreinigung/105838

Z4 E85 Z4 3.0i Soundgenerator



Nr.	Beschreibung	Erläuterungen	Anzahl	Von	Bis	Teilenummer	Preis	Ergänzungen
01	Soundgenerator		1			13747514863	$98.95	
02	Spannbügel		1			13719071752	$2.07	
03	Lagerbock		1			13747518282	$2.54	
04	Schraube	K60X22	1			11617533331	$0.75	
05	Schlauchschelle	L=47-54MM	1			07129952121	$1.42	
06	Soundleitung		1			13747514864	$34.39	
07	Dichttülle		1			13717514865	$4.82	



Motor-Talk Forum, User:golfunited

Cartec 99231 AdBlue Hochreiner Harnstoff zur Abgasnachbehandlung, mit Einfüllhilfe, 10 L: Amazon.de: Auto - Iceweasel

Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe

Cartec 99231 AdBlue...

www.amazon.de/gp/product/B00SWLLS6Y?ref_=gb1h_tit_c-4_1467_d87794fb&smid=A3JWKAKR8XB7XF

Suchen

amazon.de Prime testen

Auto & Motorrad

Anzeige

Alle Kategorien | Mein Amazon | Angebote | Gutscheine | Verkaufen | Hilfe | In English - Beta NEW!

Hallo! Anmelden Mein Konto | Testen Sie Prime | 0 Einkaufswagen | Wunschzettel

Auto | Reifen & Felgen | Werkzeug & Wartung | Navigation | Tuning | Pflege | Wohnmobil & Transport | Bestseller | Sonderangebote | Motorrad

Nach Fahrzeug einkaufen: Marke | Modell | Fahrzeugtyp | Motorisierung | Los oder Schlüsselnummern (HSN/TSN) eingeben

Marke und Modell auswählen

Meine Fahrzeuge (0)

Auto & Motorrad › Öle & Betriebsstoffe › Betriebsstoffe & Fette

Für größere Ansicht Maus über das Bild ziehen

Cartec 99231 AdBlue Hochreiner Harnstoff zur Abgasnachbehandlung, mit Einfüllhilfe, 10 L

von Cartec

10 Kundenrezensionen

Preis: EUR 18,15 (EUR 1,82 / l)

Angebotspreis: EUR 13,66 (EUR 1,37 / l) Kostenlose Lieferung ab **EUR 29** (Bücher immer versandkostenfrei). Details

Sie sparen: EUR 4,49 (25%)

Alle Preisangaben inkl. MwSt.

10% reserviert

Lieferung morgen, 18-21 Uhr: Bestellen Sie innerhalb **17 Stunden und 30 Minuten** per **Evening-Express**. Siehe Details.

Verkauf und Versand durch Amazon. Geschenkverpackung verfügbar.

1 gebraucht ab EUR 16,34

Größe: **10 L**

1 L	10 L
EUR 7,32 (EUR 7,32 / l)	EUR 13,66 (EUR 1,37 / l)

- NOx-Reduktionsmittel gemäß AUS 32 (CEFIC) und DIN 70070-05, ISO 222 41-1.
- Hochreine Harnstofflösung für SCR Abgasnachbehandlung.
- Reduktionsmittel für Dieselmotoren mit SCR Technologie.
- Der Einsatz von AdBlue führt in geeigneten Dieselmotoren zur Einhaltung der Abgaswerte.
- Inkl. Einfüllhilfe.

Empfehlen

Blitzangebot-Preis
EUR 13,66 (Sie sparen 25%)

10% reserviert
Endet in 01h 25m 21s

Menge: 1

In den Einkaufswagen

Normalpreis
EUR 18,15

Andere Verkäufer auf Amazon

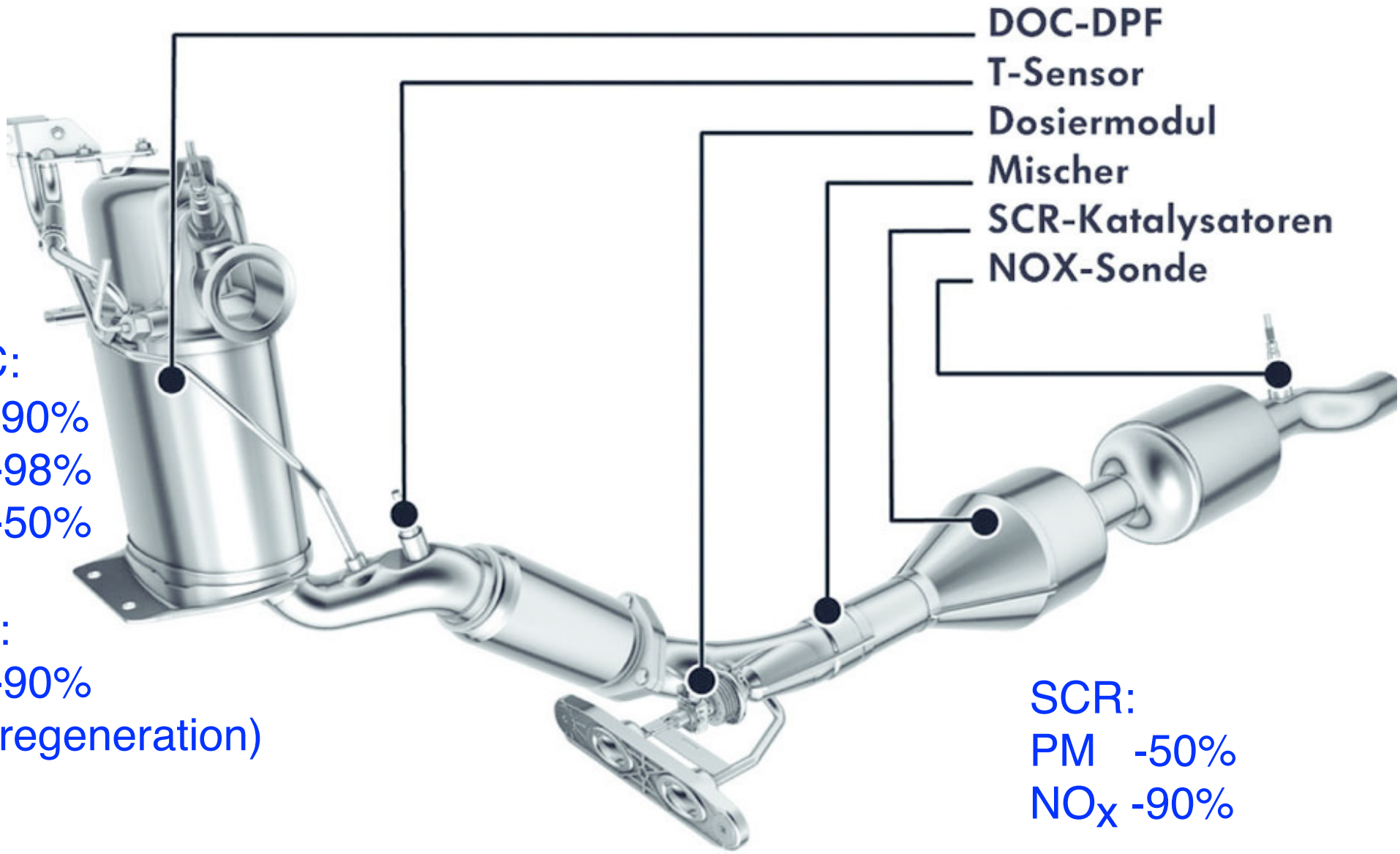
2 Angebote ab EUR 16,34

Möchten Sie verkaufen?

Bei Amazon verkaufen

Component development

- Lots of legal / industry frameworks
  (VDA yellow books, ISO, DIN, company norms, ...)
- Very structured process
- Every requirement documented in one tool
- Senior management review meetings biweekly .. monthly
- Every step is documented, often multiple times
- Q-Gates after every development phase
- Legal & purchasing involved with dedicated teams
- ~80% of the value created at suppliers (contracts)



DOC:
HC -90%
CO -98%
PM -50%

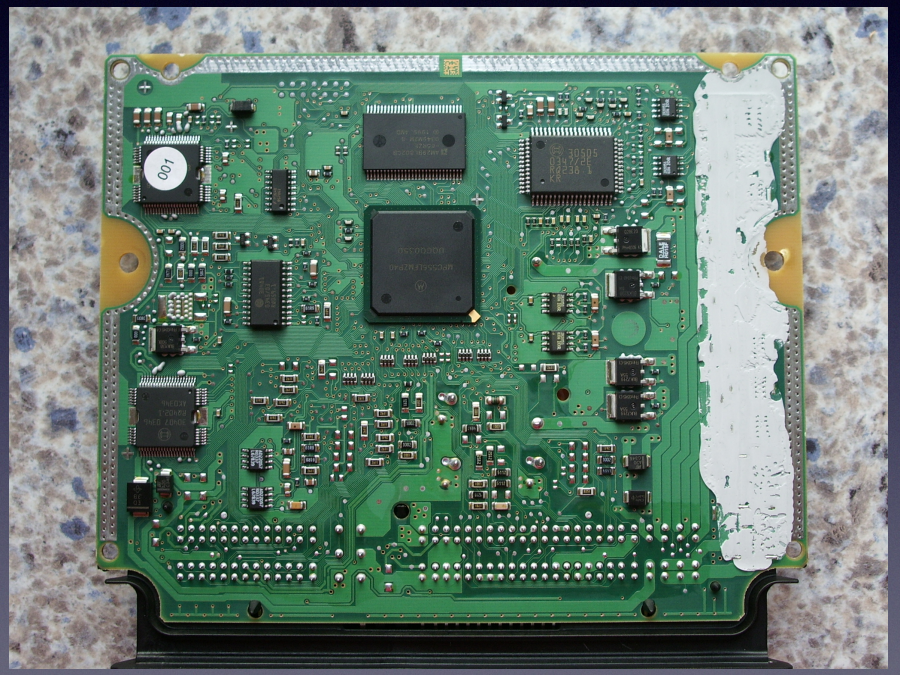
DPF:
PM -90%
(but regeneration)

SCR:
PM -50%
NO_X -90%

$$2\ NH_3 + NO + NO_2 \rightarrow 2\ N_2 + 3\ H_2O$$

Engine ECU

- Physical model of the engine
- Proprietary code by Bosch, configuration by OEM
- Typically up to 20.000 knobs to turn / tune / play with
- Extensive documentation
- Simulator, in-the-loop and in-the-car verification for 3+ years



