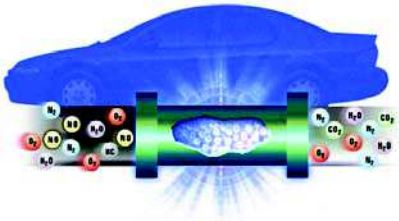
# Towards Integrated Powertrain Control

# Thermal Management of NG Heated Catayst System

TNO | Knowledge for business

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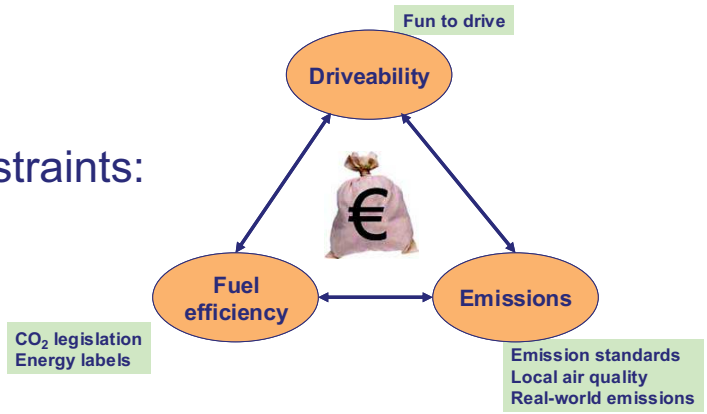
*26 November 2008*

## Outline Presentation

- Introduction Integrated Powertrain Control (IPC)
- Efficient powertrain development with IPC tools
  - Recognize interaction between subsystems
- Case study: IPC tools for catalyst heating
  - NG-engine with electrically heated catalyst system
  - System analysis
  - Heating strategy analysis
  - Measurement and simulation results
- Conclusions

## Introduction Integrated Powertrain Control

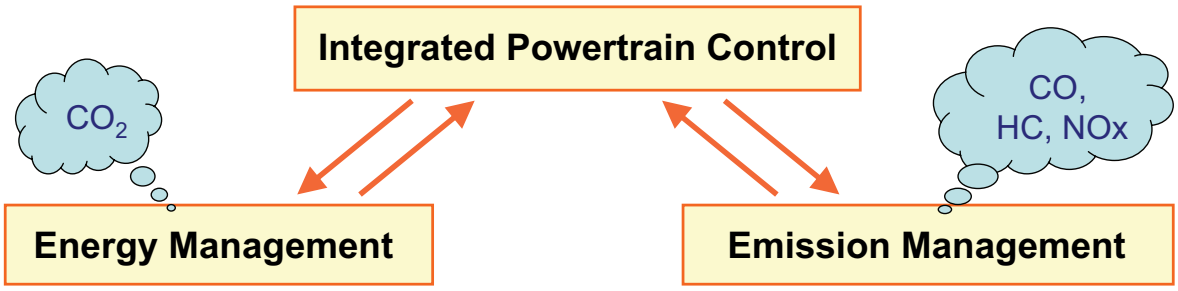
- More stringent vehicle requirements and constraints:

