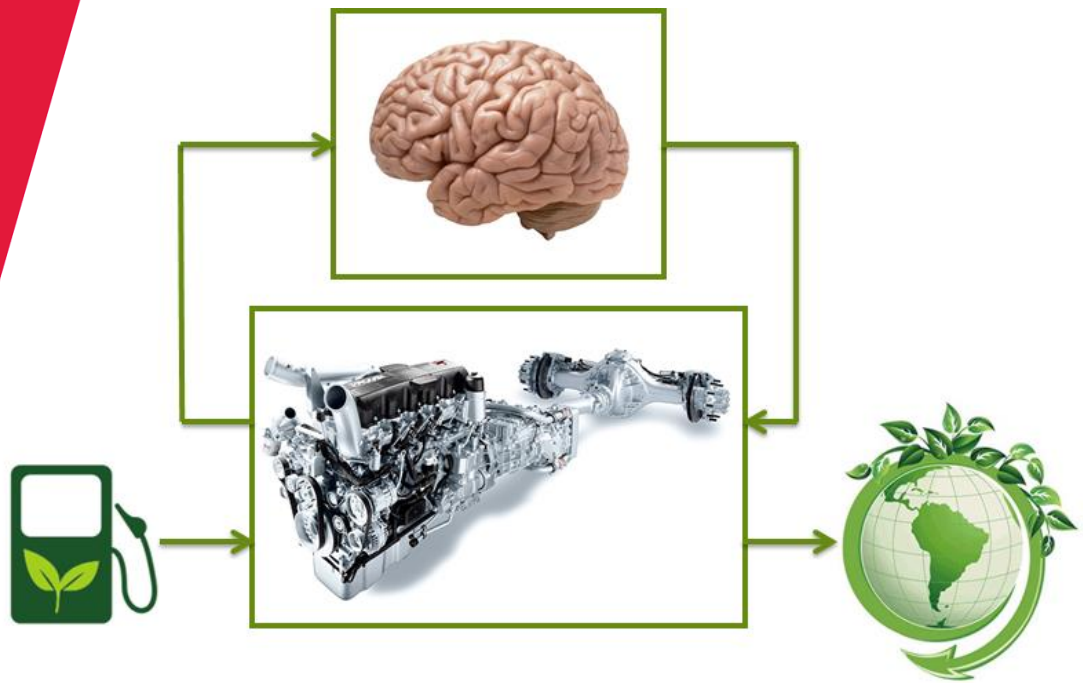
TNO innovation for life

TU/e Technische Universiteit Eindhoven University of Technology

The Self-Learning Powertrain:
towards smart and green transport



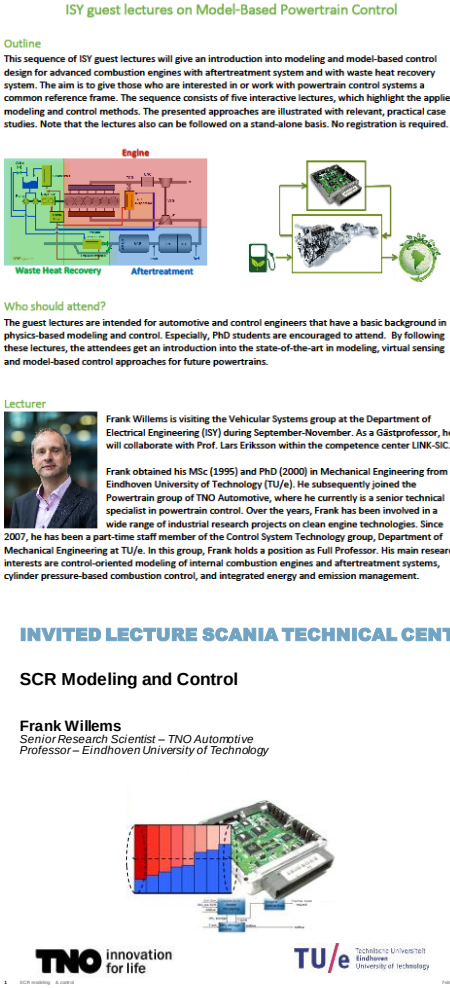
LINK-SIC Workshop 2019
ABB CRC, Västerås
19 November 2019