Wikipedia, User:Techie

Google for info

bmw edc17c45 funktionsrahmen + hex & a2l — Threaded Mode | Linear Mode

10-26-2015, 06:26 AM — **Post: #1**

ludbe
Unknown Location
Member

Posts: 148
Joined: Jan 2014
Reputation: **28**
Thanks: 5
Given 58 thank(s) in 40 post(s)

bmw edc17c45 funktionsrahmen + hex & a2l

hi,

i am selling bmw edc17c45 funktionsrahmen + hex and a2l if someone interested PM me

FIND REPLY

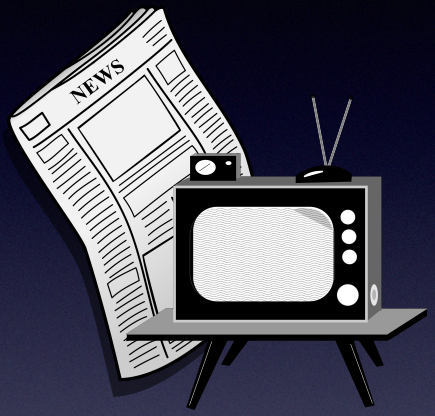
http://mhhauto.com/Thread-bmw-edc17c45-funktionsrahmen-hex-a2l

The Exhaust Emissions Scandal Part 2

A Reverse-Engineer's Look into Practical Emissions Cheating

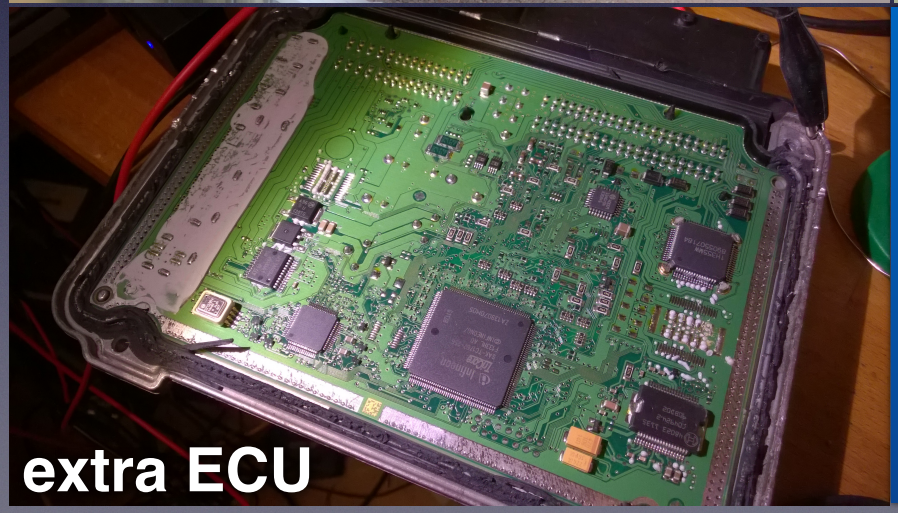
Motivation

Sources of Information



The truth is in the code!

What do we need?




```
/begin MEASUREMENT

    Exh_pMinStyPPFltDiff
    "Der gefilterte Wert des Differenzdrucks am Partikelfilter"
    SWORD
    Pres_hPa
    1
    100
    -32768.00
    32767.00


    FORMAT "%8.2"

    ECU_ADDRESS 0xD0000802

/end MEASUREMENT
```

A2L Files

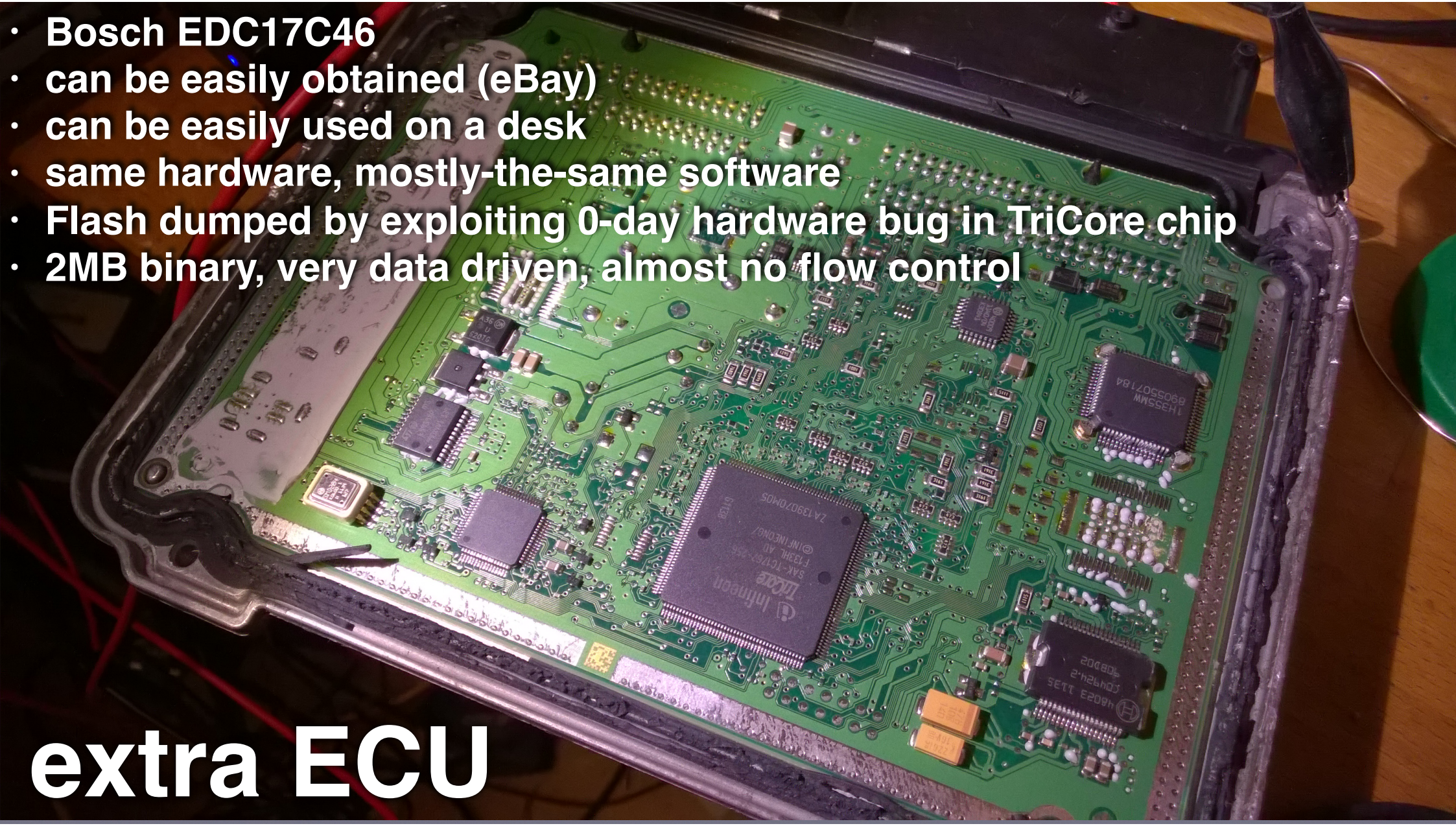
b/r: Bosch

affected VW

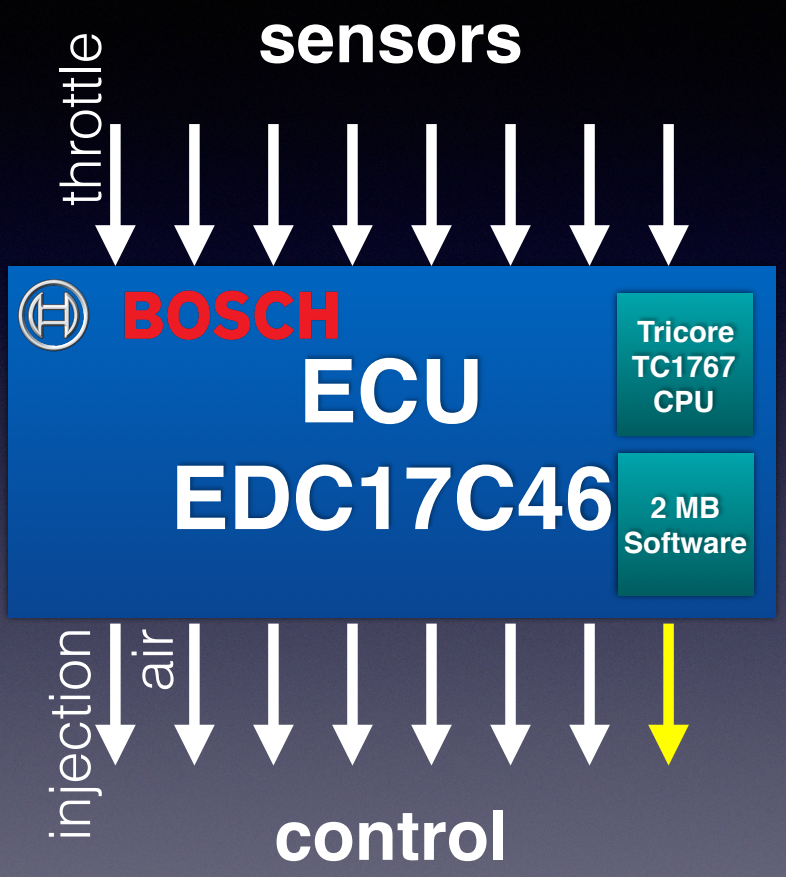
- Volkswagen Sharan (7N), MY 2013
- VIN: WVWZZZ7NZDV00xxxx
- TDI 2.0 EA189 engine, CFFB, AWD
- affected by VW recall according to online tool

*The car has an “abt Engine Control” chip tuning applied. This *should* not have any effect on exhaust after treatment.


Dyno


· Bosch EDC17C46
· can be easily obtained (eBay)
· can be easily used on a desk
· same hardware, mostly-the-same software
· Flash dumped by exploiting 0-day hardware bug in TriCore chip
· 2MB binary, very data driven, almost no flow control
extra ECU

What is an ECU?