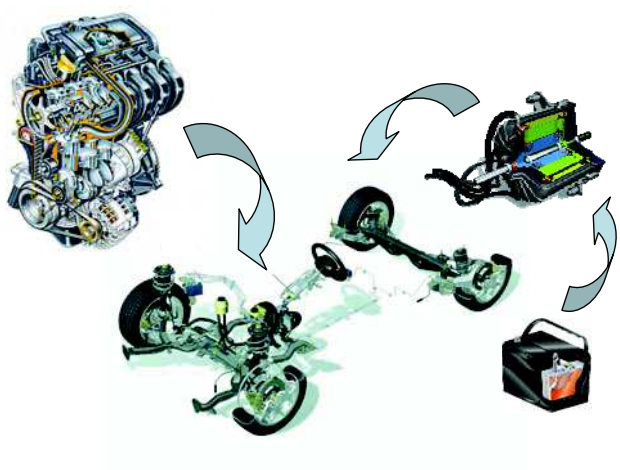


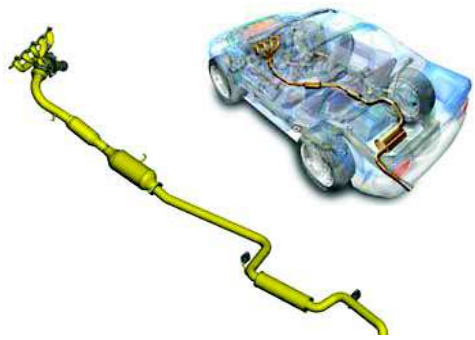

- Increasing vehicle complexity owing to new advanced automotive technologies
- Tools required to handle system complexity and developing efficient powertrains:
  - >> Integrated Powertrain Control
    - Unified framework for developing control strategies incorporating all vehicle requirements
    - Exploit synergy between components
    - Optimal integration of subsystems



## Integrated Powertrain Control: System integration



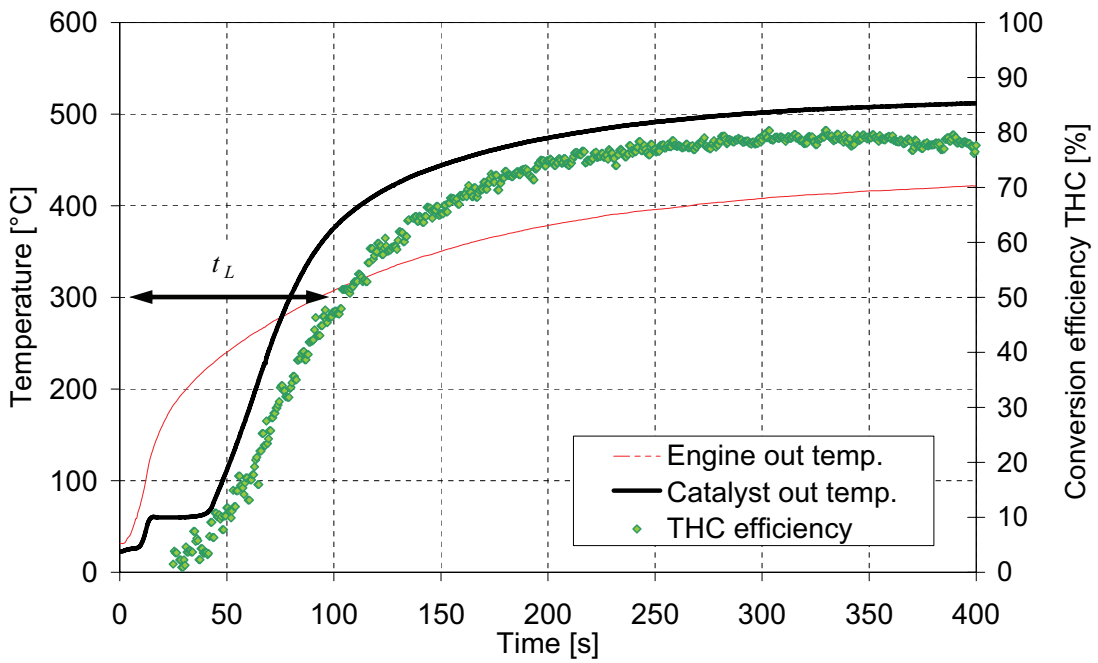


- Fast catalyst heating to reduce cold-start emissions
- Evaluate possible heating strategies
  - Ignition retard
  - Electric heated catalyst (in combination with hybrid powertrain)
- Consider fuel penalty for both heating methods
- Use IPC to analyze & develop heating strategy
- Vehicle configuration under consideration
  - Hybrid Electric Vehicle
  - Natural Gas engine
  - 3-way catalyst with electric heating

