DOE Merit Review – Flex Fuel Vehicle Systems

- Bosch FFV Project Structure and Partners
- Purpose of Work – Project Highlights
- Barriers – Existing Flex Fuel Systems and Problems
- Approach – Bosch Flex Fuel Advanced Project with DOE
- Performance Measures and Accomplishments
- Plans for Next Fiscal Year

DOE Merit Review
Bethesda, Maryland
Feb 27th, 2008

Hakan Yilmaz
Manager – System and Advanced Engineering
Bosch Gasoline Systems – North America

DE-FC26-07NT43274
DOE Project Manager – Sam Taylor

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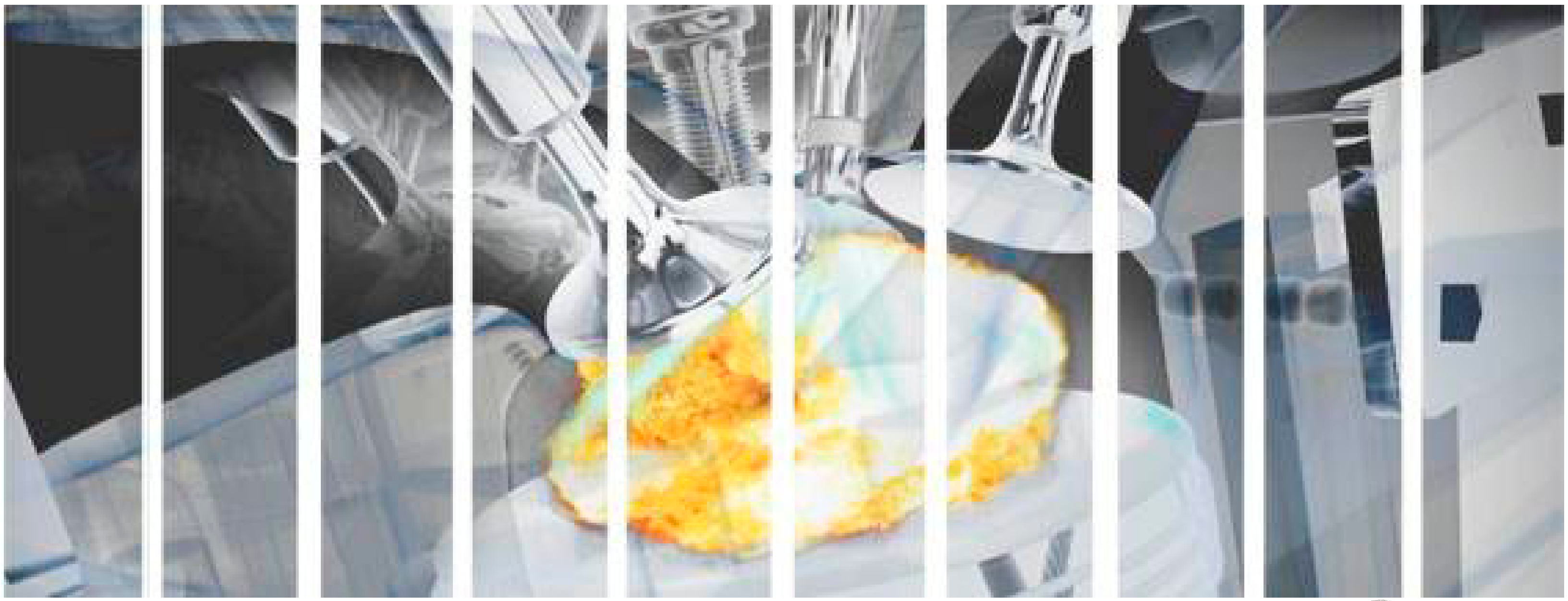
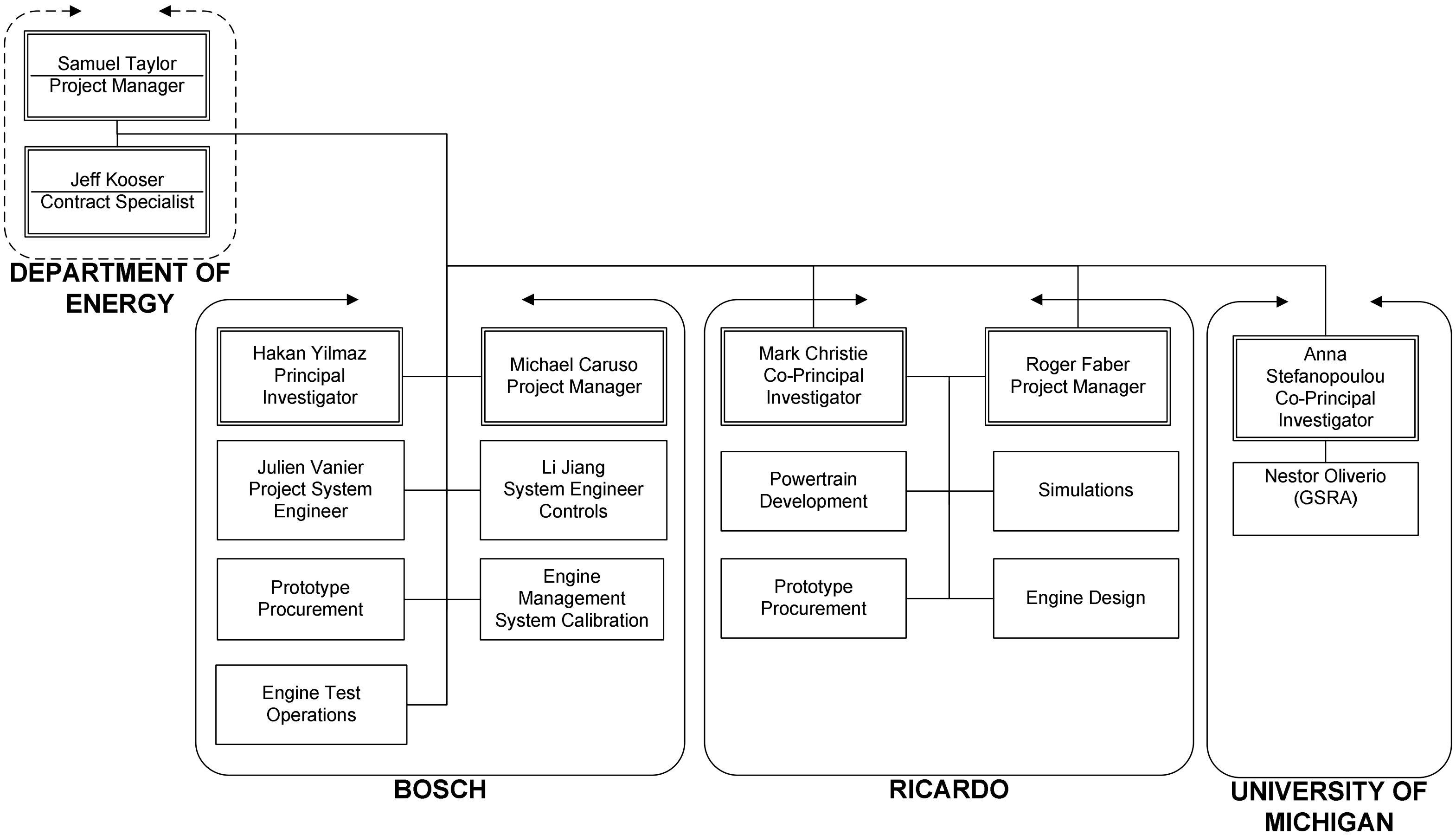
Bosch Gasoline Systems – Business Units