Engine Electronic Control Unit (Engine ECU)
Engine Control Module (ECM)
Powertrain Control Module (PCM)

controls

- air/fuel ratio
- ignition timing (gasoline)
- idle speed
- valve timing
- thermal limits
- lambda control
- …
- **emission control**

Realtime Logging

- Via Diagnostic Services (CAN subset of OBD-II), we can use UDS (Unified Diagnostic Services)
- Usually we can only read pre-determined variables (“Read By Id”), however we can also switch into a “Development Session” and do “Read By Address”.
- Memory range we can read from is limited, but we can read all interesting data (security-related data is locked out.)

A2L Files

```
/begin MEASUREMENT

  Exh_pMinStyPPFltDiff
  "Der gefilterte Wert des Differenzdrucks am Partikelfilter"
  SWORD
  Pres_hPa
  1
  100
  -32768.00
  32767.00

  FORMAT "%8.2"

  ECU_ADDRESS 0xD0000802

/end MEASUREMENT
```

symbol name

size

description

unit

min/max

address!

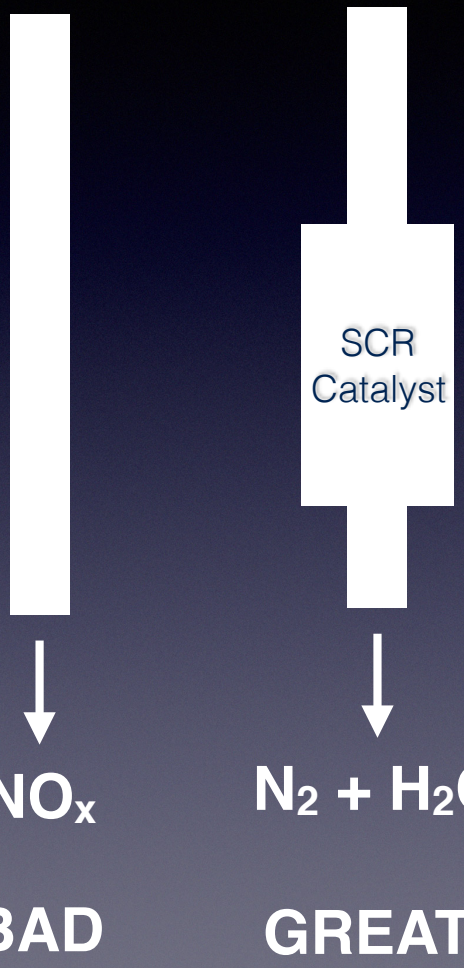
ECU Complexity

= f(RPM)?

= f(RPM, 20+ Signals)?

= f(RPM, 20+ Signals, 12 KByte Code with internal state)!

Selective Catalytic Reduction



AdBlue

correct dosage
is hard :(

NO_x

BAD

$N_2 + H_2O$

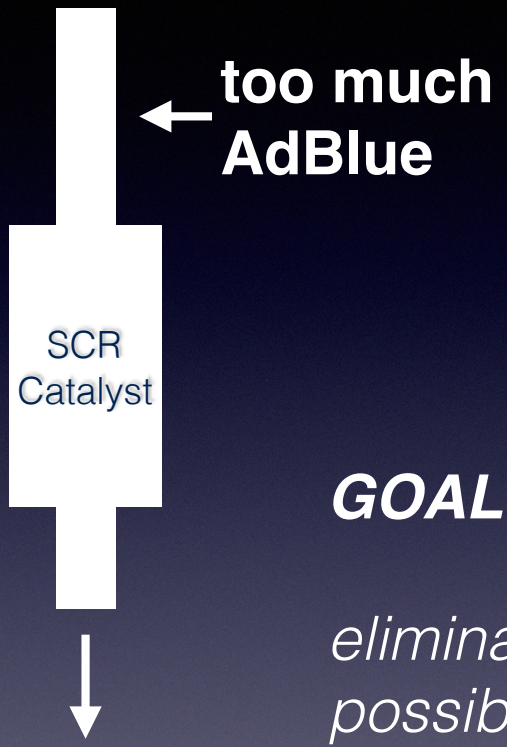
GREAT!

+ a lot of other stuff

Selective Catalytic Reduction

$N_2 + H_2O$
$+$ some NO_x

Okay…



$N_2 + H_2O$
$+ NH_3$

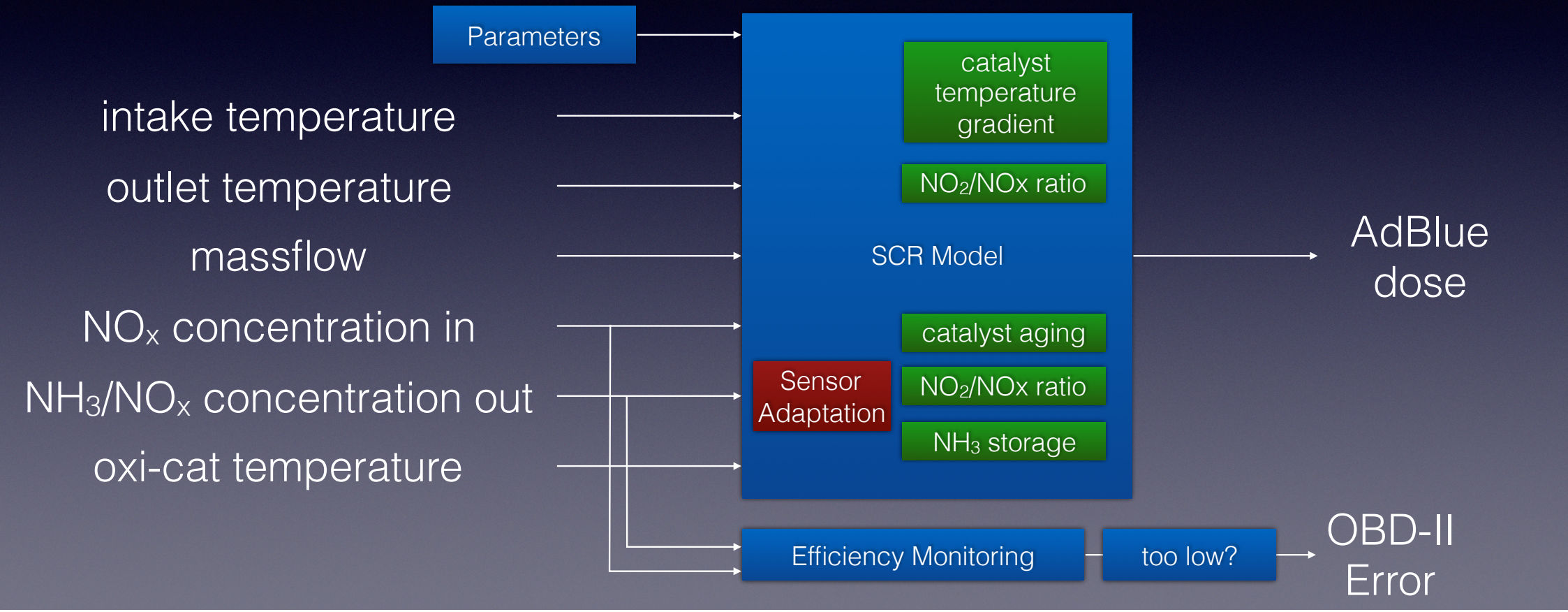
really not good!

GOAL:

eliminate as much as possible NO_x while minimizing NH_3 slip

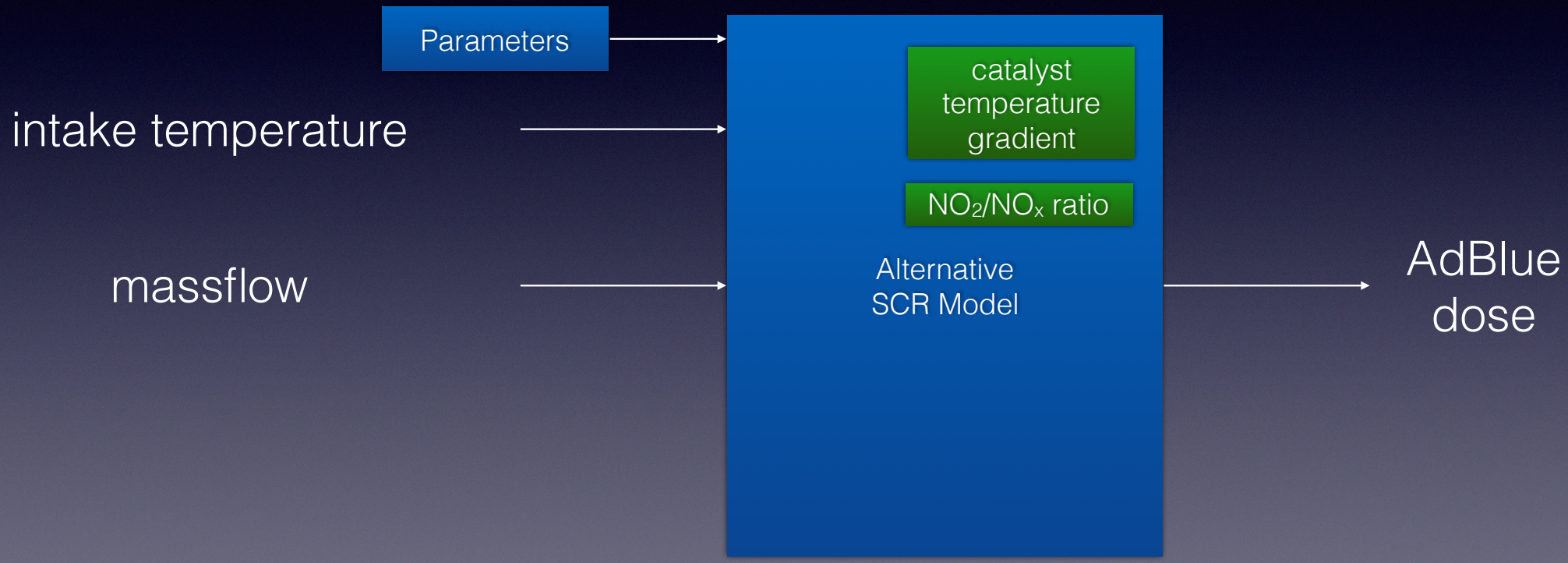
Main SCR Model

Primary Goal: Reduce NO_x (while minimizing NH_3 slip)