Frank Willems

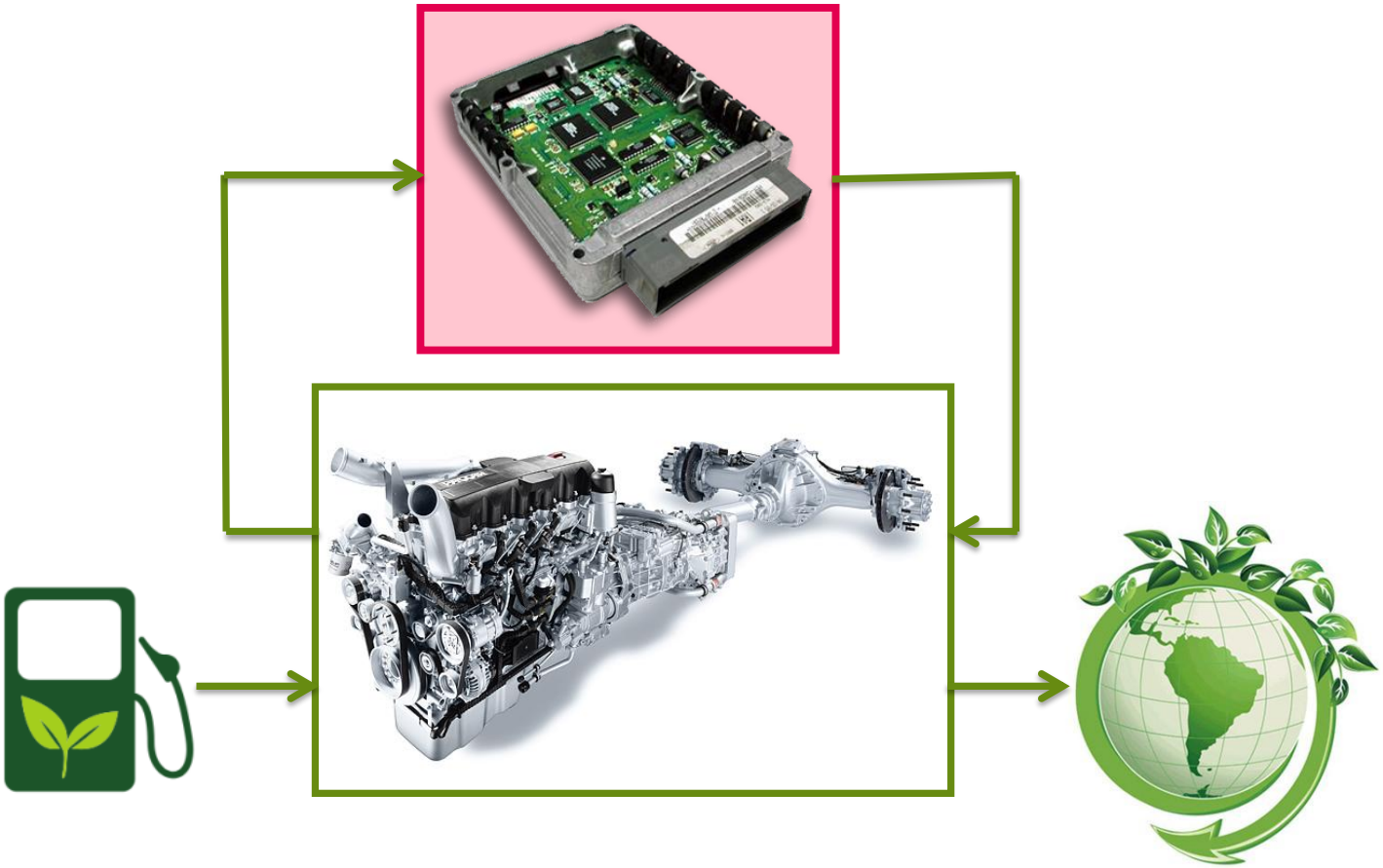
Where innovation starts

My activities in LINK-SIC

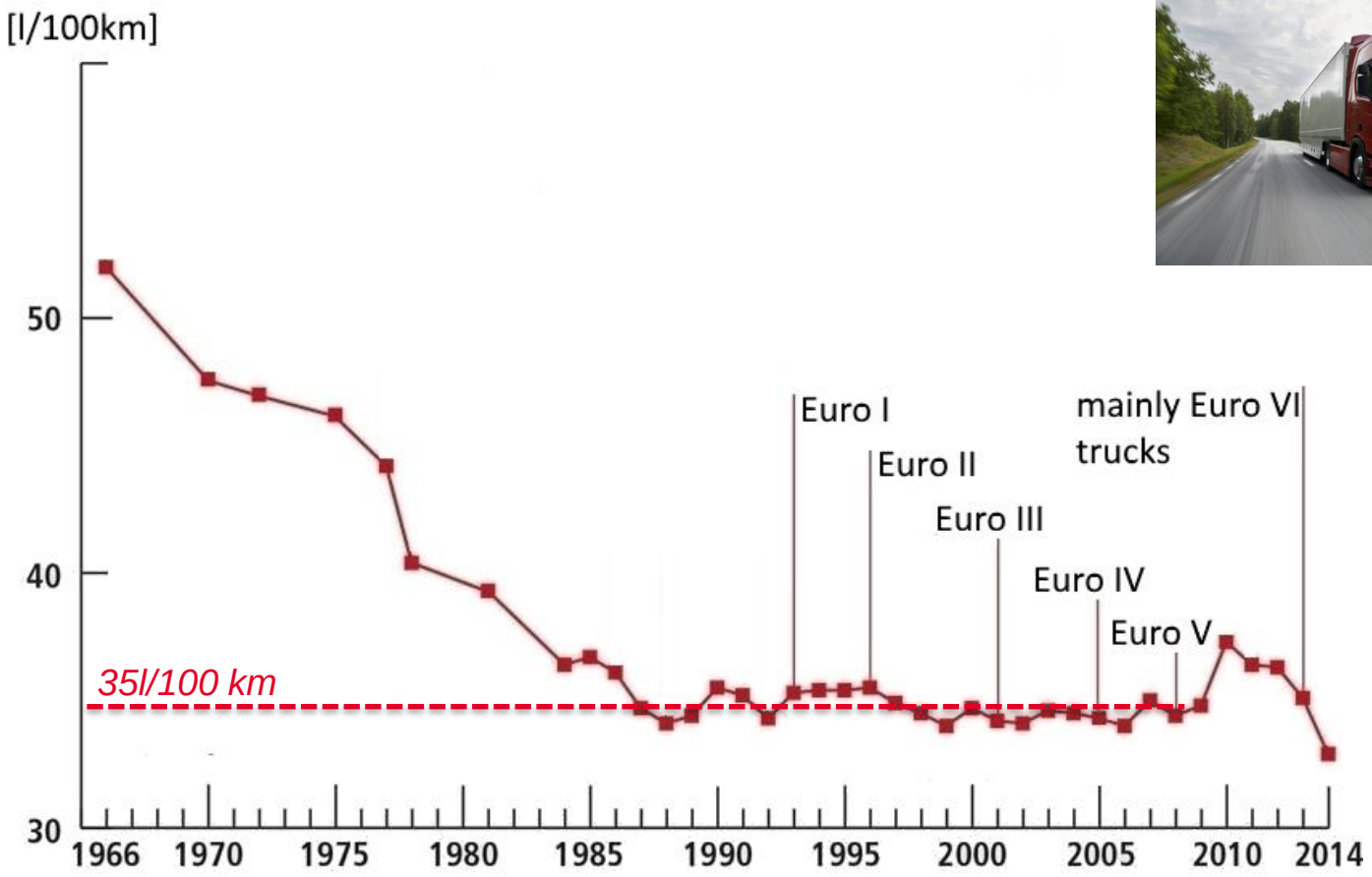
- Visiting professor LiU ISY/Vehicular Systems
  - *August – November 2019*
- Collaboration with Prof. Lars Eriksson, Kristoffer Ekberg, Robin Holmbom, Olov Holmer
- Guest lectures on Model-based powertrain control
- Company visits:
  - Scania (Erik Höckerdal)
  - Atlas Copco (Nils Dressler)



Still research to be done on powertrain control?

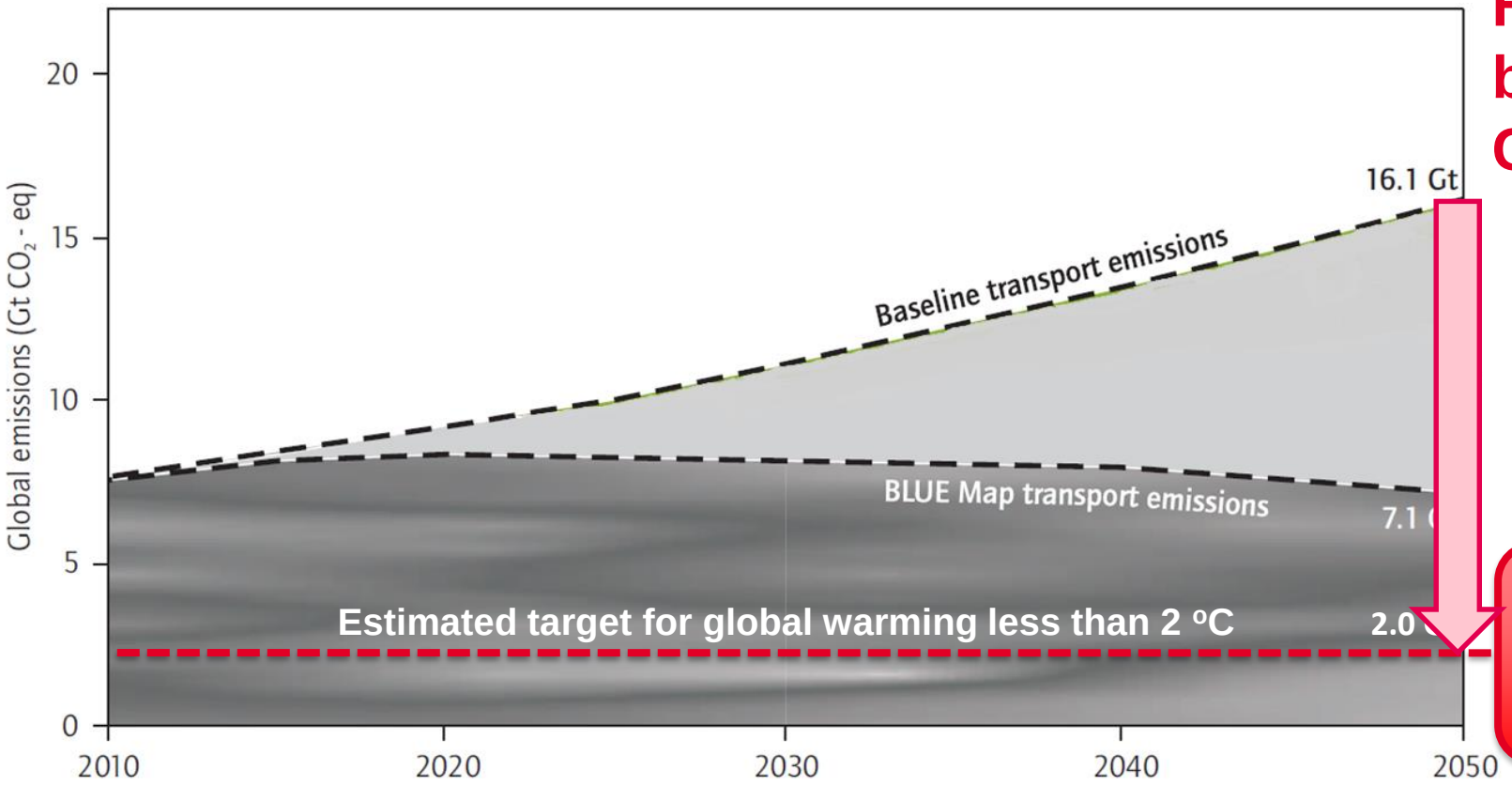


Historic real-world fuel consumption



http://www.eurotransport.de

How to bridge the CO_2 gap?



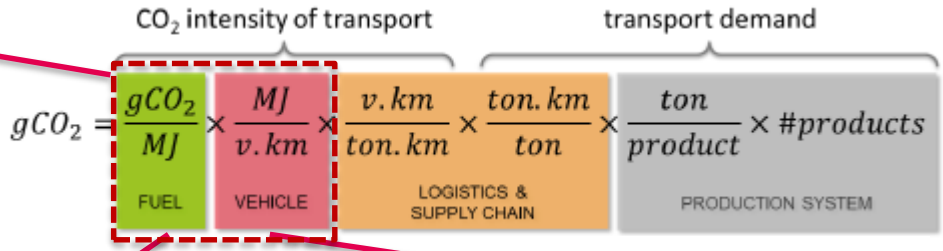
EC transport 2050 target: -60% CO_2 compared to 1990