Air Management	Fuel Injection	Direct Injection	Ignition & Sensors	Electronic Control Units	Fuel Supply	Connectors & Plastic Parts	Transmission Control	Continuously Variable Transmission	System and Advanced Engineering



Project Organization



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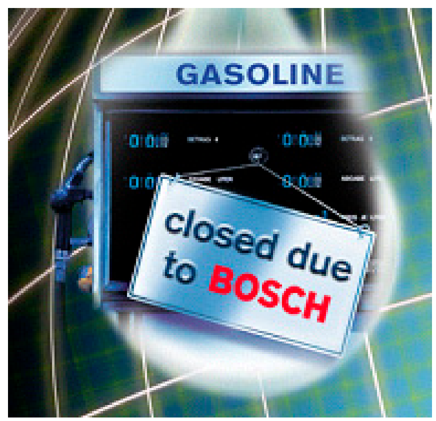
Advanced FFV – Future Technologies

1. Current FFVs
- Legislations -
- CAFE Credit -

Achievement of fuel economy not sufficient

Additional benefits
- Oil dependency
- High knock limit



2. Advanced FFVs
- Fuel Economy -
- Performance -

DI w/ Turbo Charging
- High Boosting

Dual VVT
- Effective Compression Ratio Optimization

Advanced Controls
- Optimized operation for All Ethanol blends E0..E85

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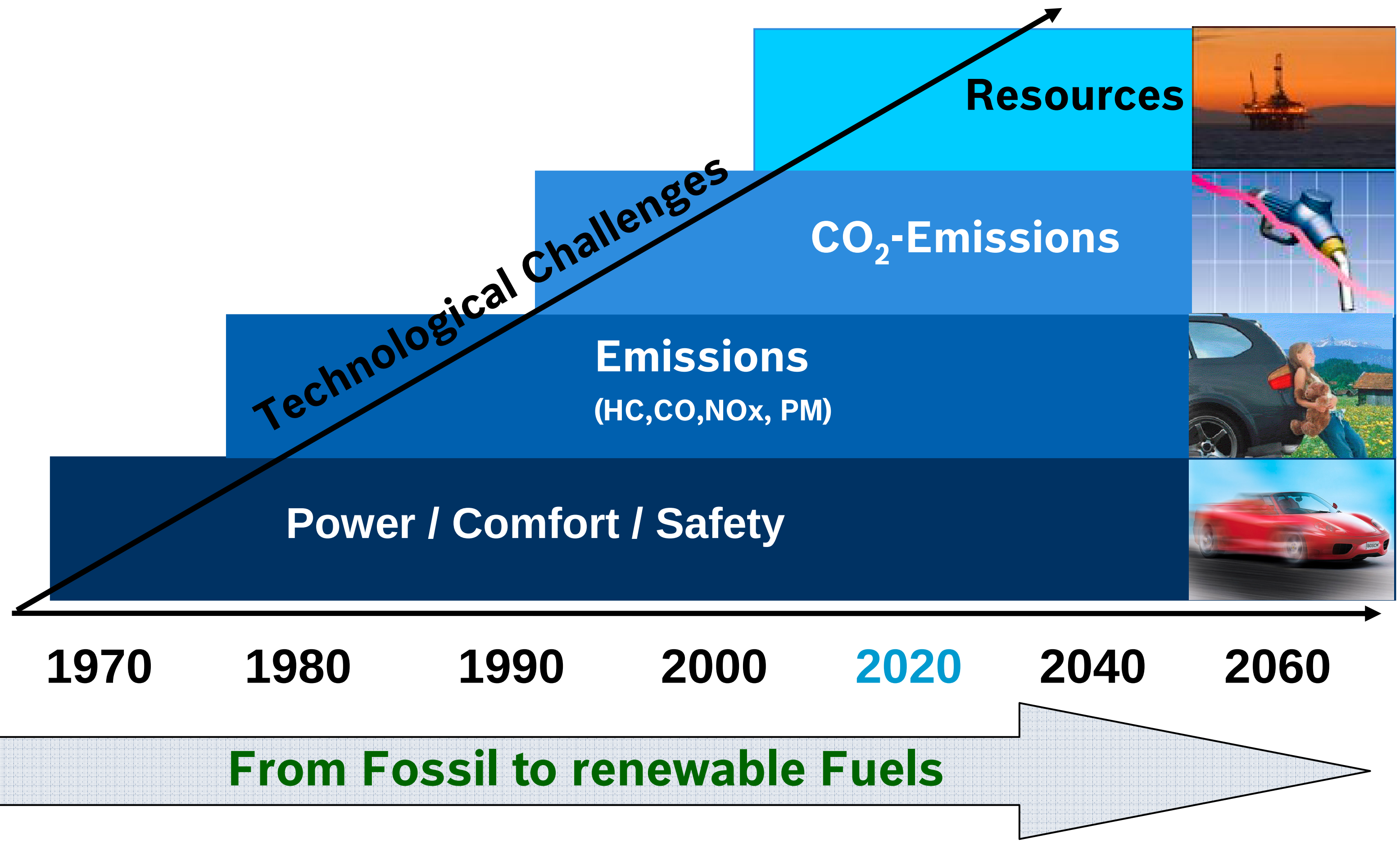
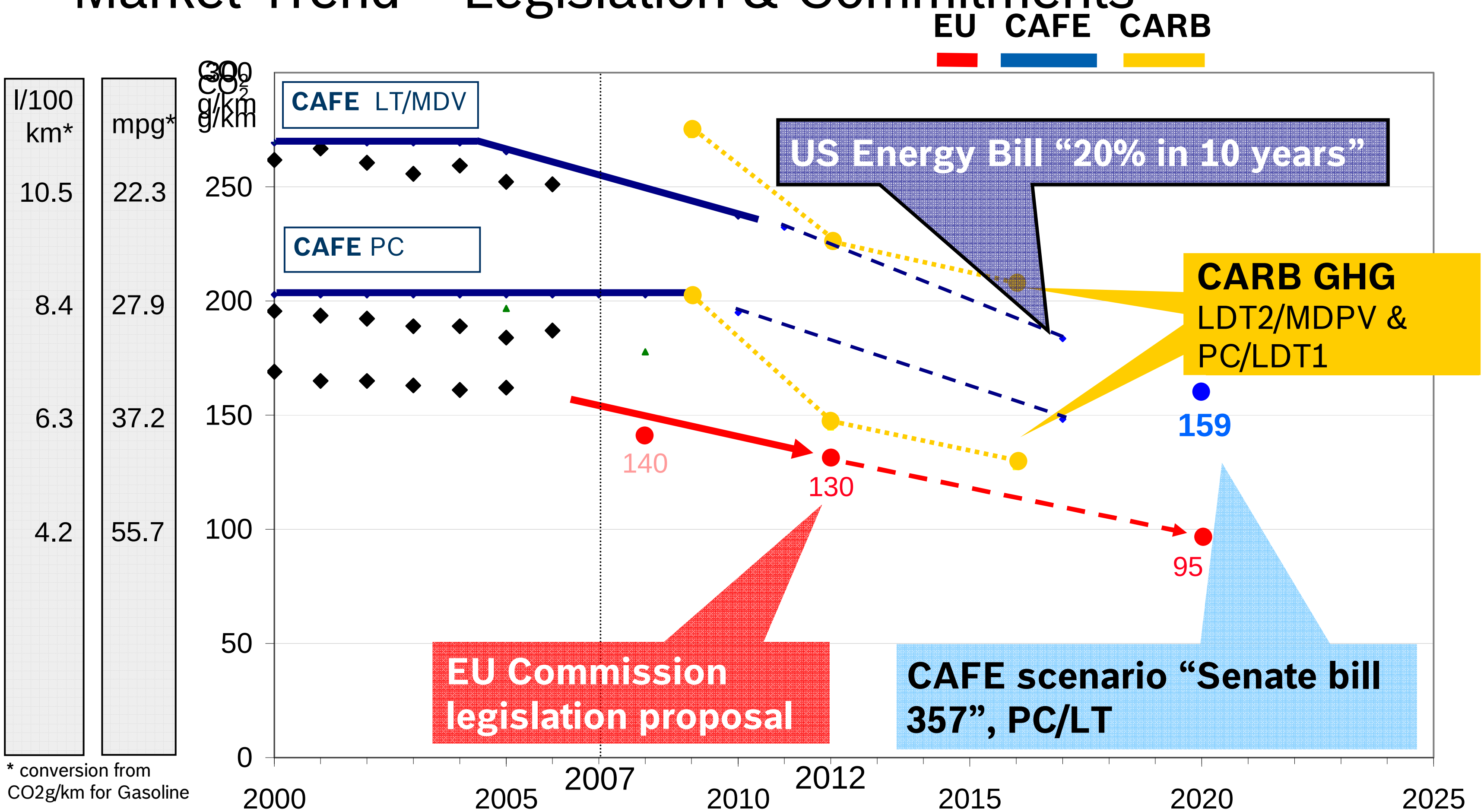
Market Trend – Challenges for Automotive Technologies