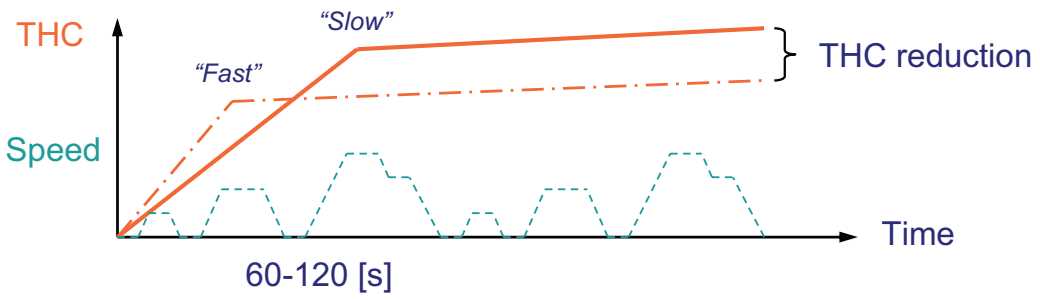




- Typical light-off profile for 3-way catalyst



- Most emissions appear during cold-start period
- Fast heating can improve overall exhaust emissions
- Required heating energy introduces fuel penalty




- How to select suitable heating strategy?
  (ignition retard / electric heating)

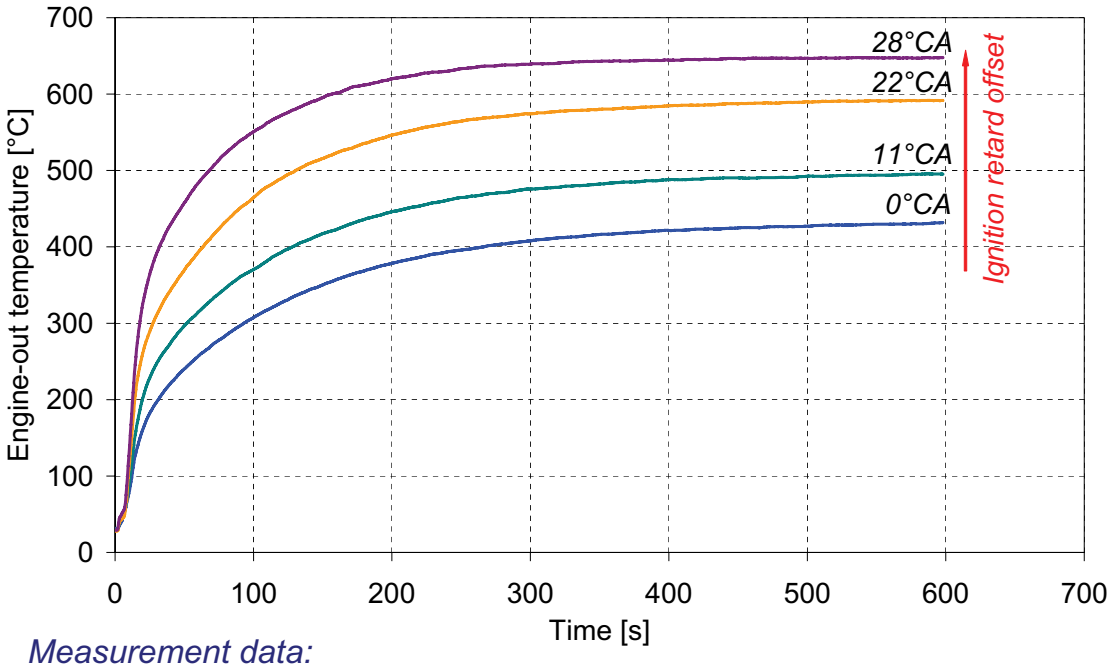




- How to make fair comparison between different heating methods?
- IPC tools characterize fuel penalty and light-off time according to heating method
  - Measurement data characterizes ignition retard
  - Simulation results reveal potential for electric heating system
  - Validated simulation model used to characterize fuel sensitivity for electric energy from hybrid powertrain
- Final assessment of heating methods learns which method is preferred