https://www.iea.org

Tank-to-wheel CO_2 reduction

No single, silver bullet

EU legislation focus: gCO_2/km VECTO



Electricity
Low carbon (bio)fuels
Sustainable fuels
Hydrogen

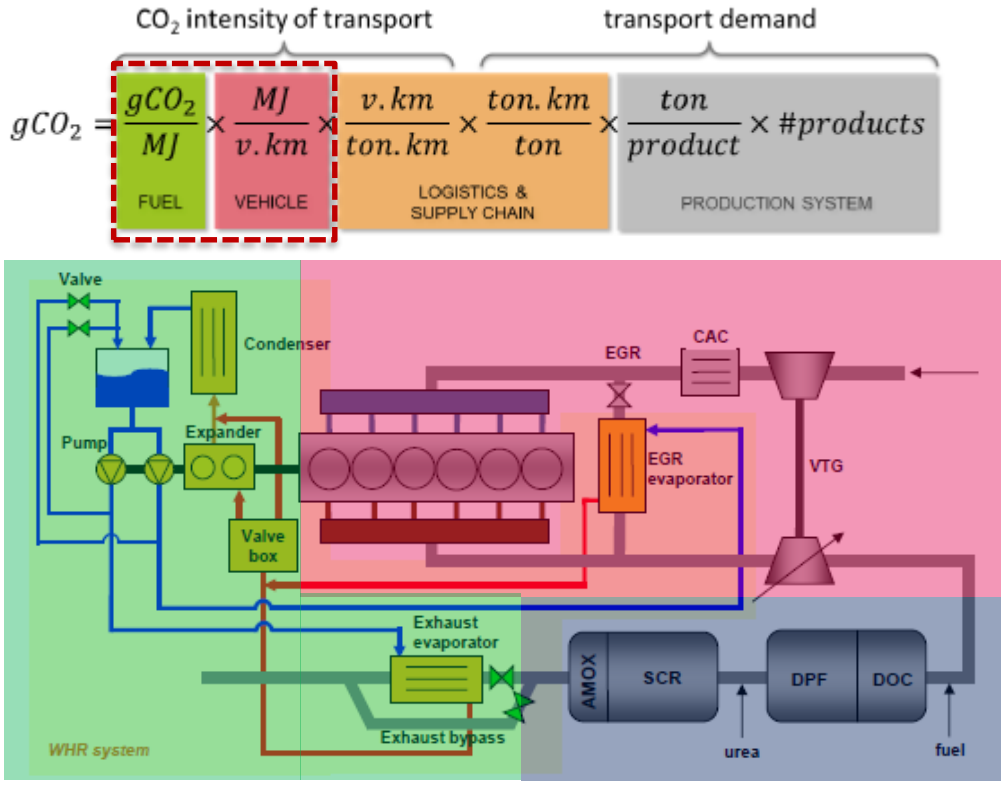
Enable

Powertrain electrification (*x-EV, E-AUX*)
Ultra efficient engine (*RCCI, PPC*)
High efficient aftertreatment
Energy recovery (*e.g. regen. braking, E-WHR*)
Advanced control