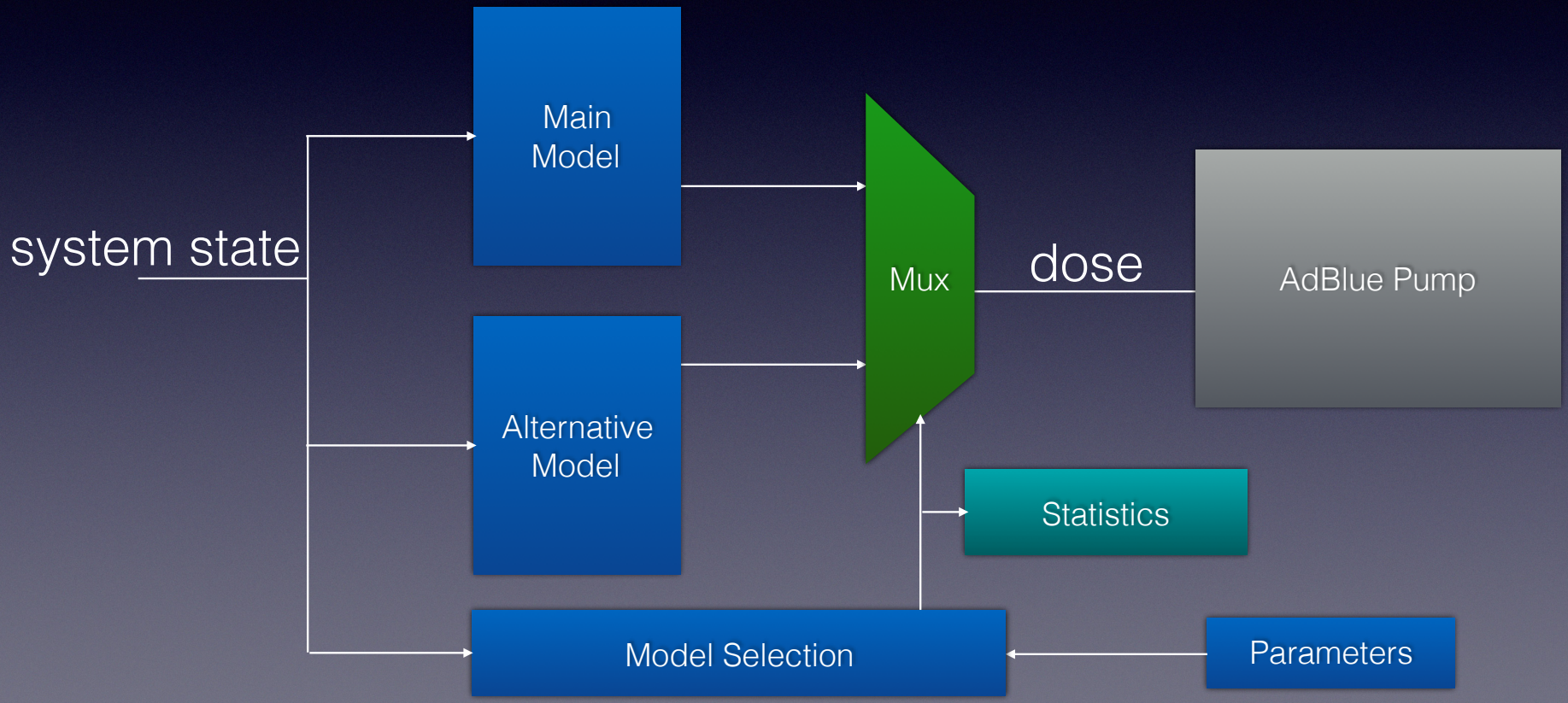


Alternative SCR Model

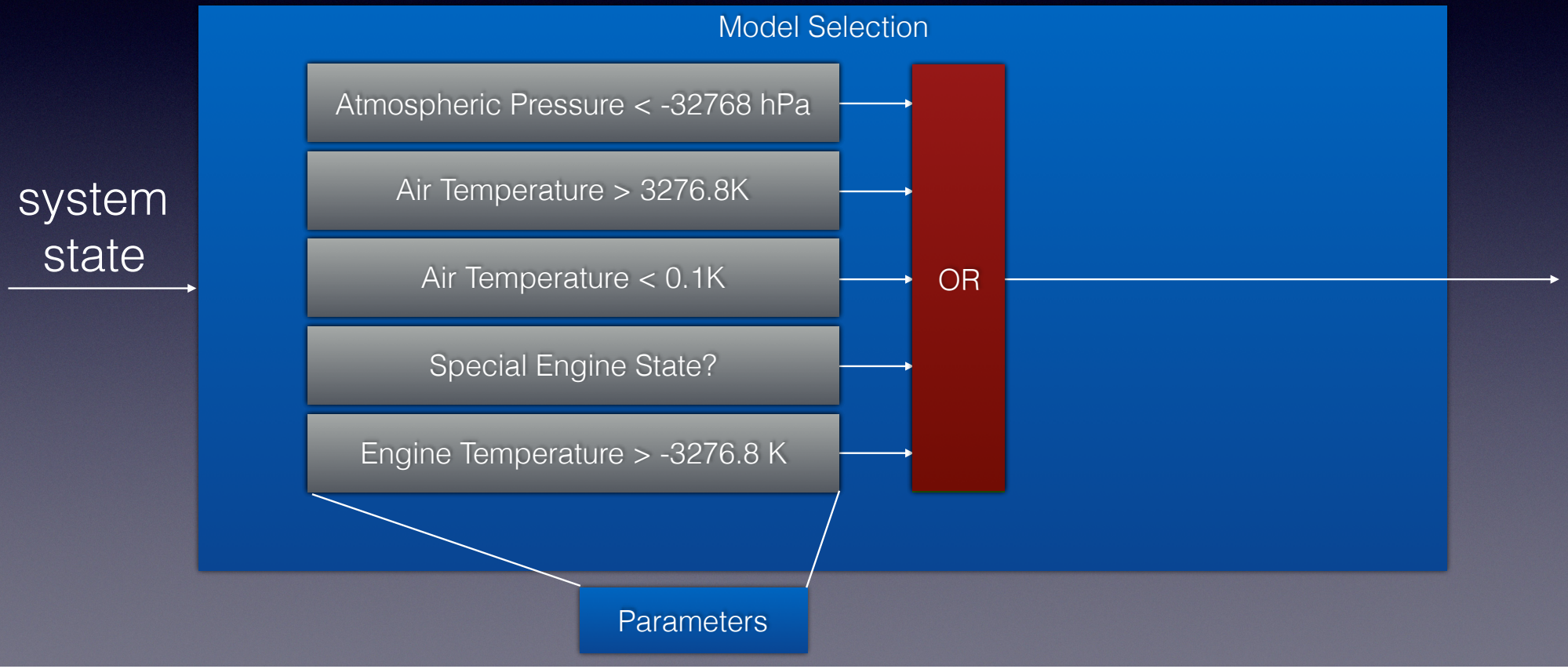
Primary Goal: Minimize NH_3 slip (while still reducing NO_x)



Model Switch

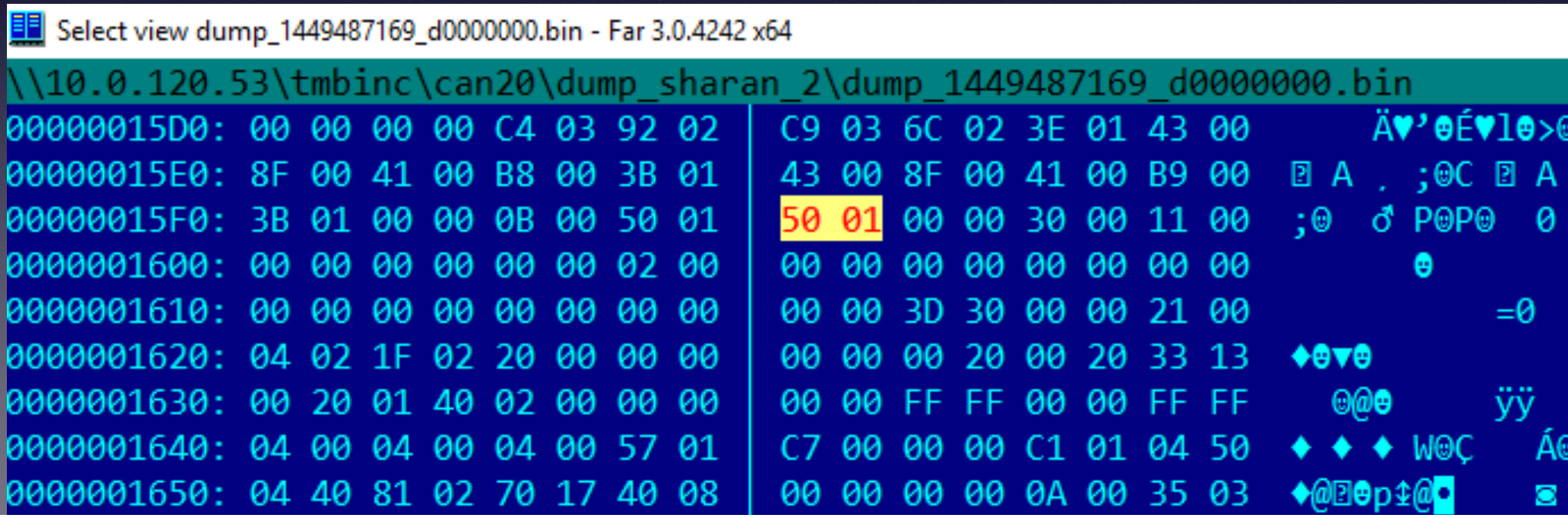


Selection Criteria



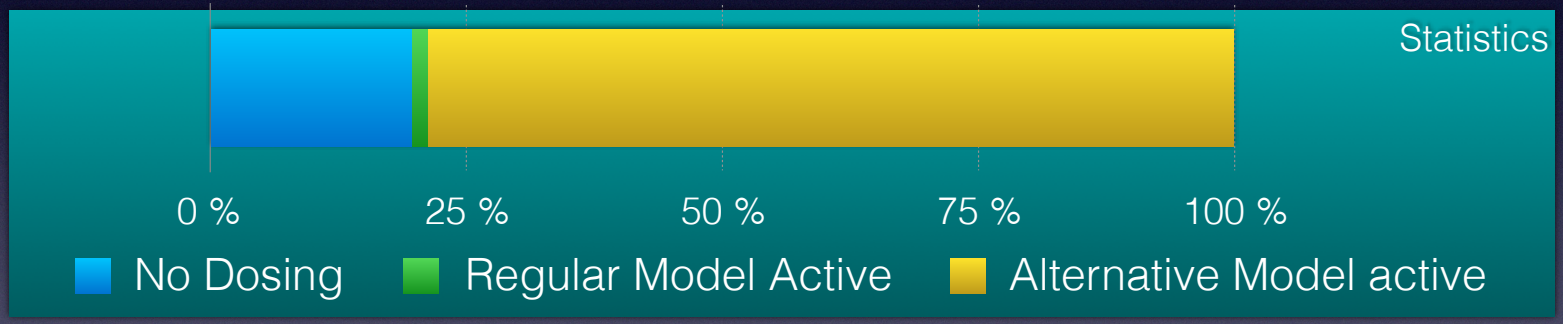
Model Selection Tweaks

- Based on memory dump, we indeed see bit 4 (“too high temperature”) set (little endian)!