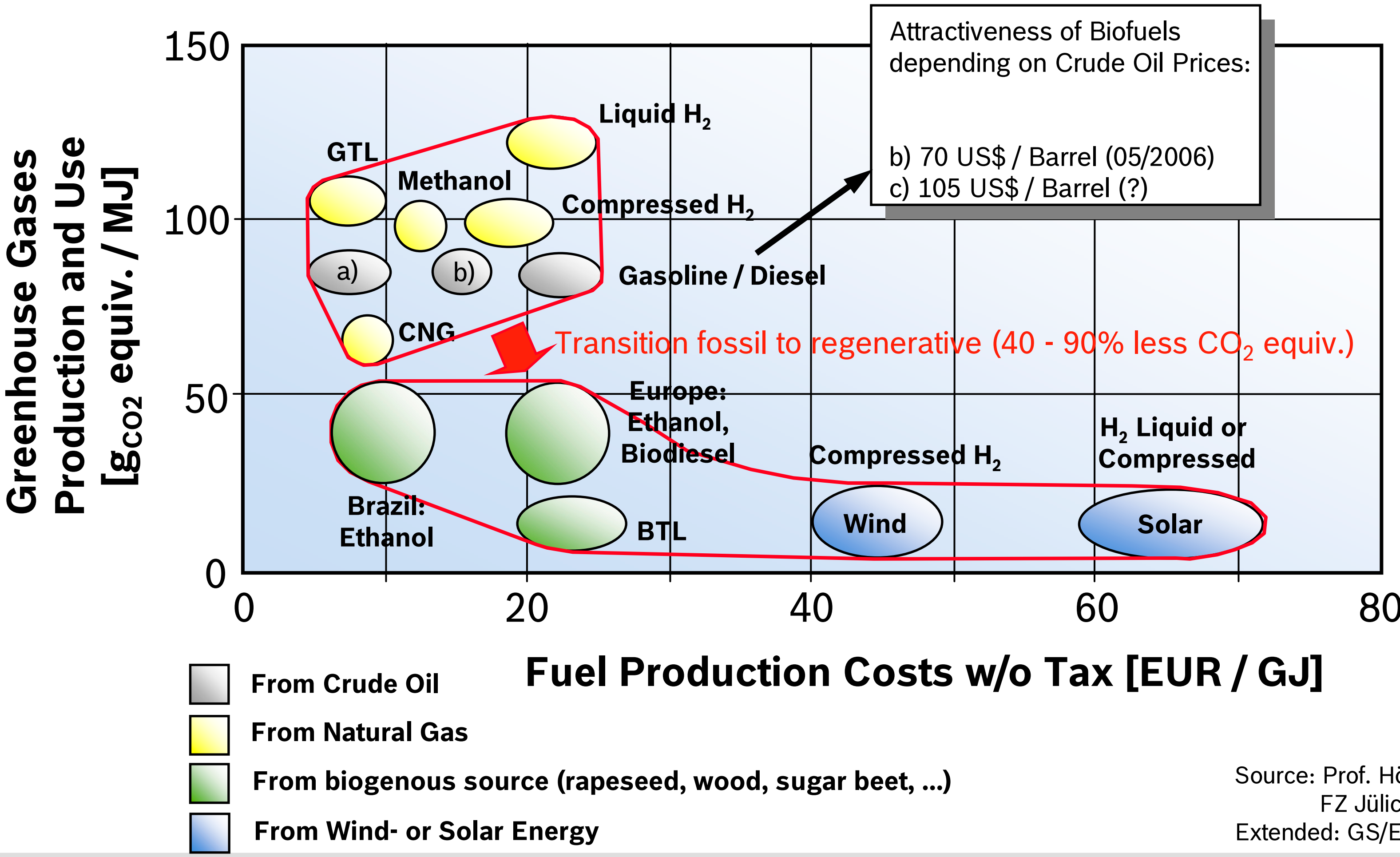


Market Trend – Legislation & Commitments



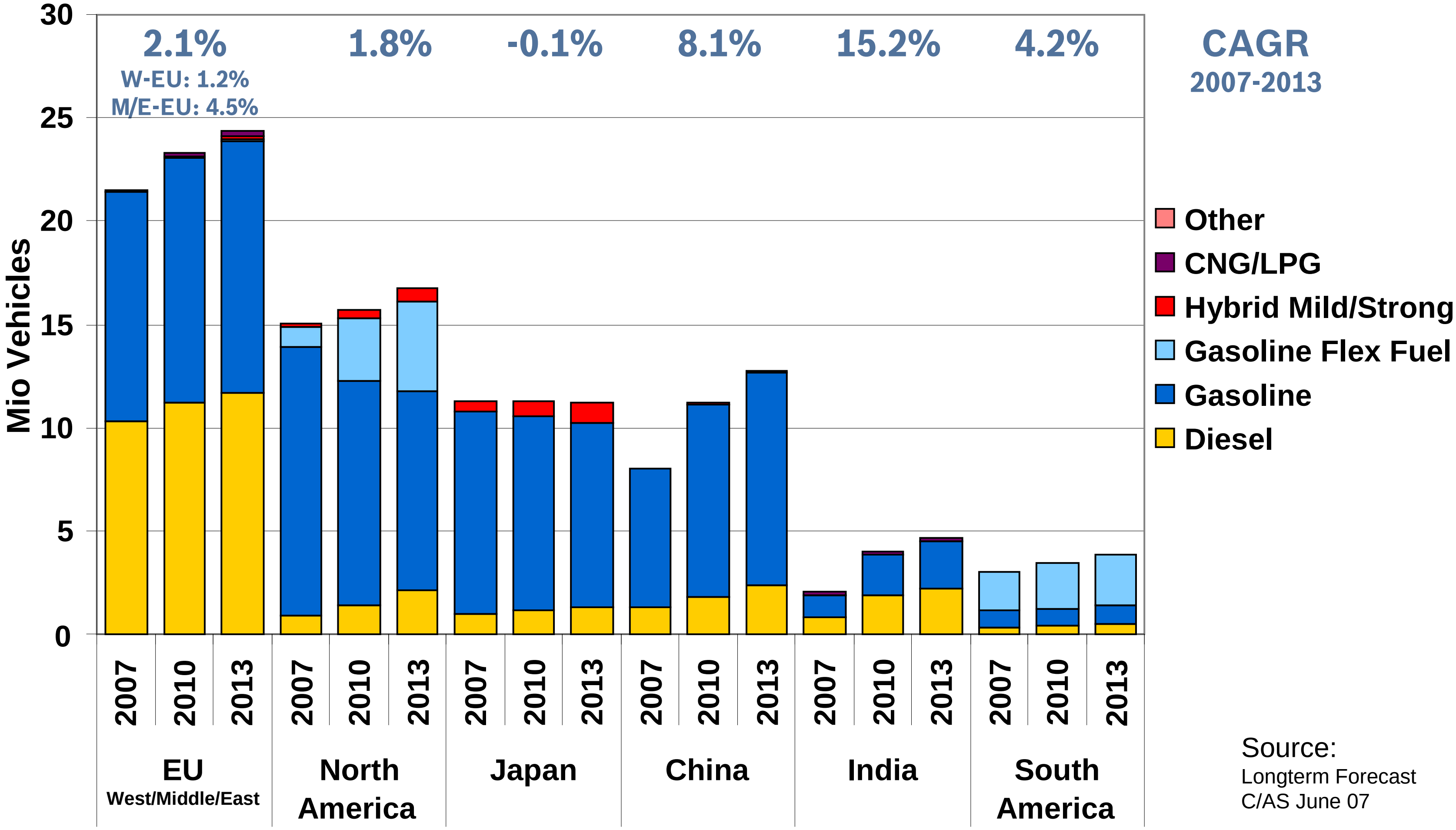
CAFE = Corporate Average Fuel Economy PC = Passenger Cars, LT / LDT = Light Trucks (pick-ups, vans, SUVs), MD(P)V = Medium Duty (Passenger) Vehicles
CARB = California Air Ressources Board mpg = miles per gallon EU data for ACEA (Association des Constructeurs Européens d'Automobiles)