## Catalyst heating through ignition retard

- Ignition retard $\phi$ [°CA] increases exhaust temperature

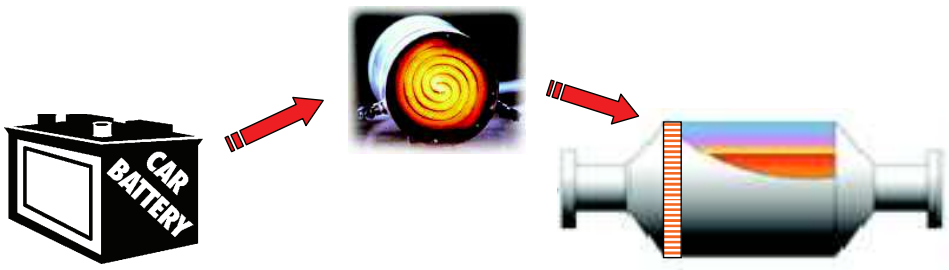



*Measurement data:*
NG-engine - 2.3L - 5 cylinders



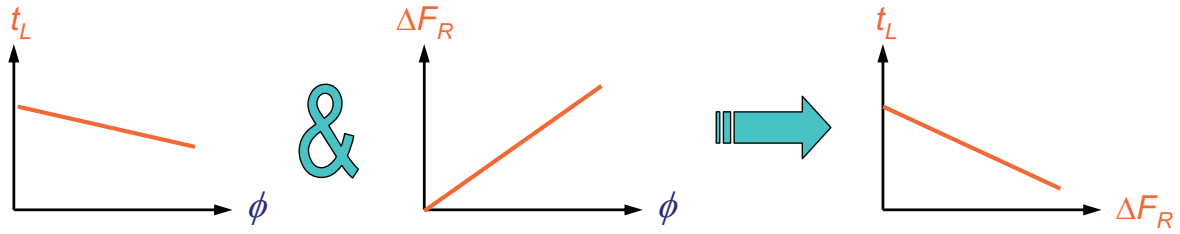
## Electric heated catalyst system

- Electric heating can be applied in two ways
  - Direct heating of catalyst brick (heat transfer ⇒ conduction)
  - Indirect heating ahead of catalyst (heat transfer ⇒ convection)
- Current research considers only direct heating
  - Direct heating also works with engine stop
- Heating applied to first segment only
  - Reaction heat used for light-off downstream catalyst

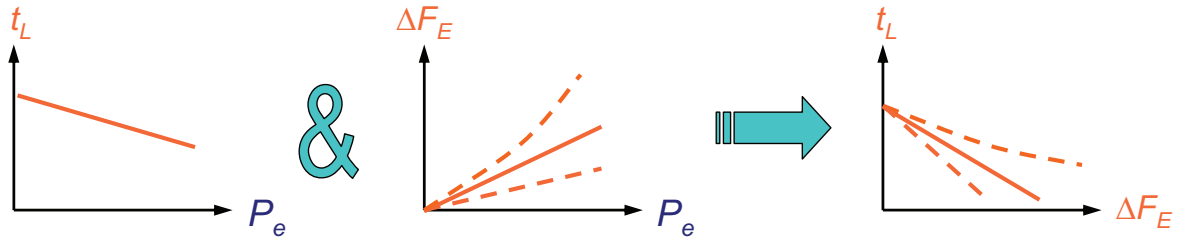


## IPC Tools - Graphical overview

- Ignition retard: $\phi$ [°CA]



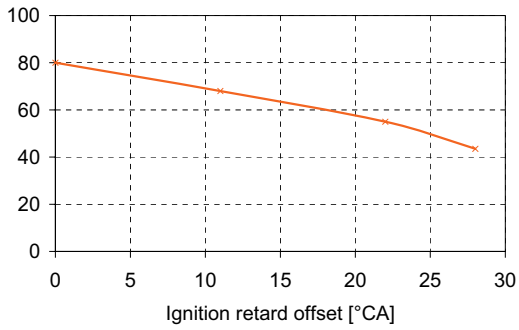

- Electric heating power: $P_e$ [W]