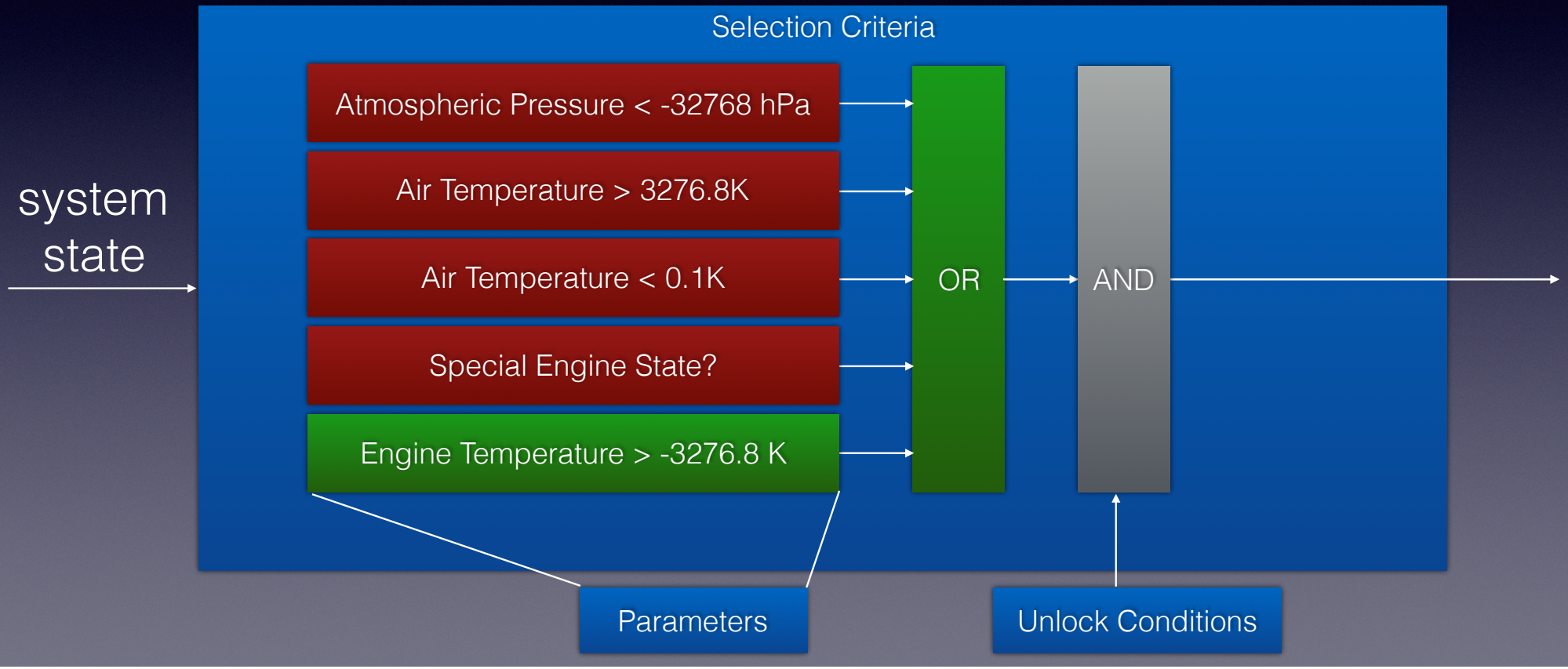
Model Selection Tweaks

- Can this be true? This sounds fishy.
- Luckily, the ECU counts how often it is in each state, and saves that to EEPROM:

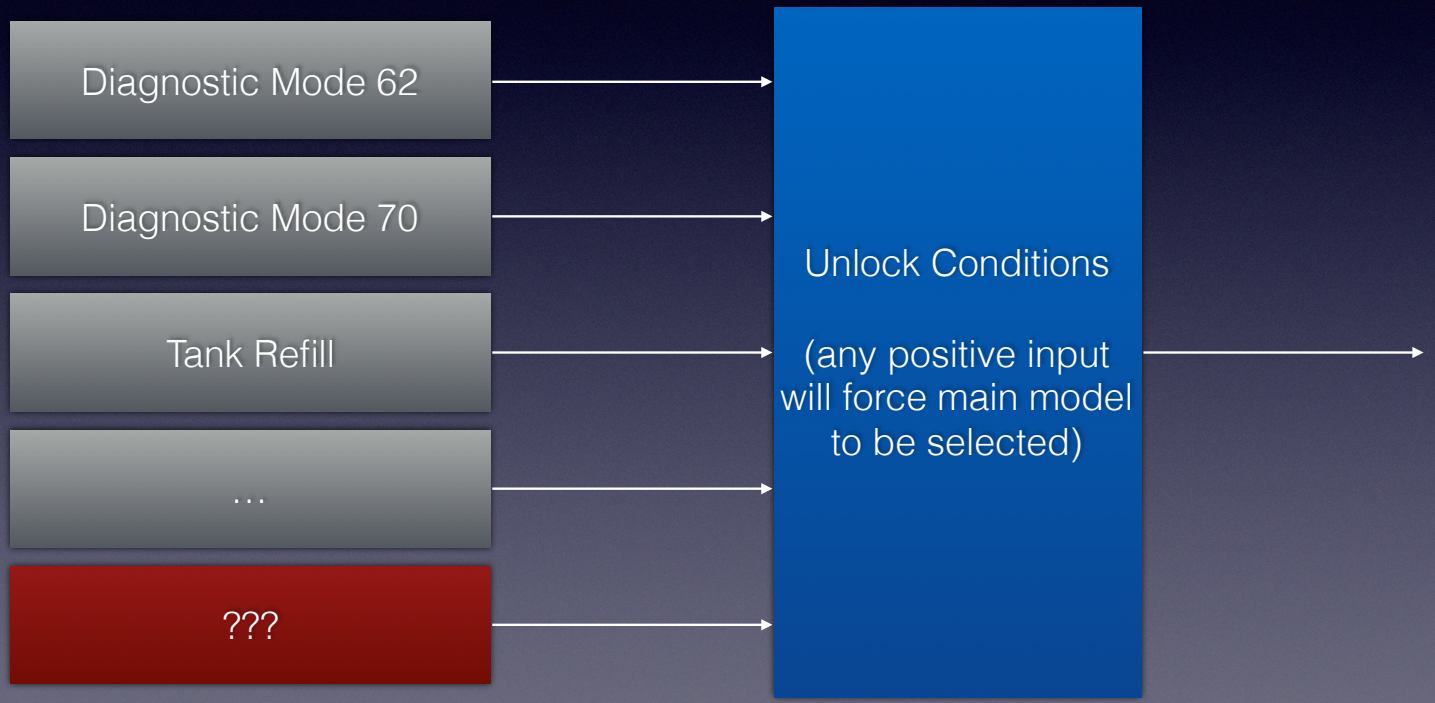


- Average AdBlue consumption is well below expectations as well. Alternative model tends to under-dose to avoid NH_3 slip (and, as a side effect, reduce AdBlue consumption)
- Averaged consumption on my car, as calculated by ECU, is ~0.6l/1000km. Expected for full efficiency would be around 2.5l/1000km.
- Ok, this is fishy. Let's investigate. (And how can the Regular Model still be selected sometimes?)