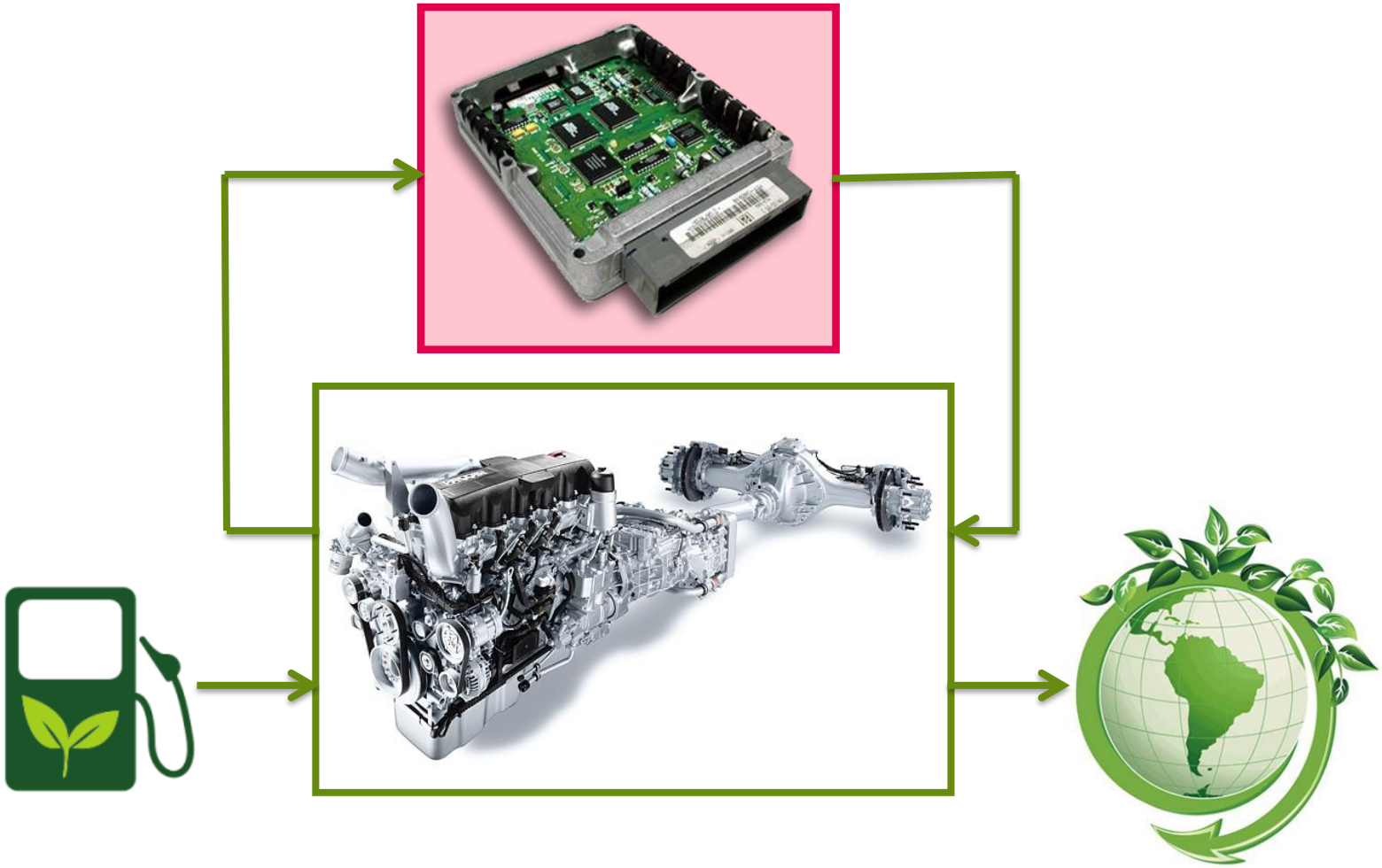
Powertrain research topics

Tank-to-wheel CO_2 reduction

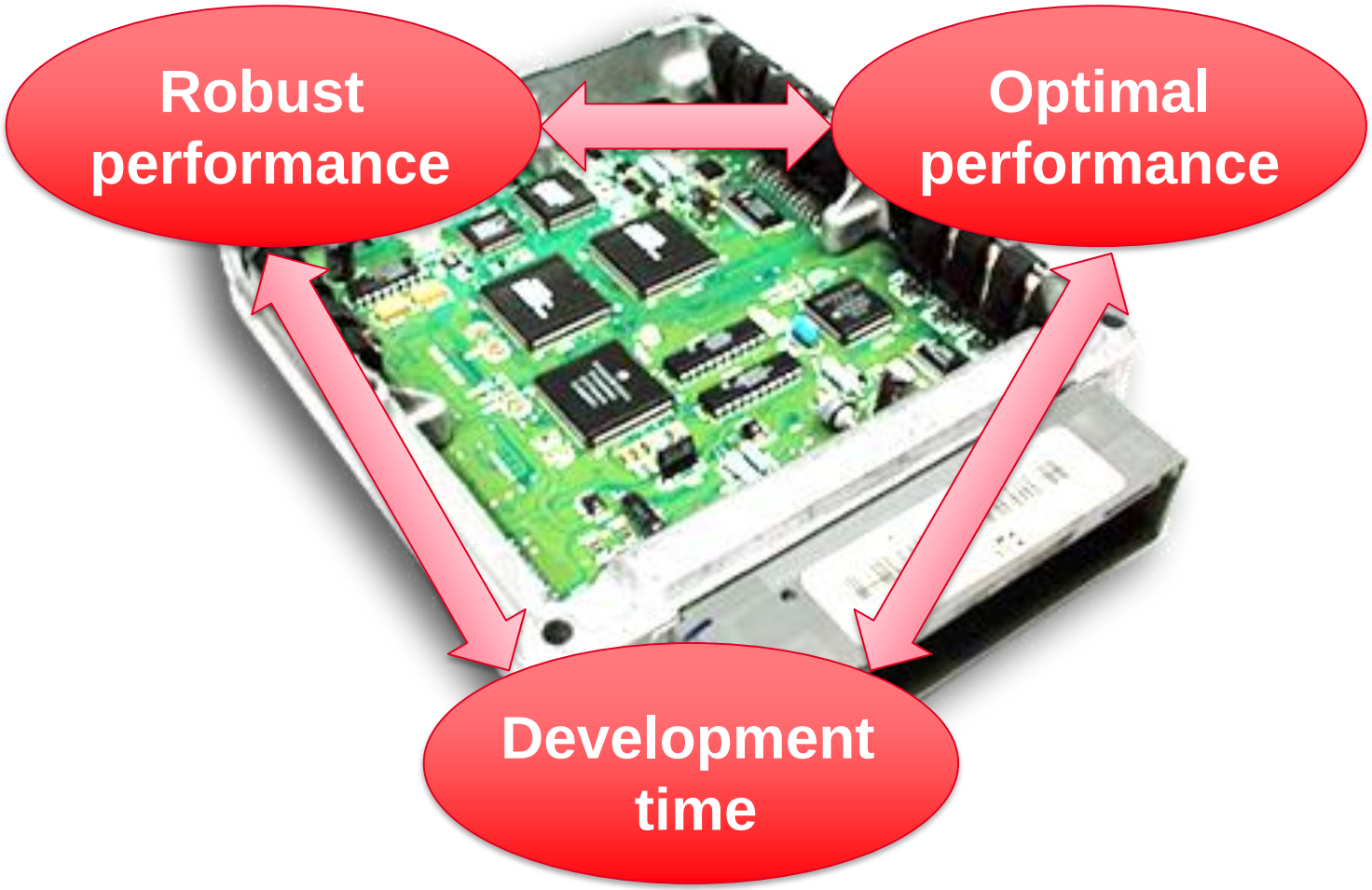
Growing complexity



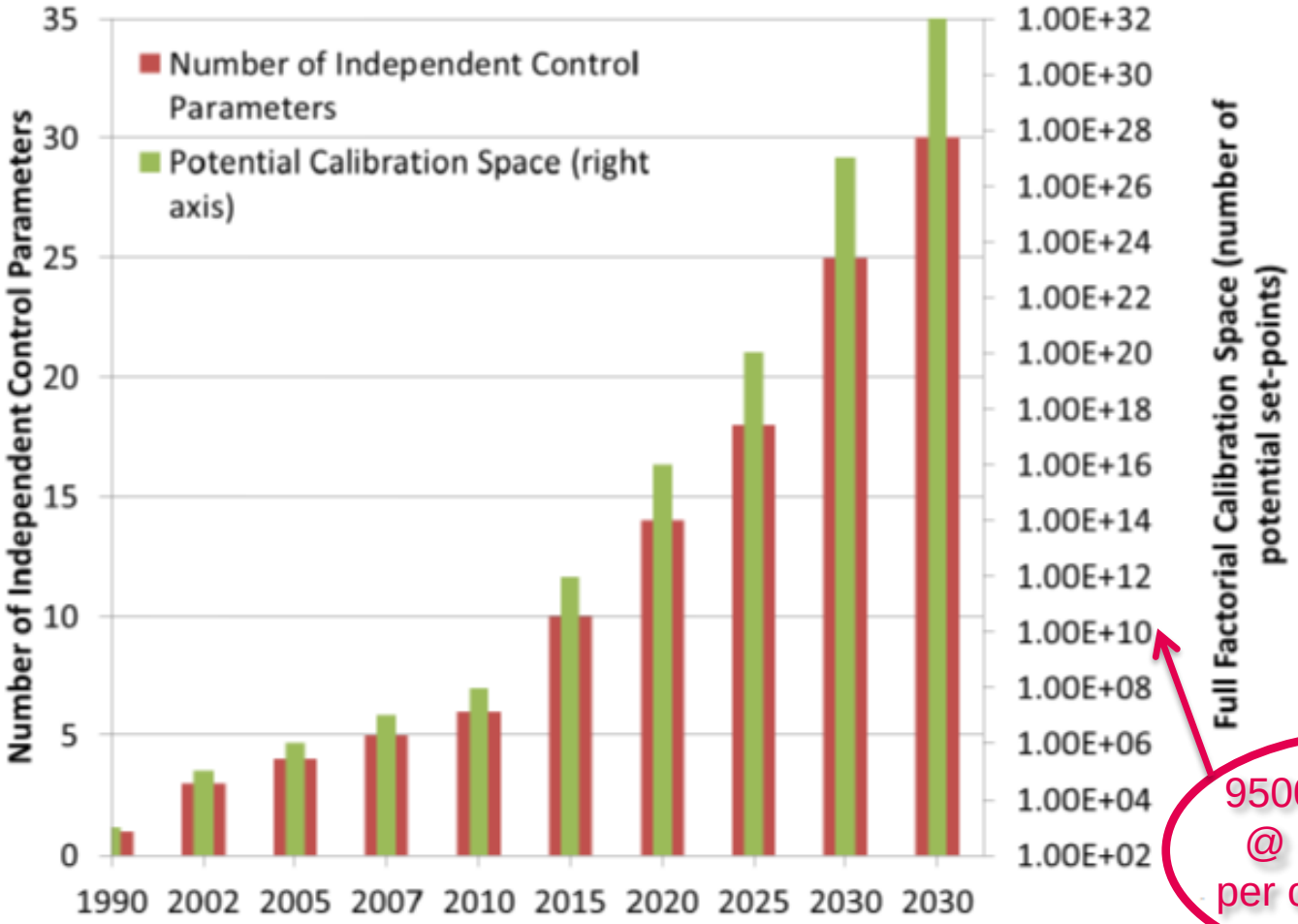
Growing importance of powertrain control