Market Trend – Cost of Alternative Fuels



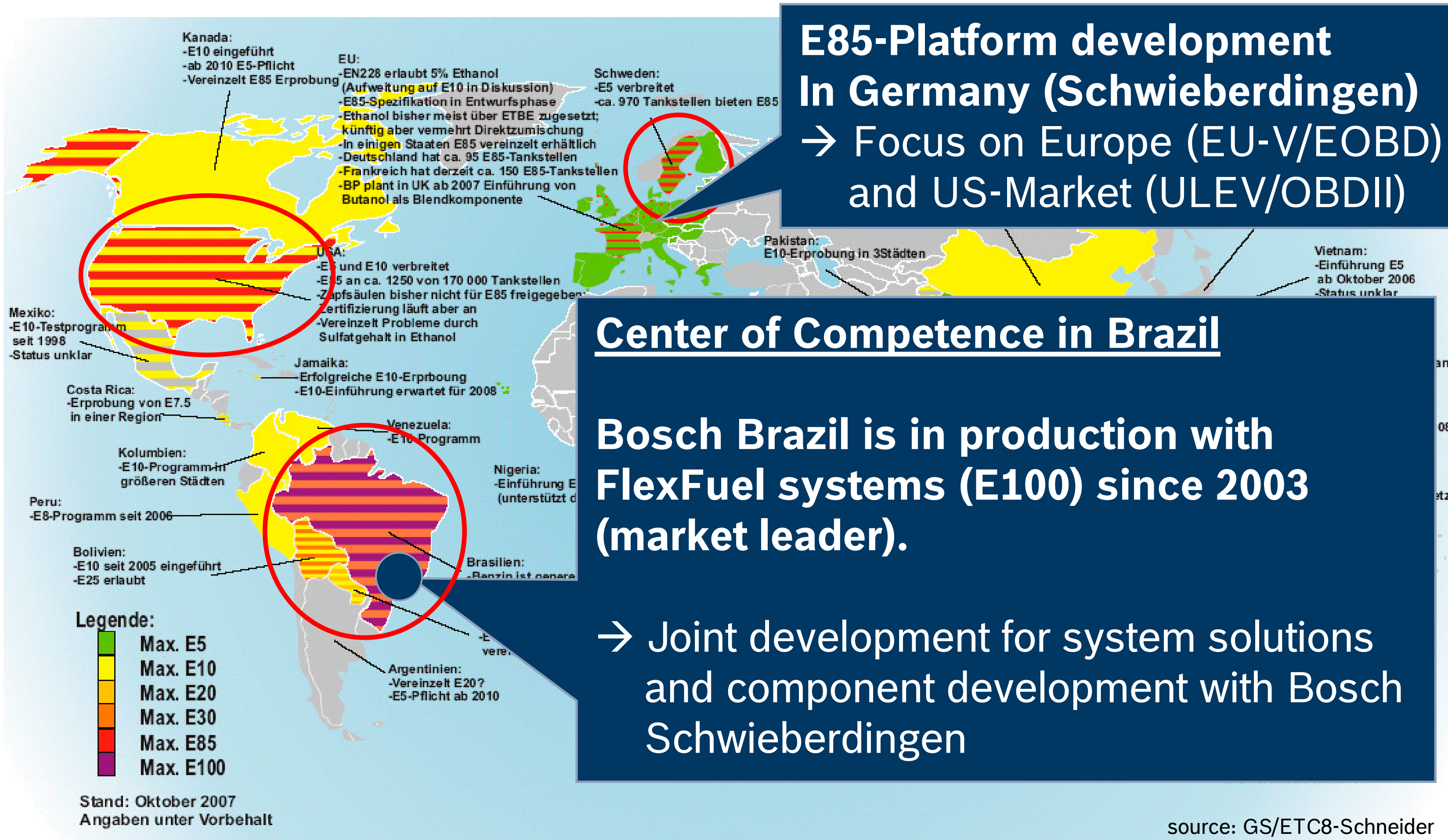
Source: Prof. Höhnlein
FZ Jülich 2005
Extended: GS/ENS

Forecast – Vehicle Production World Wide



Source:
Longterm Forecast
C/AS June 07

Market Trend – Ethanol Containing Fuels - Worldwide



E85-Platform development In Germany (Schwieberdingen)

→ Focus on Europe (EU-V/EOBD) and US-Market (ULEV/OBDII)

<u>Center of Competence in Brazil</u>

Bosch Brazil is in production with FlexFuel systems (E100) since 2003 (market leader).