Selection Criteria

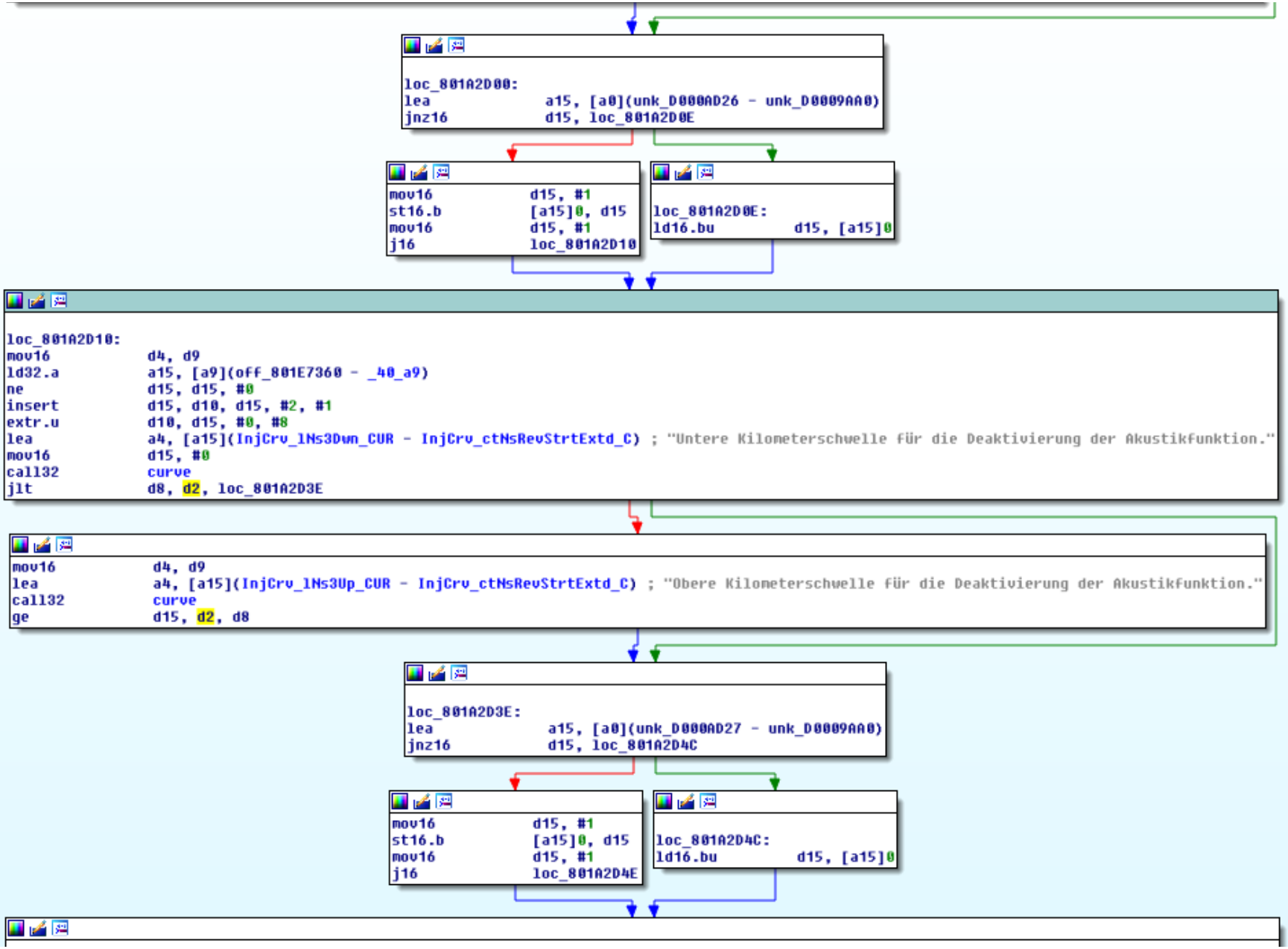


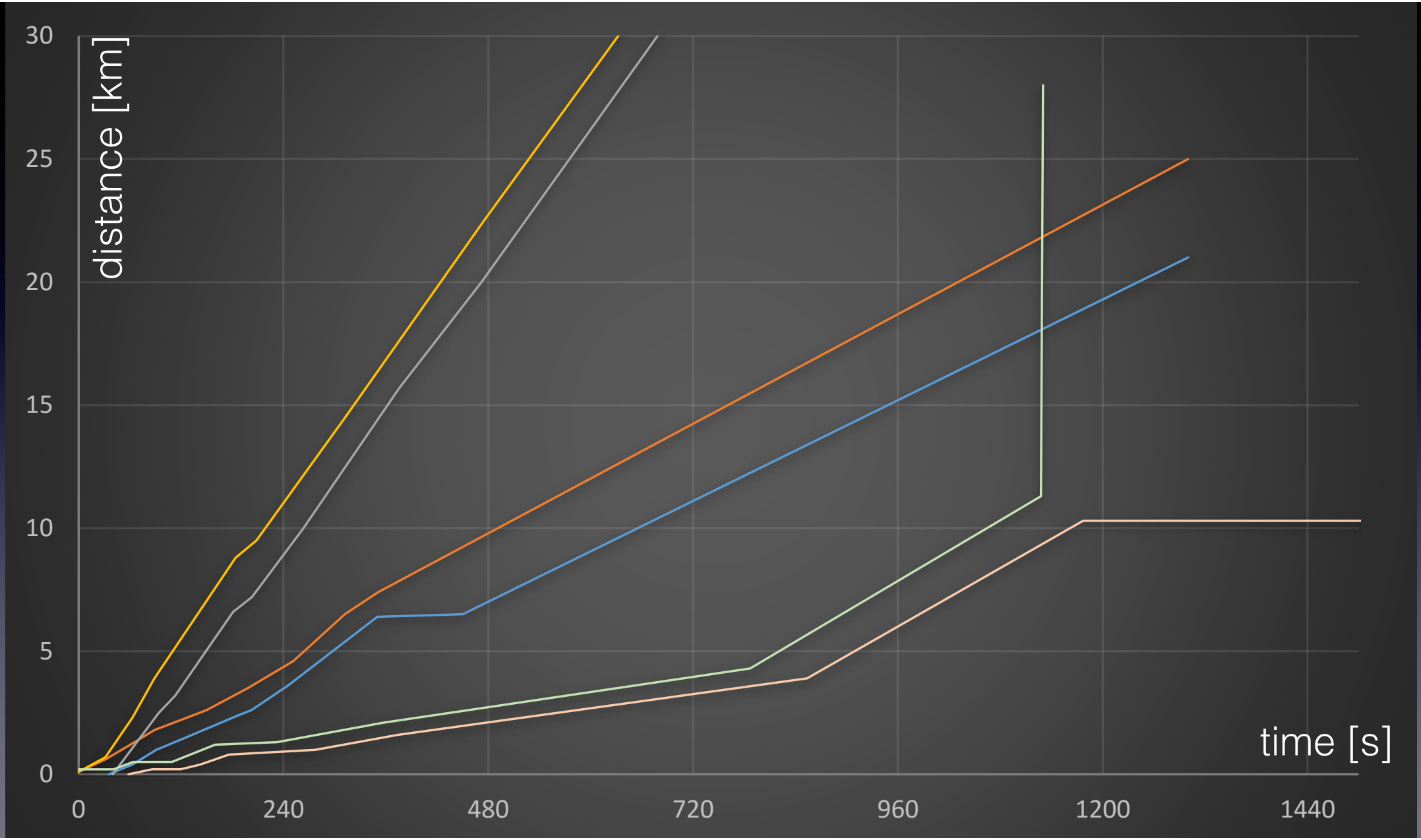
Unlock Conditions?!