Growing importance of powertrain control

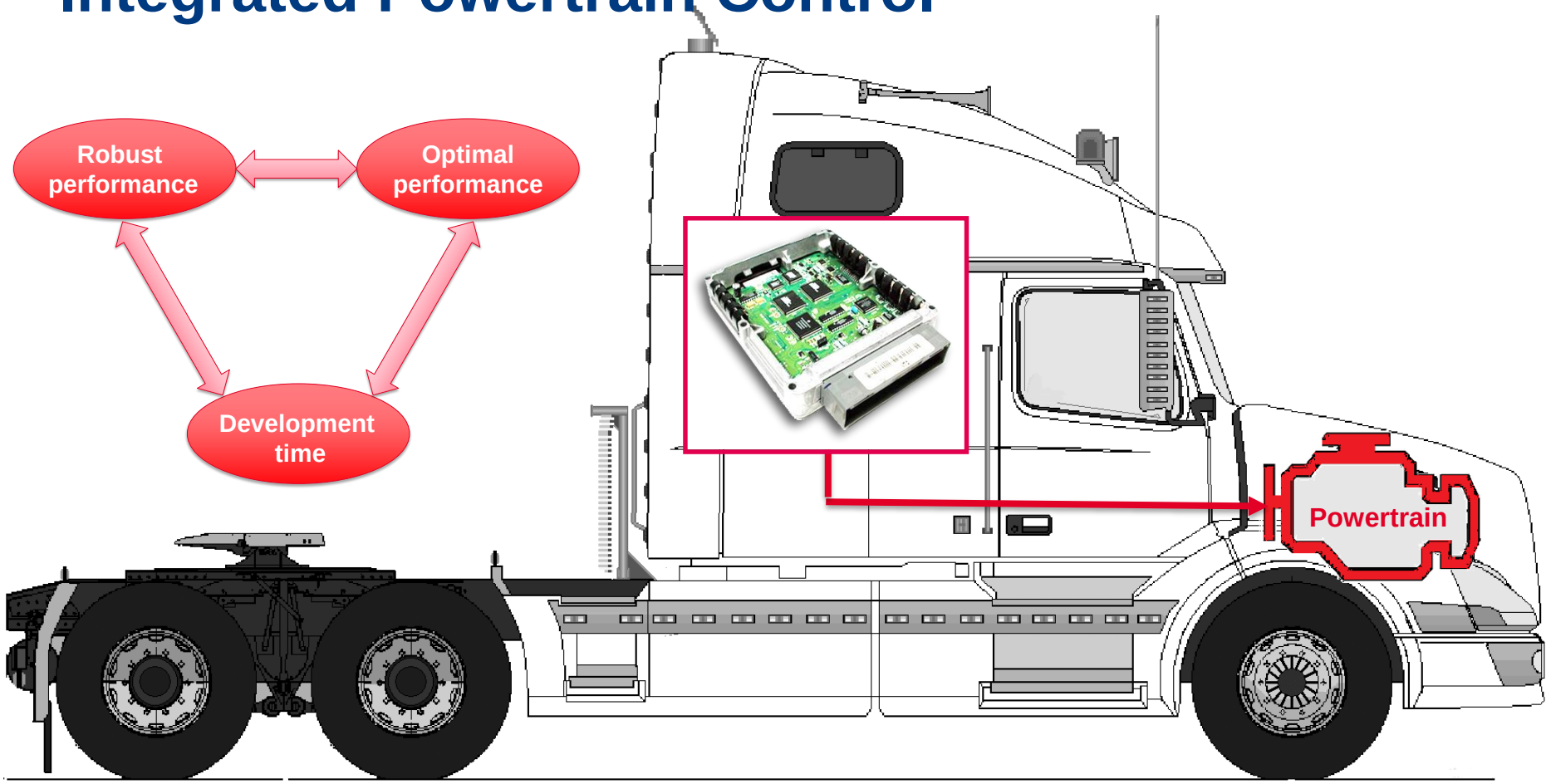


Map-based control is facing turning point

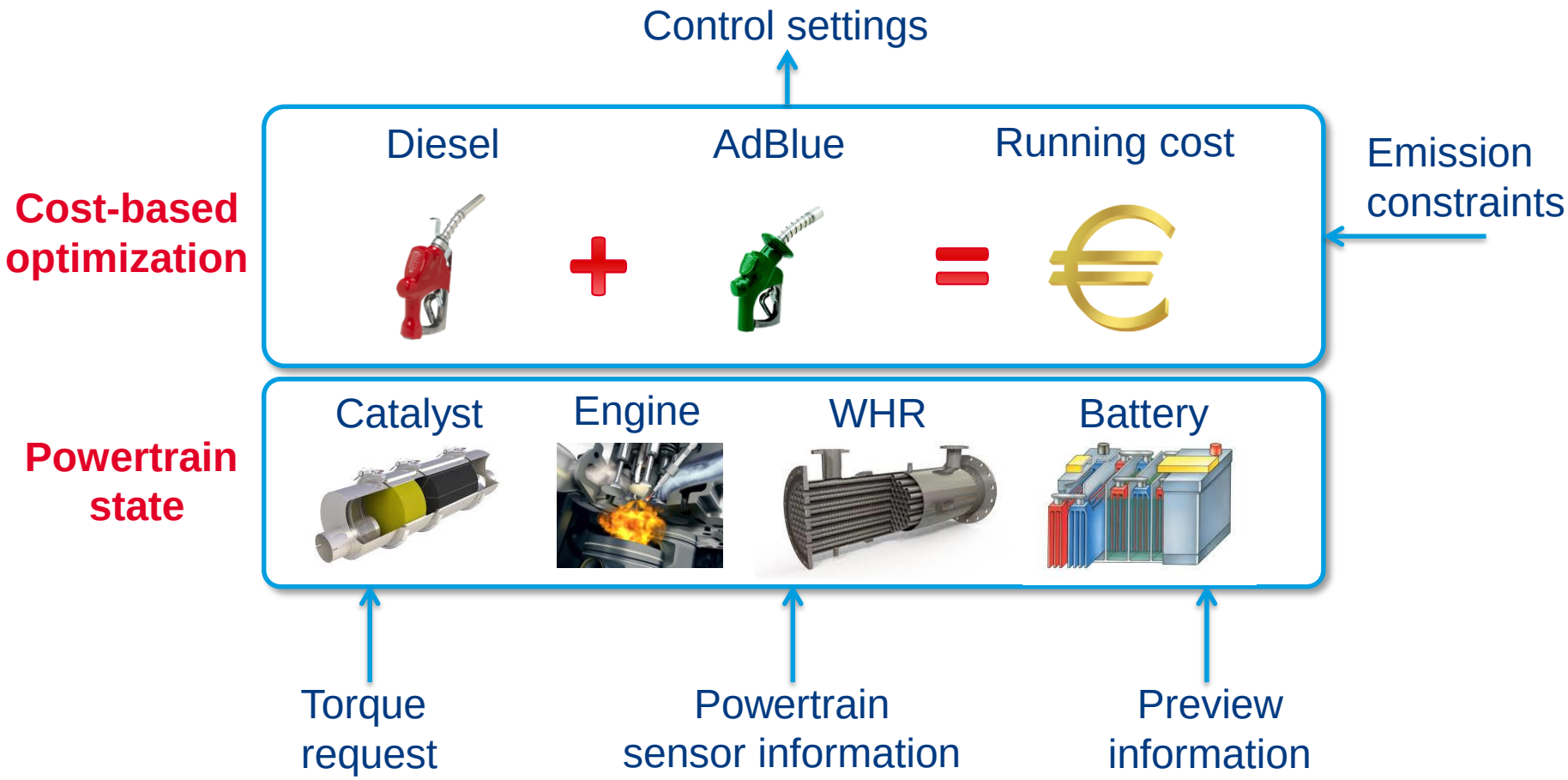


C. Atkinson, presentation at SAE HEE2014

Integrated Powertrain Control

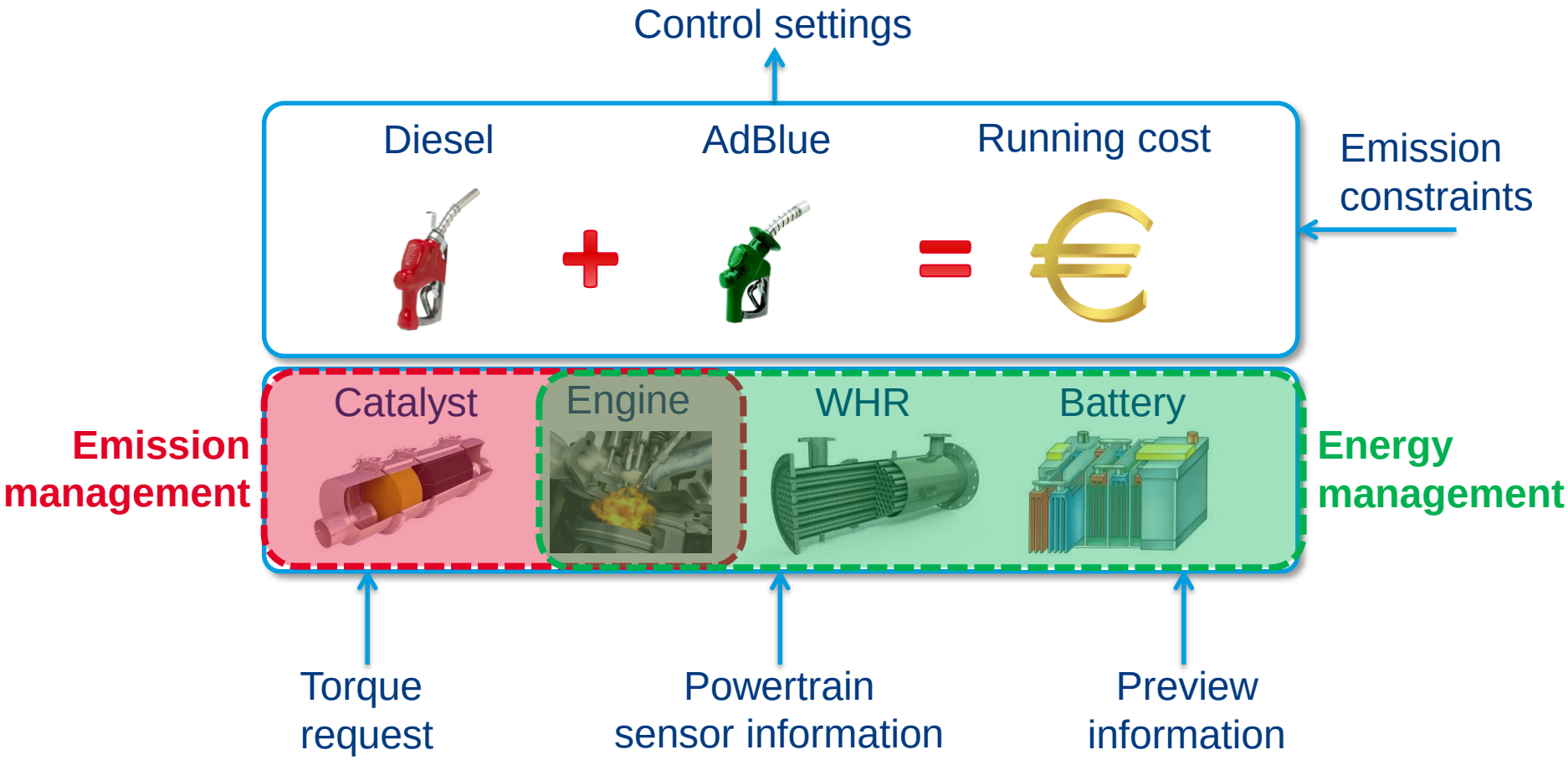


Integrated Powertrain Control

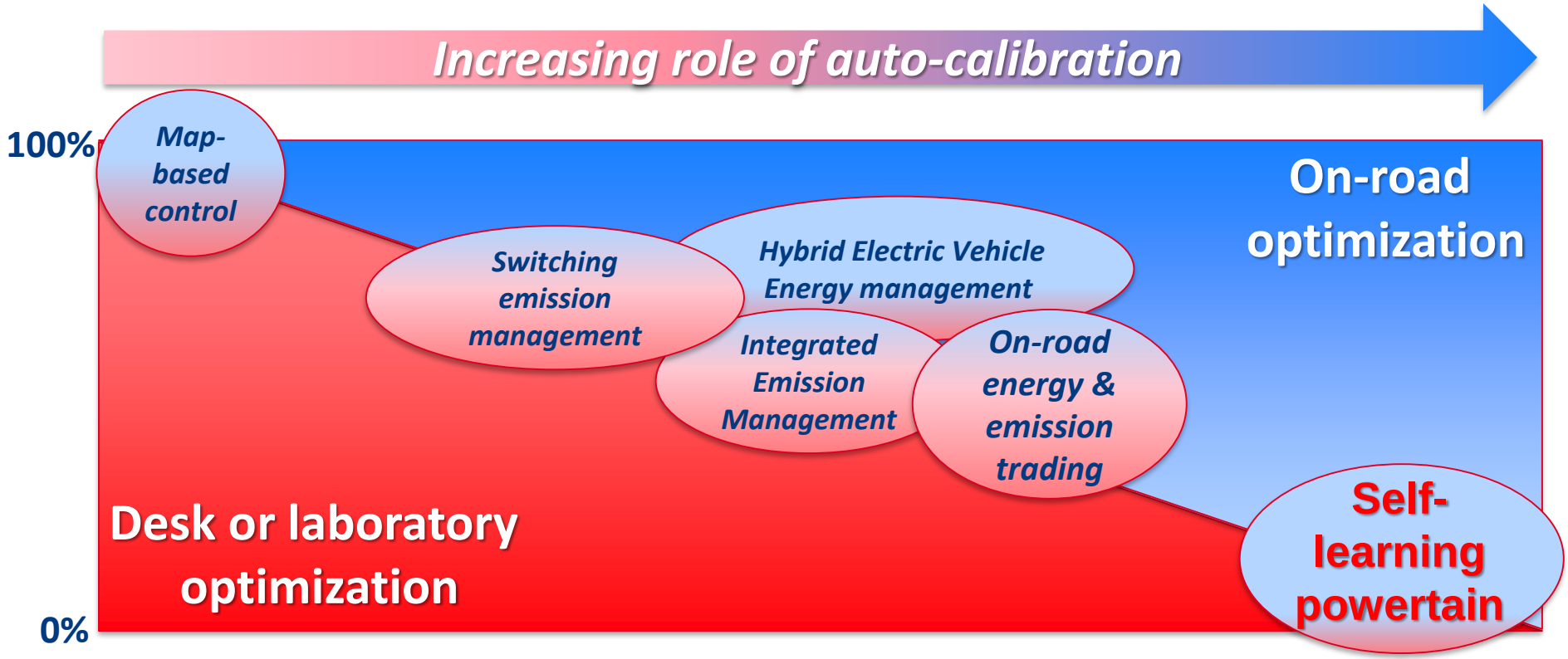