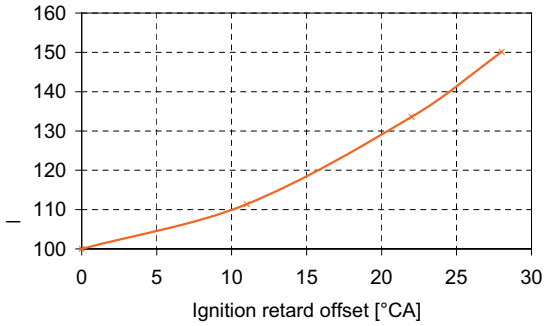


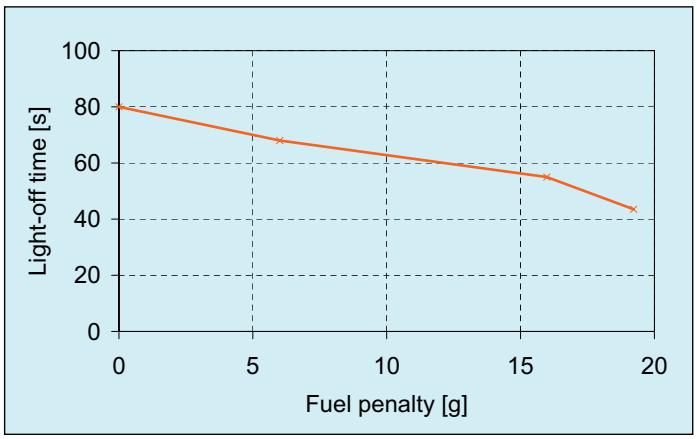

## Measurement data - Ignition Retard

Light-off time [s]

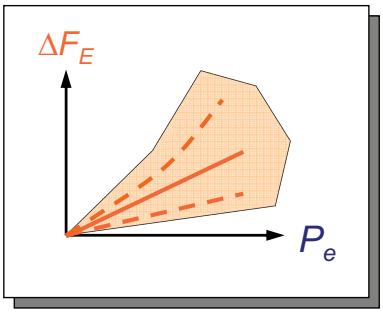



Relative fuel use [%]



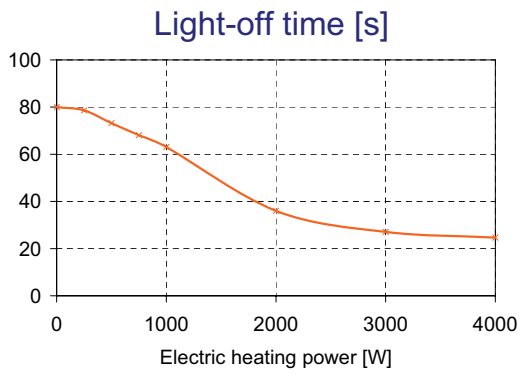
- Simulation model supports sensitivity analysis for (hybrid) vehicle parameters:
  - Engine fuel map characteristics
  - Power limits motor/generator
  - Charge acceptance battery
  - Battery losses
  - Available regen-braking energy
  - Vehicle driveability
  - Energy management strategy
  - …