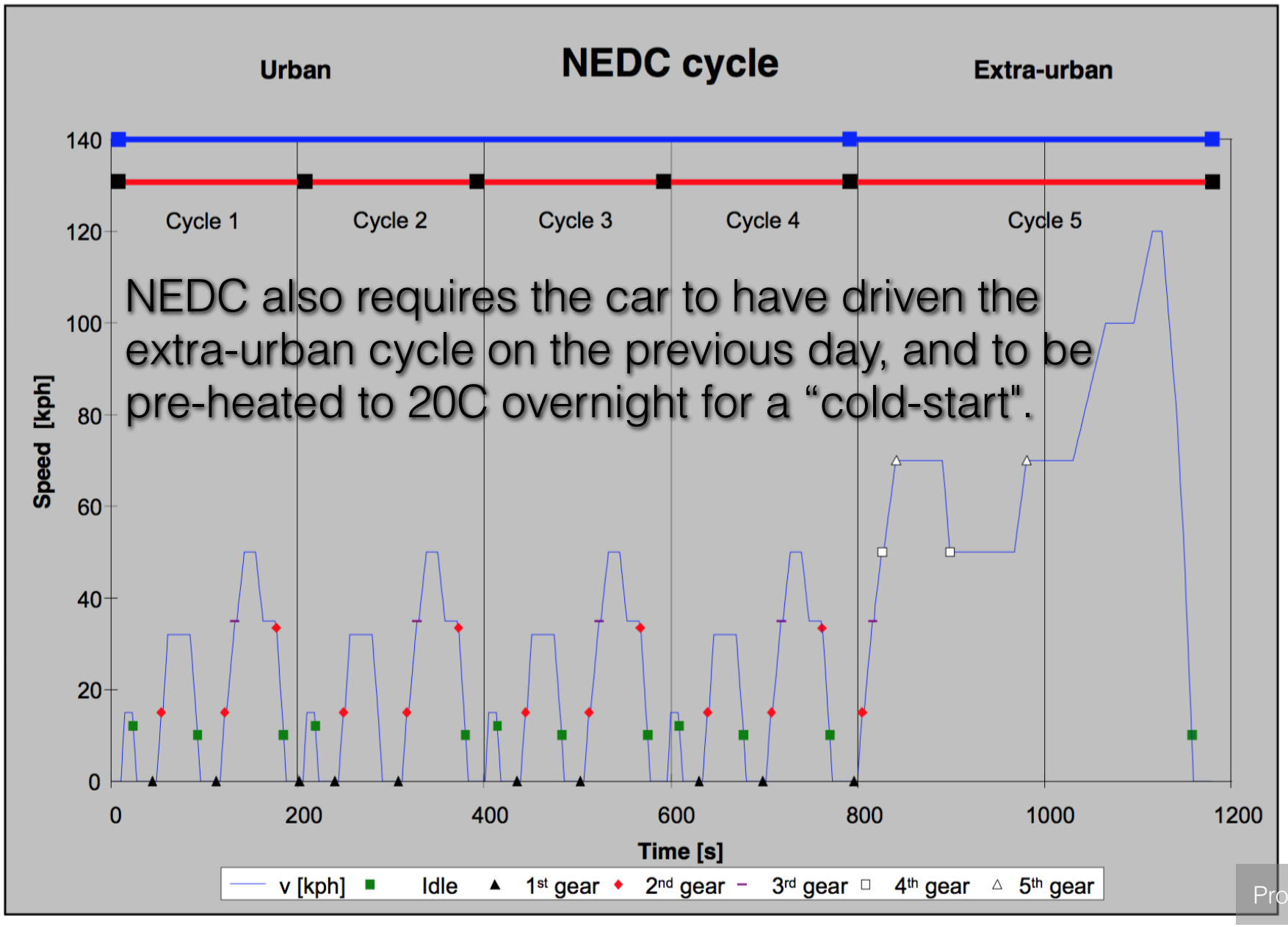


Weird Unlock Criteria

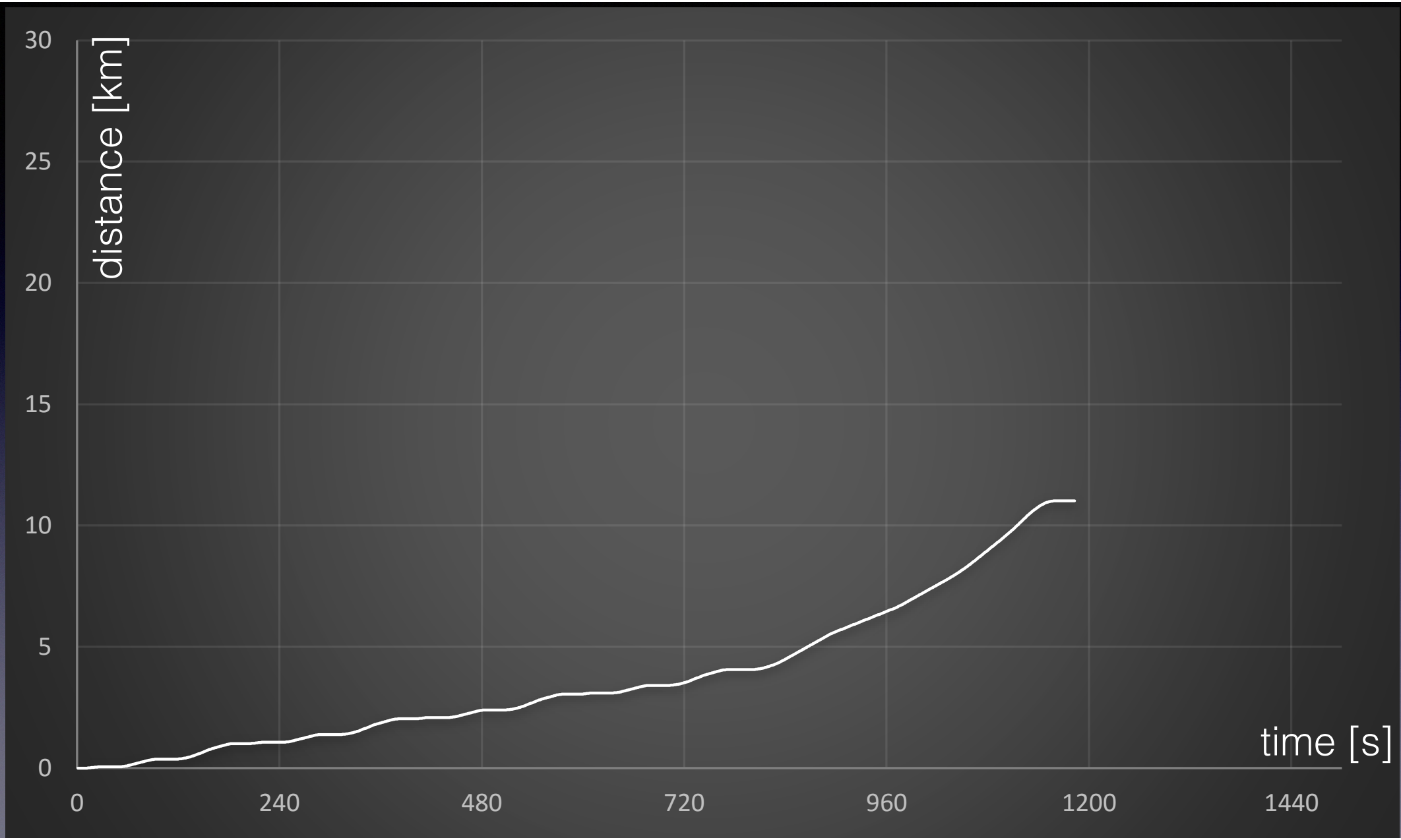
- Engine- and Fuel-temperature must be >15°C
- Atmospheric pressure must be >920 hPa (<~750m over sea level)
- Driving profile must follow given limits.
- Limits are defined by 7 piecewise-linear min/max curves: distance-driven vs. time-since-motor-start.

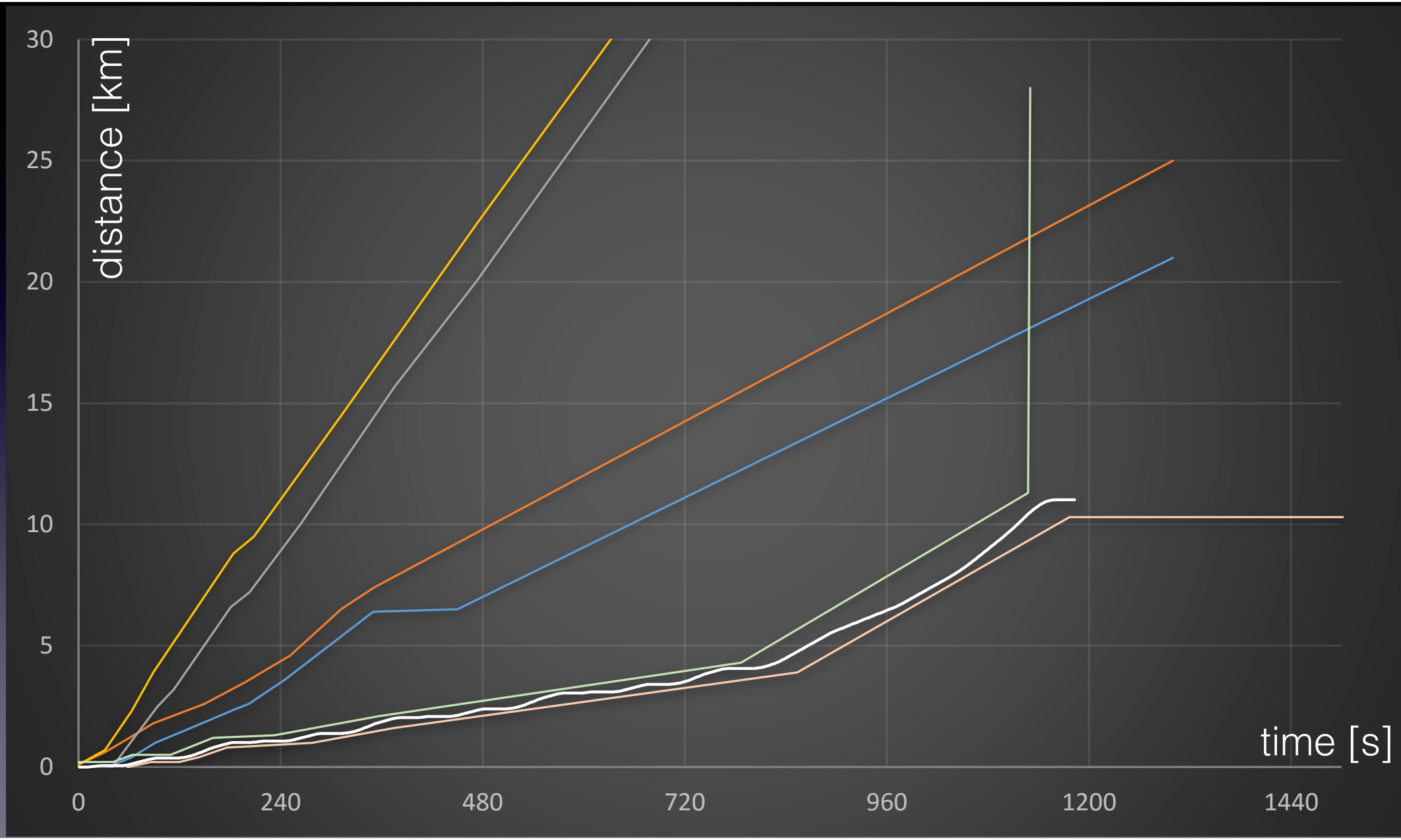

loc_801A2D00:
lea a15, [a0](unk_D000AD26 - unk_D0009AA0)
jnz16 d15, loc_801A2D0E
mov16 d15, #1
st16.b [a15]0, d15
mov16 d15, #1
j16 loc_801A2D10
loc_801A2D0E:
ld16.bu d15, [a15]0
loc_801A2D10:
mov16 d4, d9
ld32.a a15, [a9](off_801E7360 - _40_a9)
ne d15, d15, #0
insert d15, d10, d15, #2, #1
extr.u d10, d15, #0, #8
lea a4, [a15](InjCrv_lNs3Dwn_CUR - InjCrv_ctNsRevStrtExtd_C) ; "Untere Kilometerschwelle für die Deaktivierung der Akustikfunktion."
mov16 d15, #0
call32 curve
jlt d8, d2, loc_801A2D3E
mov16 d4, d9
lea a4, [a15](InjCrv_lNs3Up_CUR - InjCrv_ctNsRevStrtExtd_C) ; "Obere Kilometerschwelle für die Deaktivierung der Akustikfunktion."
call32 curve
ge d15, d2, d8
loc_801A2D3E:
lea a15, [a0](unk_D000AD27 - unk_D0009AA0)
jnz16 d15, loc_801A2D4C
mov16 d15, #1
st16.b [a15]0, d15
mov16 d15, #1
j16 loc_801A2D4E
loc_801A2D4C:
ld16.bu d15, [a15]0