Integrated Powertrain Control

On-road energy and emission trading



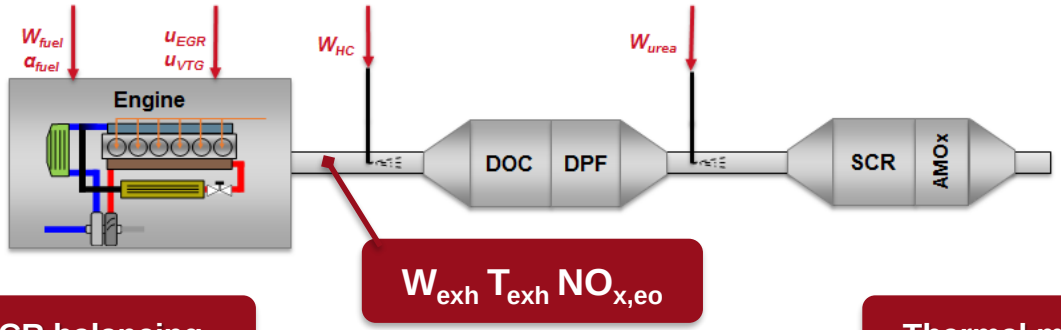
Towards Self-Learning Powertrains



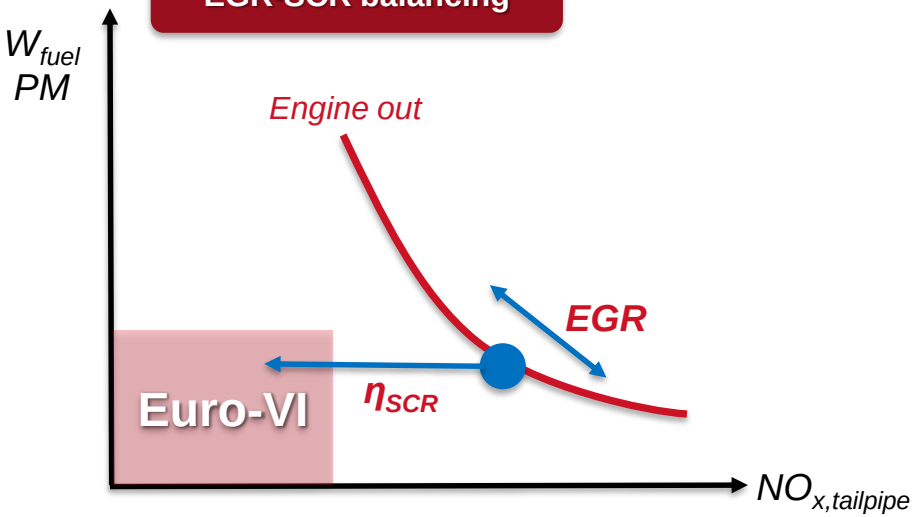
Frank Willems, Inaugural lecture, 2017

Emission management
Case study

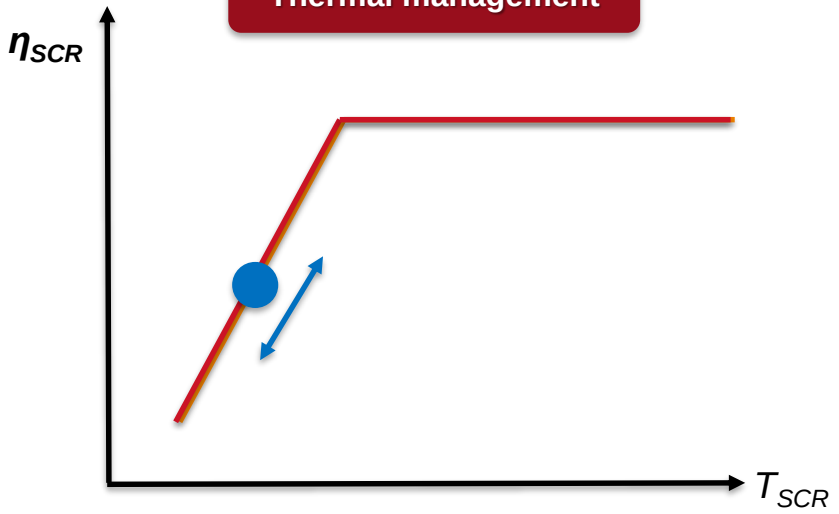
WHAT IS EMISSION MANAGEMENT?