→ Joint development for system solutions and component development with Bosch Schwieberdingen

source: GS/ETC8-Schneider

FFV Systems – Ethanol Fuel Characteristics

Properties	Unit	Gasoline	E85
Calorific value	MJ/kg	**42,5**	**29,1**
Air-Fuel Ratio	-	**14,8**	**9,8**
Boiling Temperature	°C	**25…215**	**~78**
Evaporation Enthalpy	kJ/kg	**380…500**	**~800***
Octane	RON	**>91**	**≥108***

(* approximated values)

Ethanol (C_2H_5OH)

Benefits / Drawbacks

-Requires Higher Injection Quantity up to 35%

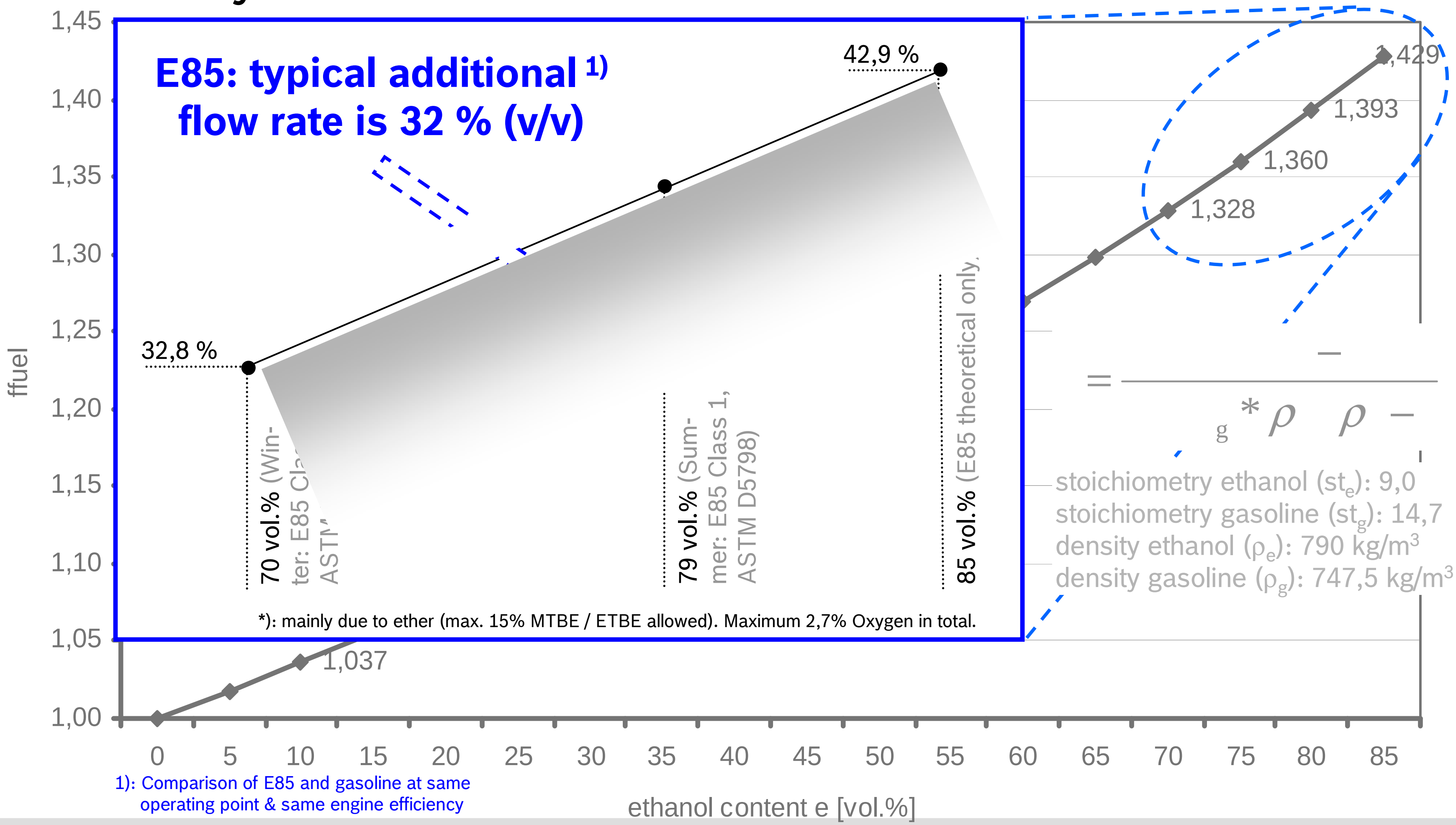
-Cold start critical beyond -10°C (E85)

- produces more water, retarded Cat warm up

- More wall wetting
- More oil contamination
+ More Power / Higher Efficiency (up to 6%) (Stronger Air Cooling)