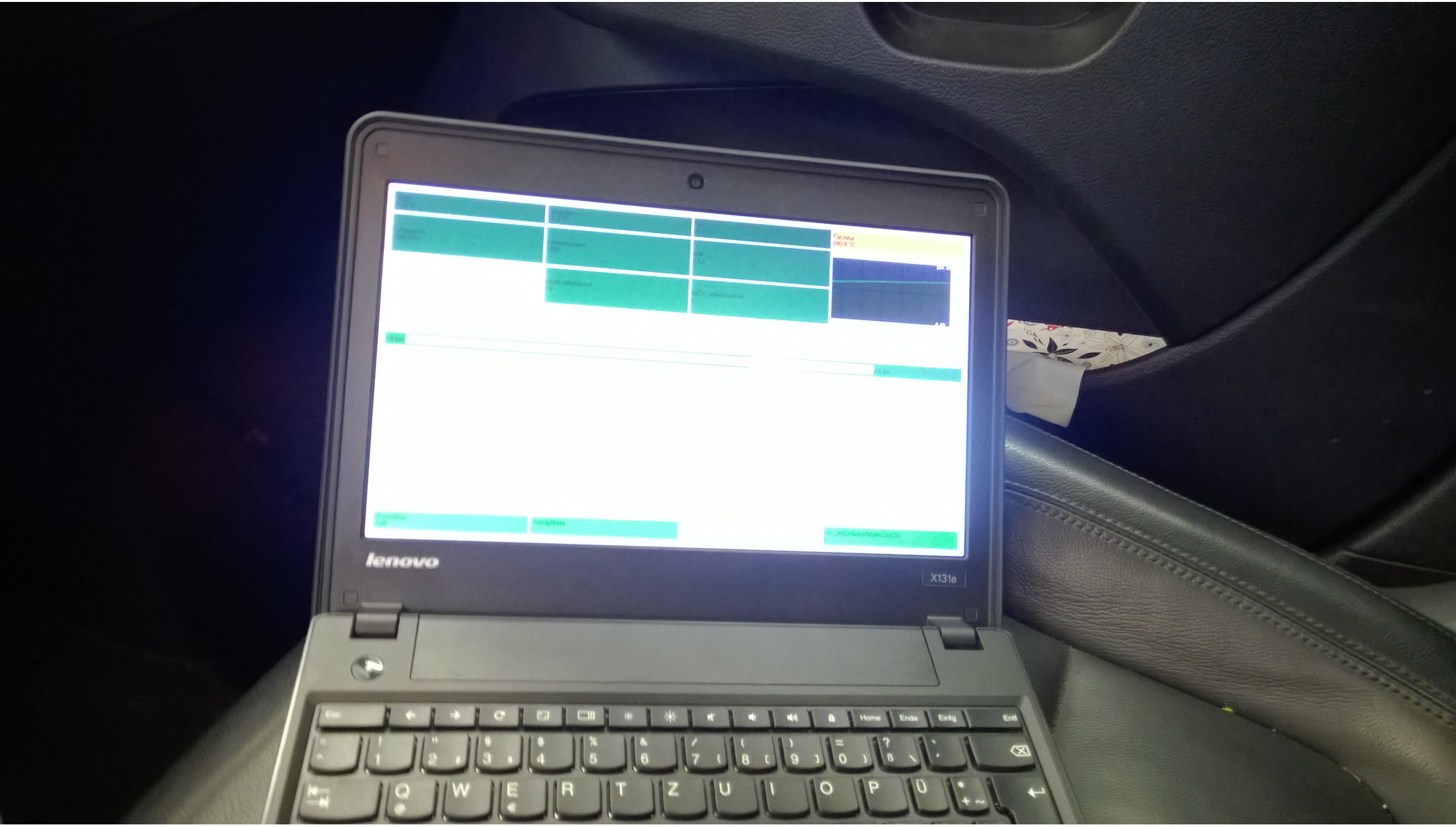

distance [km]
30
25
20
15
10
5
0
0
240
480
720
960
1200
1440
time [s]

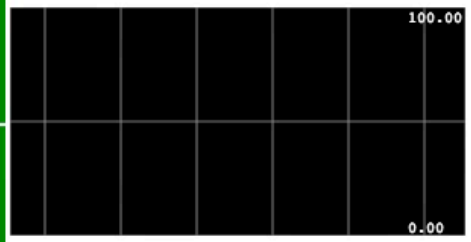


Prof. Kolke, ADAC


distance [km]
30
25
20
15
10
5
0
0
240
480
720
960
1200
1440
time [s]

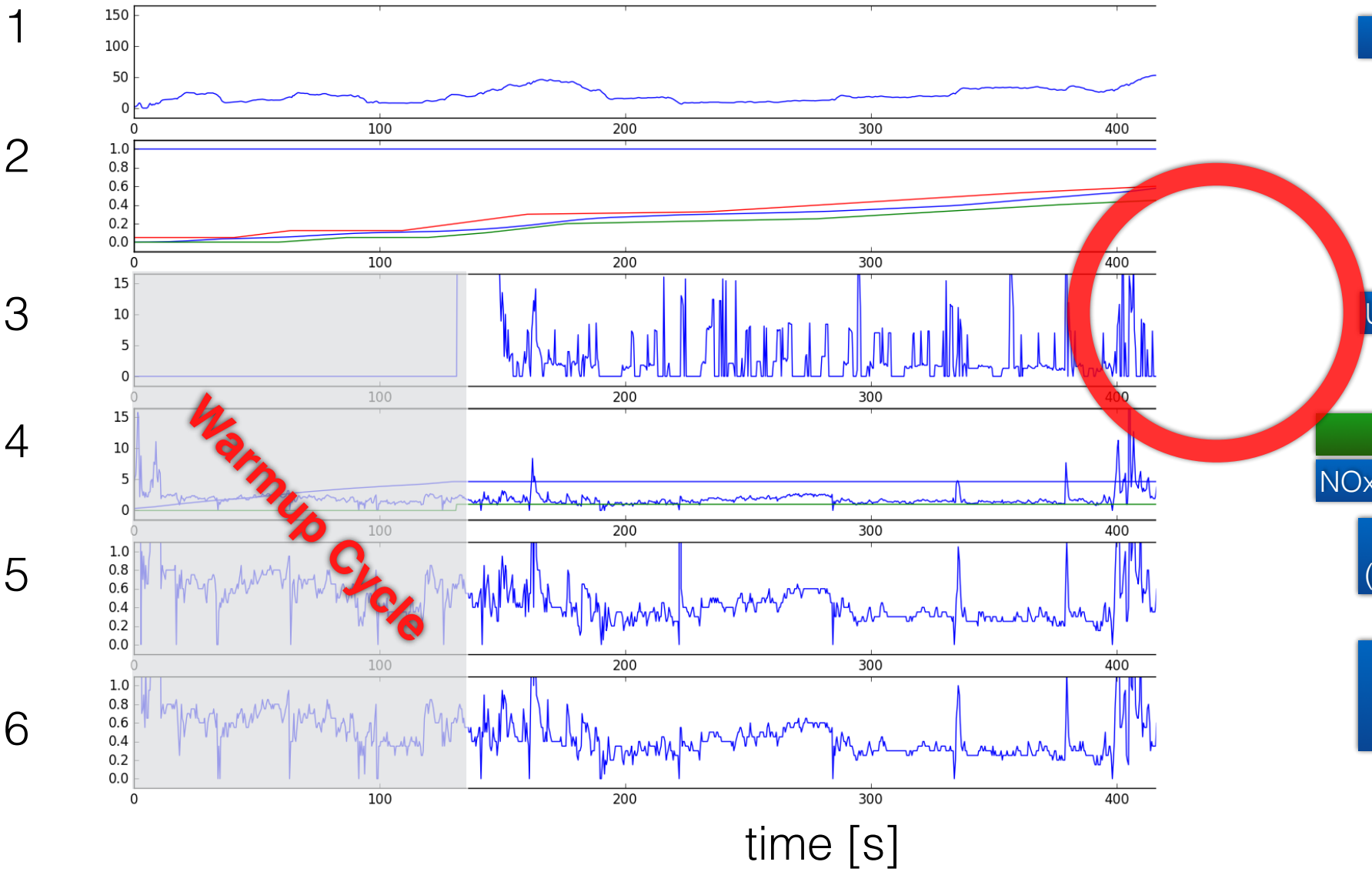

distance [km]
30
25
20
15
10
5
0
0
240
480
720
960
1200
1440
time [s]


lenovo
X131e

T_{Motor} 85.4 °C	$T_{Kraftstoff}$ 37 °C	$T_{Öl}$ 90.1 °C	T_{SCRKat} 187.9 °C
$P_{Umgebung}$ 1023 hPa	Umdrehungen 134	APP_r 0	
InjCrv_tiNsRun 0 s	InjCrv_stNsReset 0 1 2 5	InjCrv_stNsCharCor 1	
VehV_v 0 km/h (NEFZ 0 km/h)	ASMod_lSumVehAct 0 km (NEFZ 0 km)	delta 0 / 0.2 / 0	

0 km — 0.2 km

SCRFFC_dmNOxUs2S16_mp 1.4 mg/s	SCRFFC_rPPMNOxUs 131 ppm	SCRFFC_stMskPreCtlMode2 336	CoEng_tiNormalRed 10.08 s
SCRFFC_dmNH3PreCtlMode2_mp 0 mg/s	SCRFFC_stMskNsPreCtlModDsbl 1	InjCrv_tiNormalRedStrtStop 9.92 s	SCRFFC_stPreCtlLck_mp 0
SCRFFC_etaPreCtlMode2 0	SCRFFC_dmNH3PreCtl 0.35 mg/s	SCRMod_etaEst 0.69	SCRFFC_dmNH3Cnv 0.35 mg/s
SCRFFC_stPreCtlModeActv 0	DStgy_dmRdcAgDes 0 mg/s		
SCRFFC_dmNH3PreCtlMode2UnLim_mp 0 mg/s	SCRFFC_stMskPreCtlMode2_mp 336	SwsVW_bStopActv 0	
CoEng_st 3	StSys_stStrt 0	CoSCR_st COSCR_PRESSURECTL	
SCRFFC_dmNOxUs 1.4 mg/s	SCRFFC_dmNH3FdRat1 0.55 mg/s		
StCondDos f00ffb	DosingState 0	DewDet 9.36 / 310 / 0	Exh_stNOxSensRdyNoCat2Ds 0


1
2
3
4
5
6
Warmup Cycle
time [s]
Vehicle speed
Actual Distance
Upper Bound
Lower Bound
Urea (NH_3) Dosing
Mode Selection
NOx exhaust massflow
Dose before Mux (main model output)
Dose after Mux (selected model output)

Limitations

- All code-analysis is best-effort. We have not verified our findings with a third party yet. Take with a grain of salt.
- We couldn't do quantitative external NO_x conversion measurements due to equipment availability.
- We have only looked at one particular affected car from the German market. It may not be representative for any other market or series.

Results

- Most of the time, a non-standard after treatment mode is active. We can show the code that's responsible ("negative temperature limit"), as well as logs (current state as well as counters for the SCR state).
- There is severe NH_3 under-dosing in this state, leading to inefficient NO_x conversion; efficiency checks are disabled in this mode by design. This is indicated by absence of error messages while exceeding limits, and much-smaller-than-expected DEF consumption.
- Following the NEDC (environmental parameters and distance-over-time) will cause a switch to the main model. We can show the code that's responsible (driving cycle detection), as well as the effect on SCR state ("0x1" vs "0xB"). We can show the effect on DEF dosing.
- In the main model, all efficiency checks are enabled, enabling detection of bad Urea or catalyst.
- These results are in-line with VW press releases covering the manipulation.

Thank you!

- Questions?
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Felix wants to thank:
Christian Schmidt / Michael Steil / [unnamed] / Giuliano Dianda

Legal advice: Udo Vetter