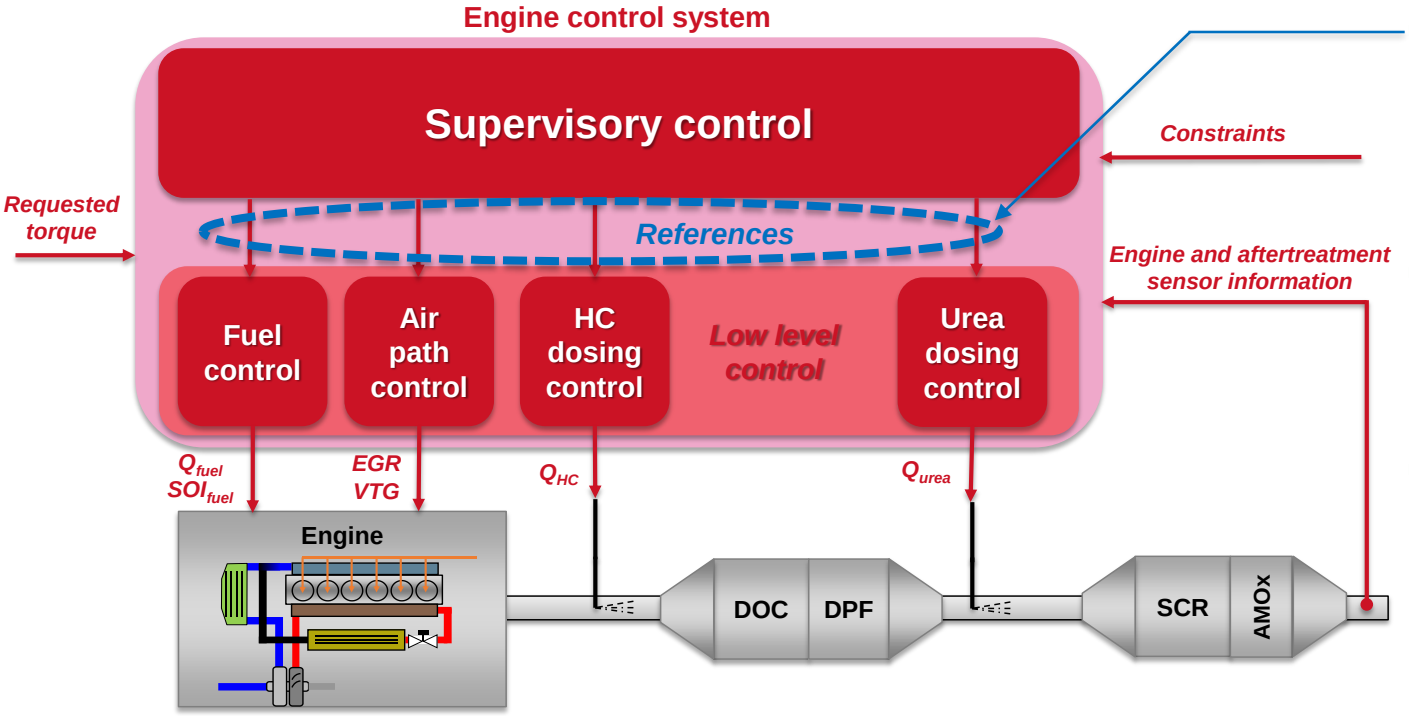
EGR-SCR balancing



Thermal management

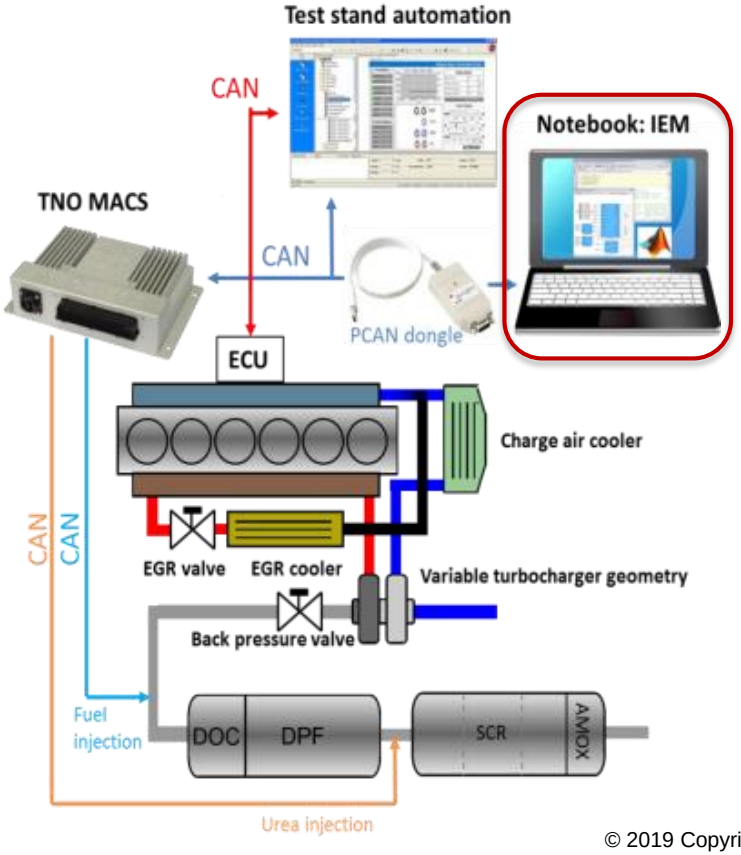


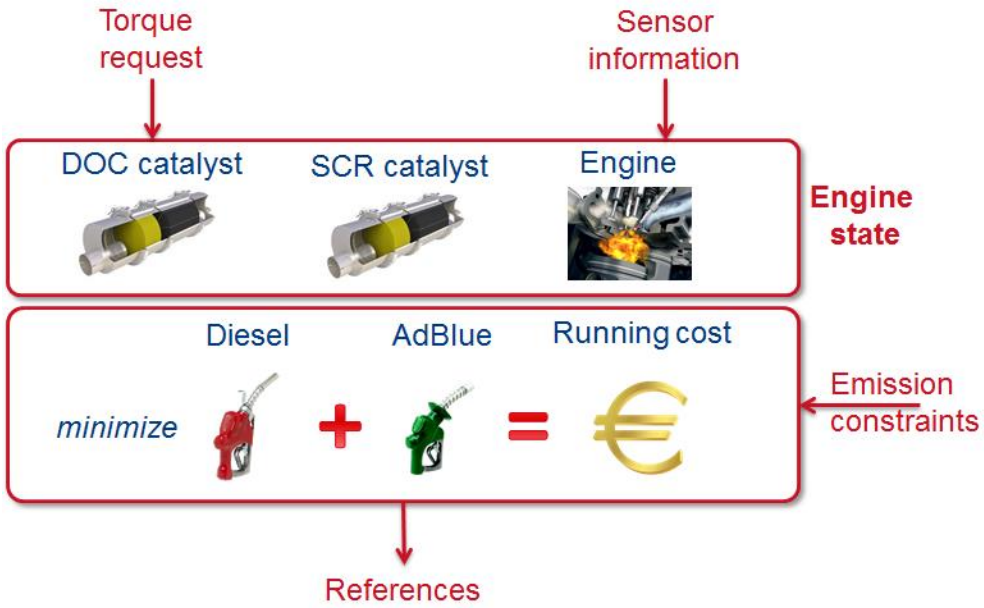
INTEGRATED EMISSION MANAGEMENT



- **Supervisory control** determines optimal references for low level controllers
- From fixed maps towards **on-line adaptation** based on actual engine state
- Deal with
  - (Varying) constraints
  - System uncertainties / disturbances

INTEGRATED EMISSION MANAGEMENT
ON-LINE COST-BASED OPTIMIZATION

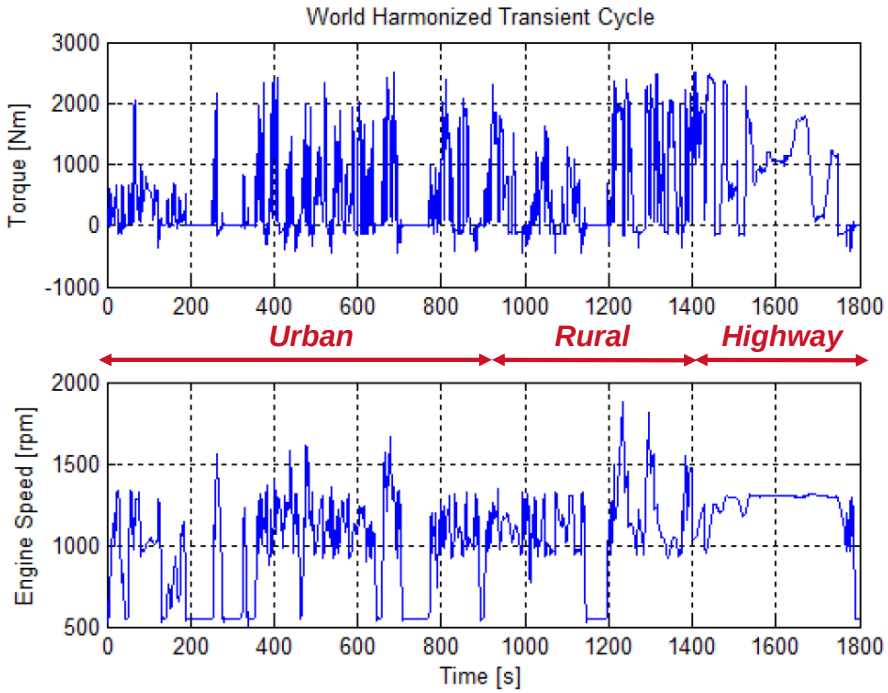




Willems, F., Mentink, P., Kupper, F. & Van den Eijnden, E. (2013). Integrated emission management for cost optimal EGR-SCR balancing in diesels, 7th IFAC Symposium on Advances in Automotive Control, p. 701-706

EXPERIMENTAL DEMONSTRATION

WORLD HARMONIZED TRANSIENT CYCLE (WHTC)



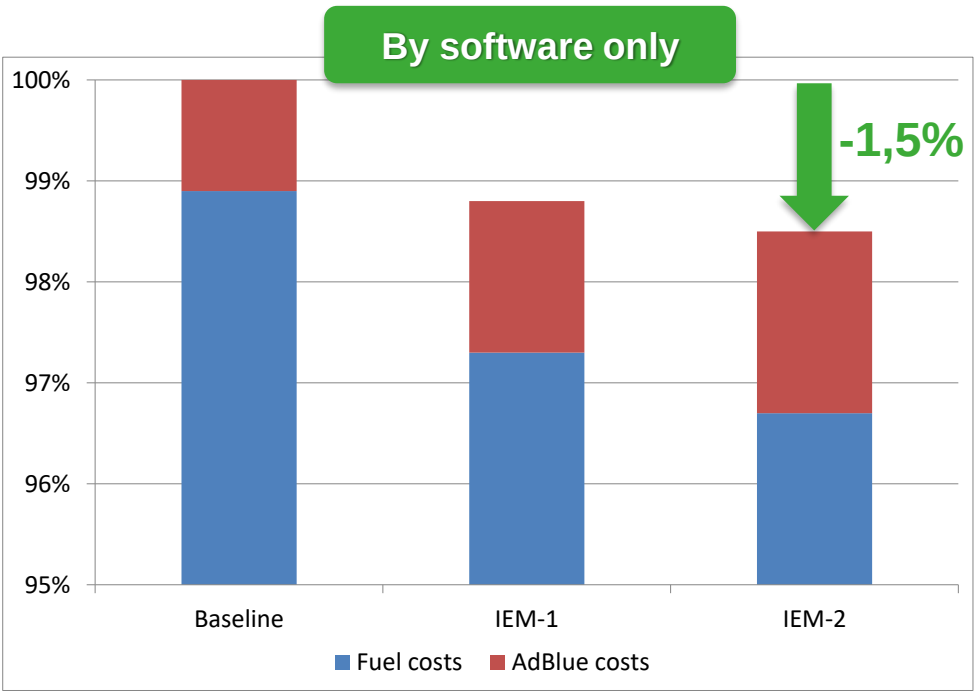
Comparison of:

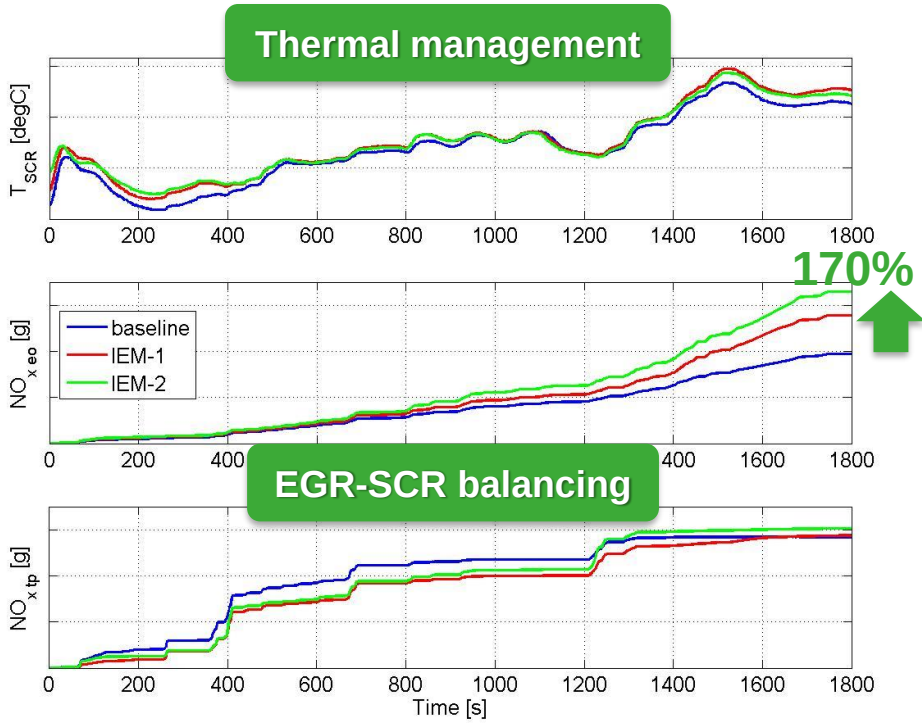
- Production Euro-VI baseline strategy
- Two IEM strategies (different λ_3 calibrations)
  - IEM-1: NO_x EURO-VI compliant
  - IEM-2: low BSFC