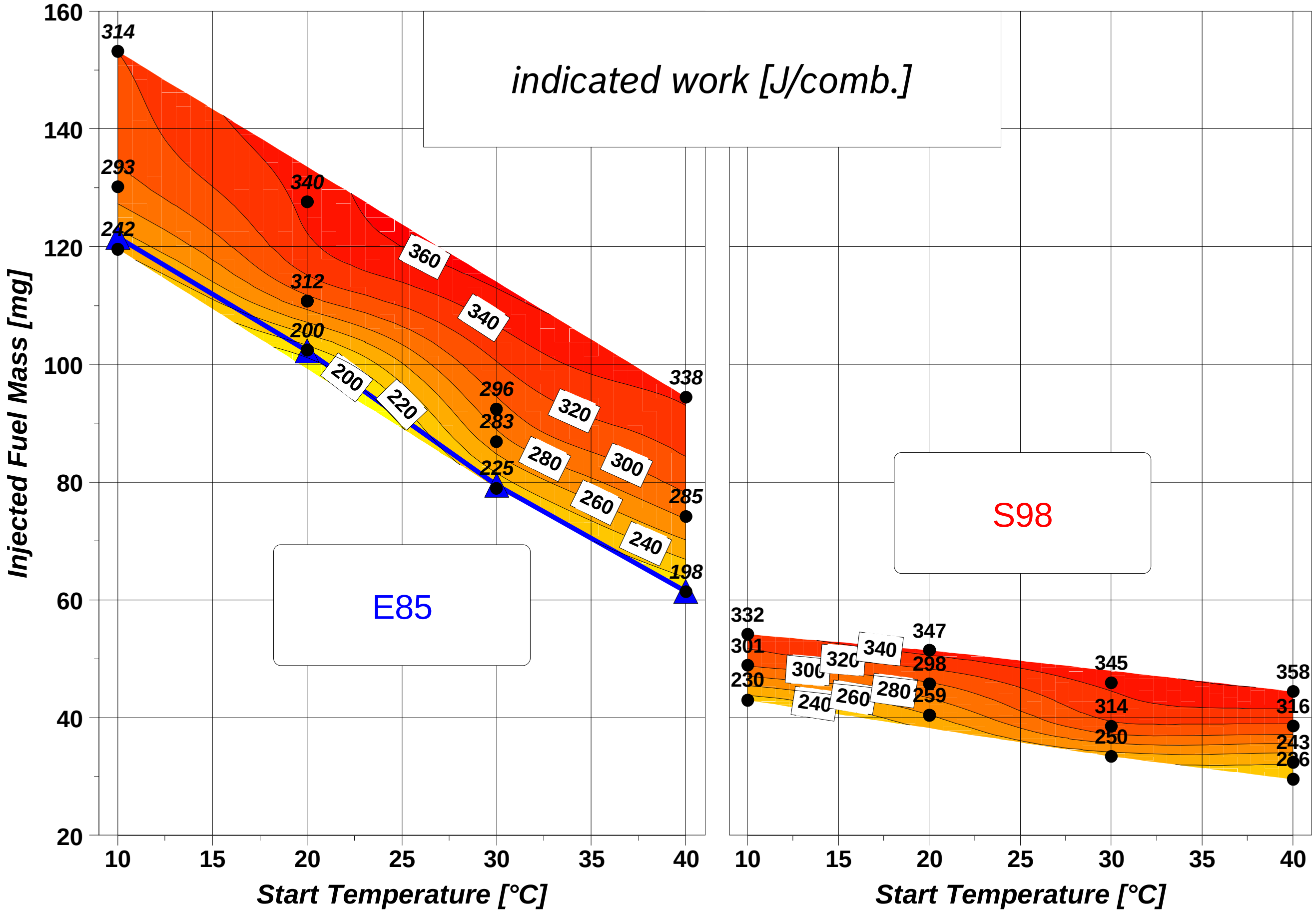
+ High Knock Limit
+ More Power / Higher Efficiency (up to 6%)

FFV Systems – Additional Flow Rate with Ethanol Fuel



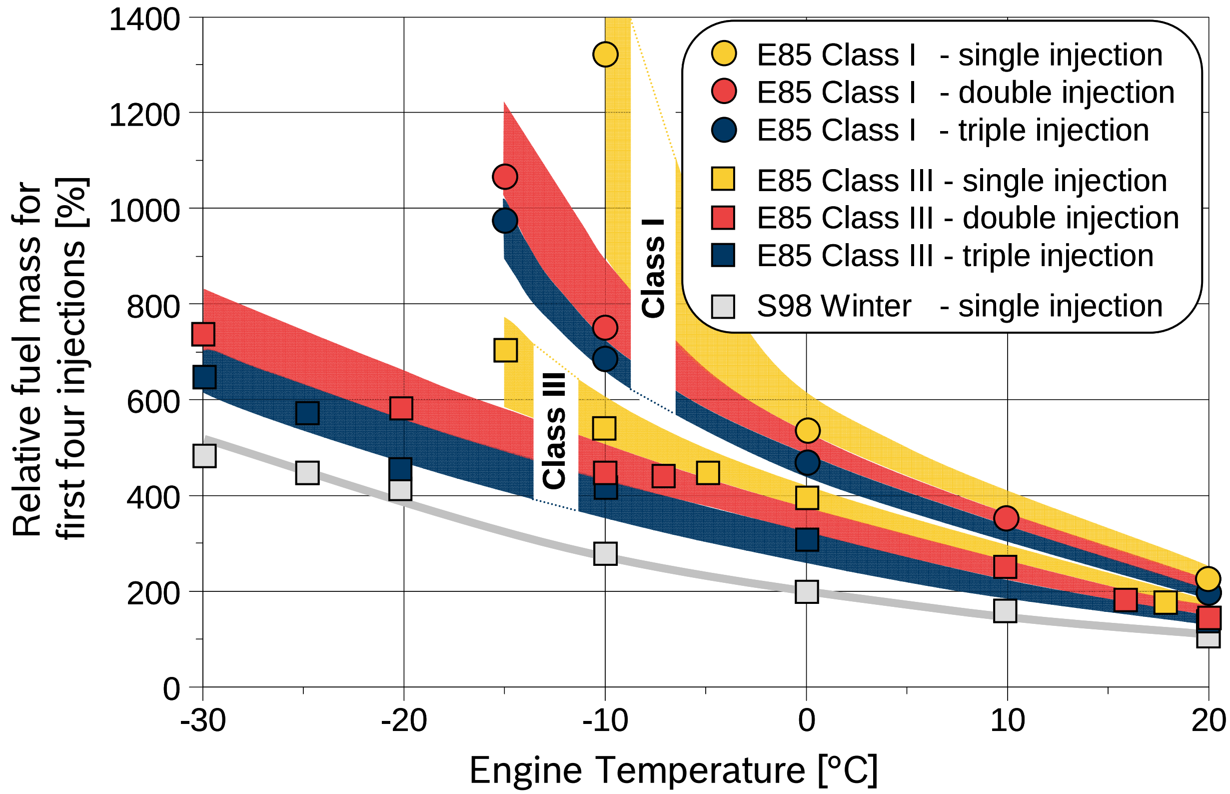
1): Comparison of E85 and gasoline at same operating point & same engine efficiency