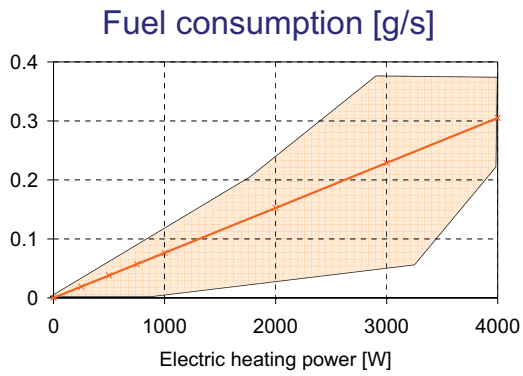


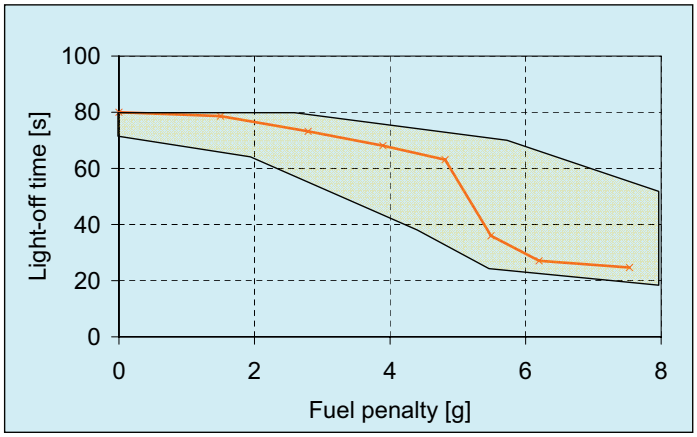

- All vehicle parameters are graphically visualized in an uncertainty area for fuel penalty $\Delta F_e$



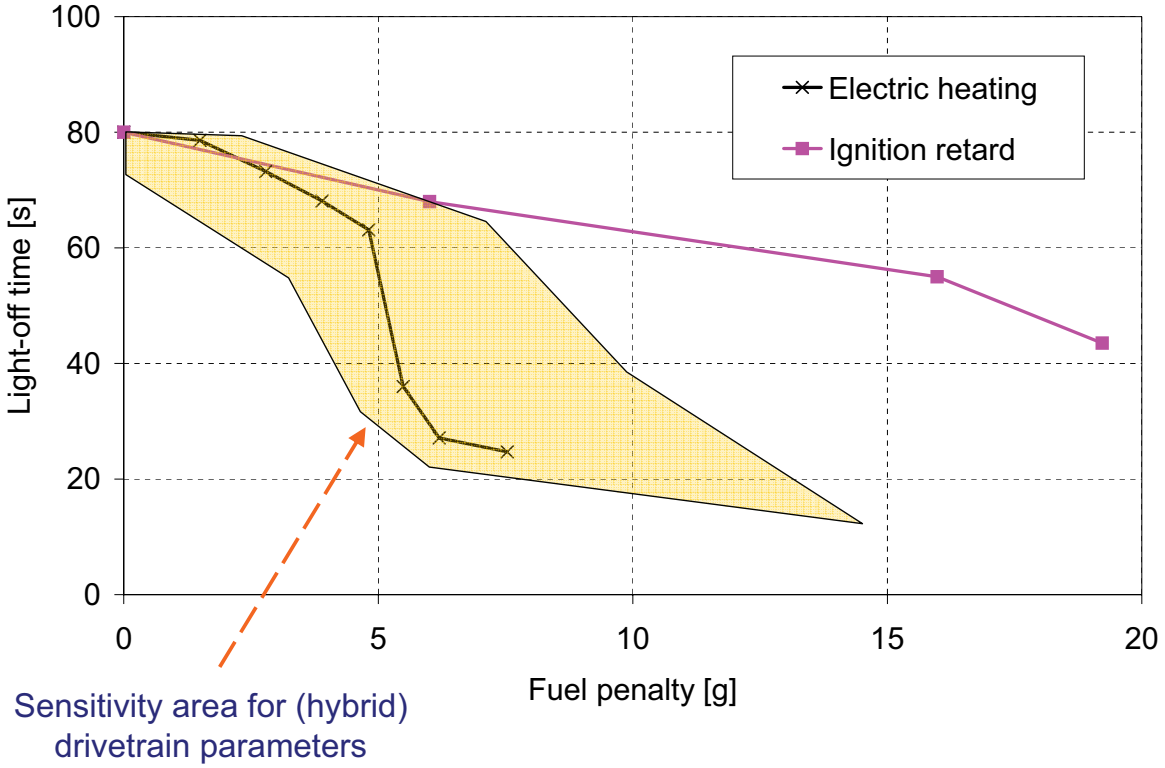




## Final assessment of both heating methods






## Conclusions

- Powertrain development with IPC tools
  - Handle system complexity
  - Efficient powertrain: integration of subsystems
- Case study presents IPC tools for catalyst heating
- Focus on fuel penalty, but emissions can be included in similar way
- IPC will be applicable to many other projects
  - E.g. DPF regeneration by increasing engine operating point with hybrid system