Focus on hot start WHTC

Willems, F., Mentink, P., Kupper, F. & Van den Eijnden, E. (2013). Integrated emission management for cost optimal EGR-SCR balancing in diesels, 7th IFAC Symposium on Advances in Automotive Control, p. 701-706

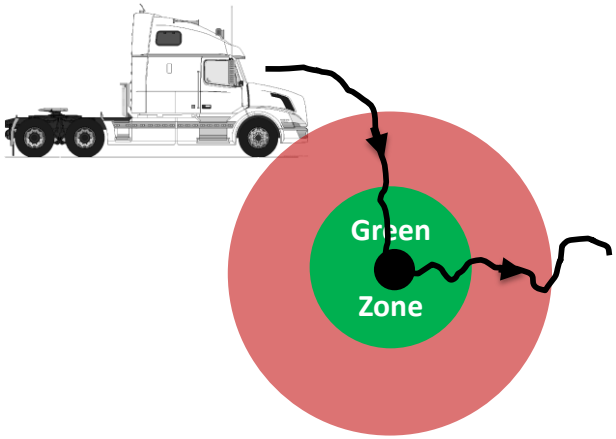
INTEGRATED EMISSION MANAGEMENT
EXPERIMENTAL RESULTS



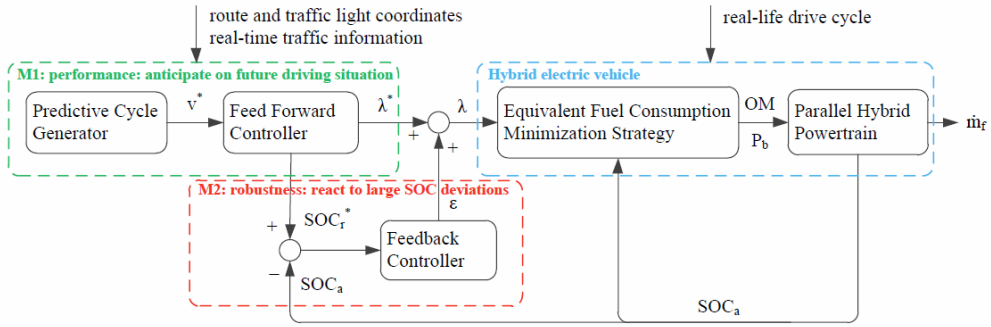


OUTLOOK

- **Challenges for hybrid-electric vehicles: integrated energy & emission management**
  - Frequent engine on/off
  - Low temperature operating conditions for SCR system
  - IEM approach can easily be extended:
    - Hybrid Electric Vehicles (HEV)
    - Waste Heat Recovery (WHR)

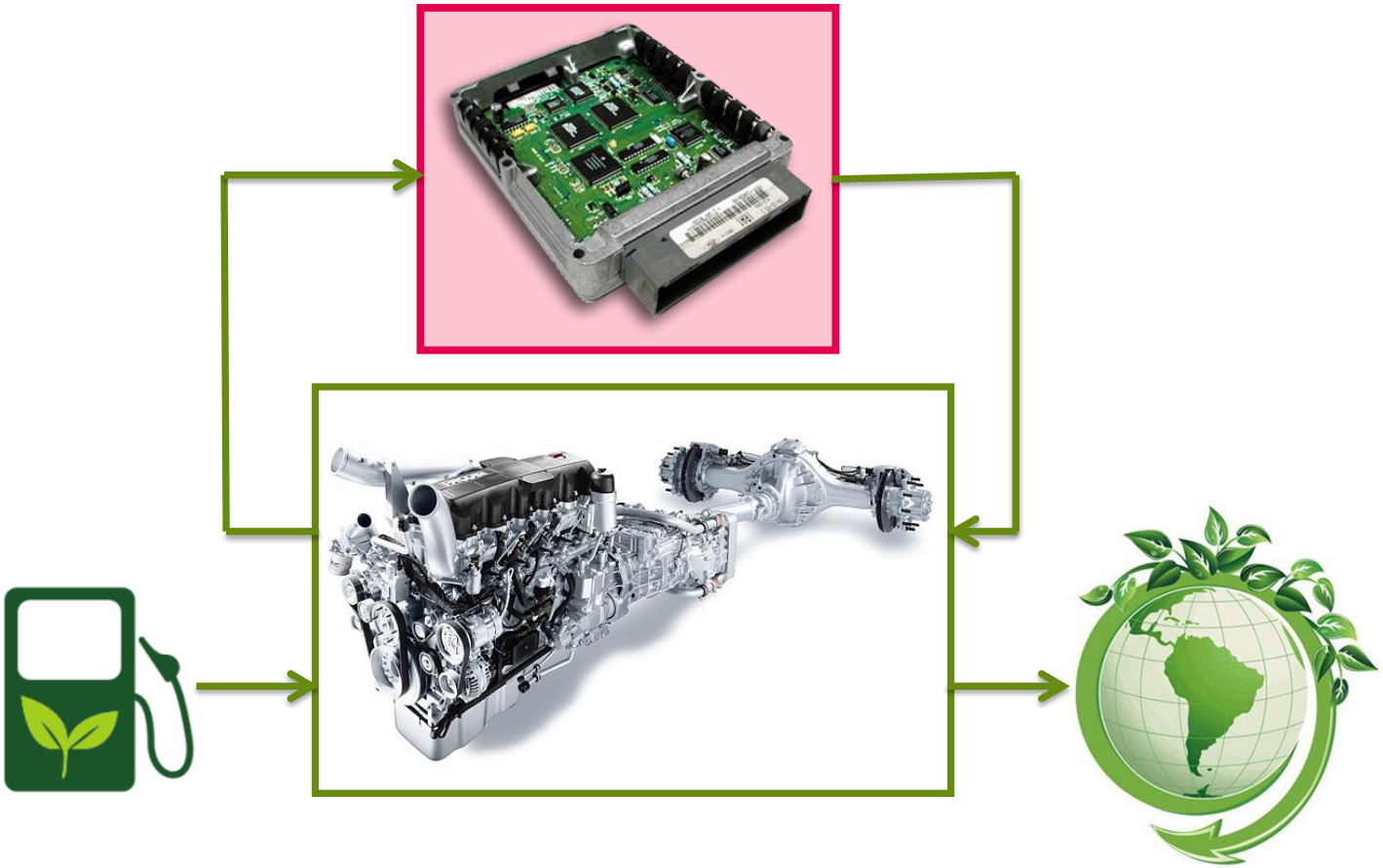


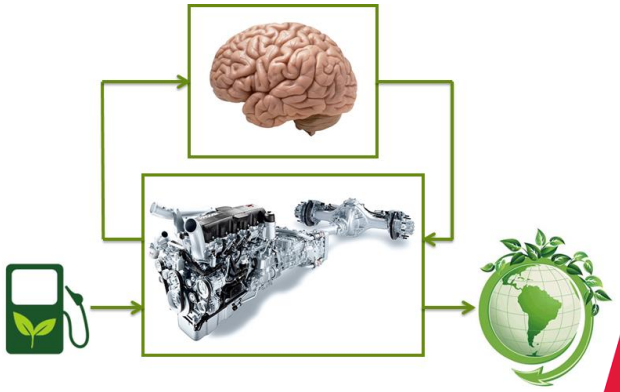
- **Opportunities for autonomous vehicles**
  - How to benefit from route, traffic, weather info?
    - Predictive control
    - Self-learning powertrain

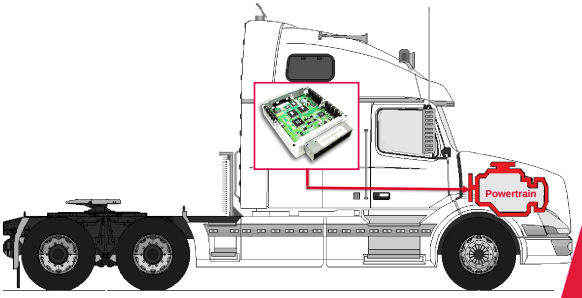


Source: Bouwman et al., IFAC-PapersOnLine, 2017

New, exciting chapter for powertrain control







Thank you for your attention

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