FFV Systems –Start Fuel Mass with Ethanol



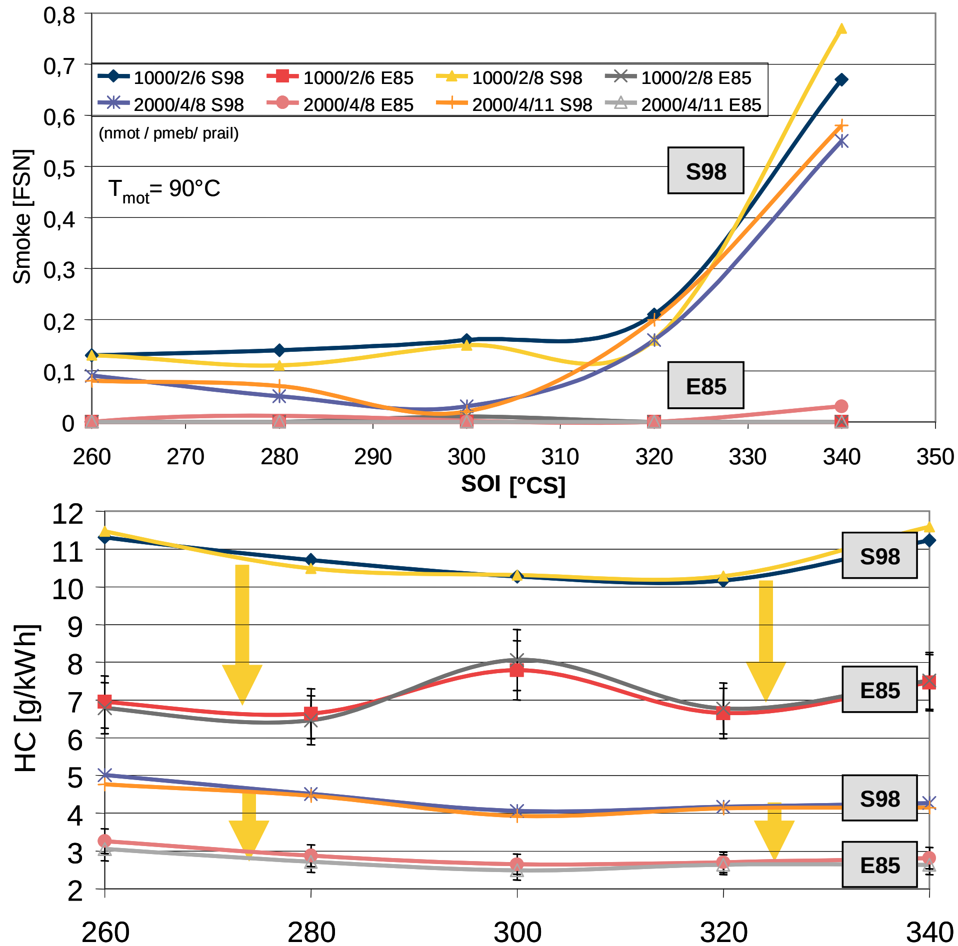
Source: GS-PJ/CCT, GS/ENA3

FFV Systems – Cold Start Fuel Enrichment with DI



E85 Class III + modified start strategy (multi-injection & 20 MPa start rail pressure)
→ Engine start feasible down to -30°C

FFV Systems – Soot and HC-Emissions Idle & Part Load



Test engine:

- 2.0l DI TC production
- HDEV5.1 side mounted

- E85-Fuel enables negligible soot emissions at warm engine operation
- HC Raw-emissions at idle and part load reduced about 33%.
- Injection pressure has no significant influence on the HC-emissions at part load.

Cause:

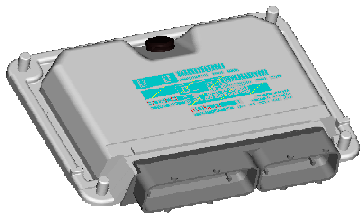
- Lower boiling point of alcohol (78°C).

Effect:

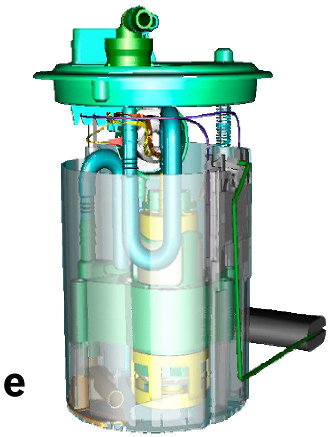
- Lack of soot limit enables enlarged injection window.

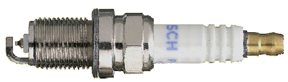
FFV Systems – Ethanol & Flex Fuel Specific Components

ECU
- Software
- Calibration



High Pressure Pump
- Stainless steel
- Flow Range



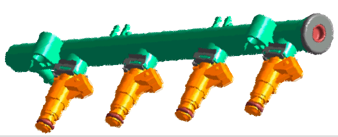


Spark Plug
- Wider thermal range

High Pressure Injector
- Stainless steel
- Flow Range

Fuel Pump Module
- Fuel Pump for E85
- Sealed electrical connectors (fuel pump)
- Fuel level sensor ethanol resistant

Fuel Rail Assembly
- Ethanol resistant



Injector
- Monel Filter
- Flow Range

Fuel Pressure Regulator
-Ethanol resistant

Barrier – E85 Performance

E85		Gasoline
Fuel Economy		
11mpg/15 mpg	EPA (City/Hwy)	15mpg/21 mpg
7 mpg	City	9 mpg
15 mpg	Highway	21 mpg
13 mpg	150 mile trip	18 mpg
10 mpg	Overall	14 mpg
Acceleration		
3.4 sec	0 – 30 mph	3.5 sec
8.9 sec	0 – 60 mph	9.1 sec
5.7 sec	45 – 65 mph	5.8 sec
16.8s/84.6 mph	¼ Mile	16.9s/84.5 mph
Emissions (parts per million)		
1	NOx	9
1	Hydrocarbons	1
0	CO	0

Example: 2007 Chevy Tahoe FFV

Range
430 miles/tank (Gasoline)
vs
300 miles/tank (Ethanol)

Source: Consumer Reports, October, 2006

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+ High Knock Limit
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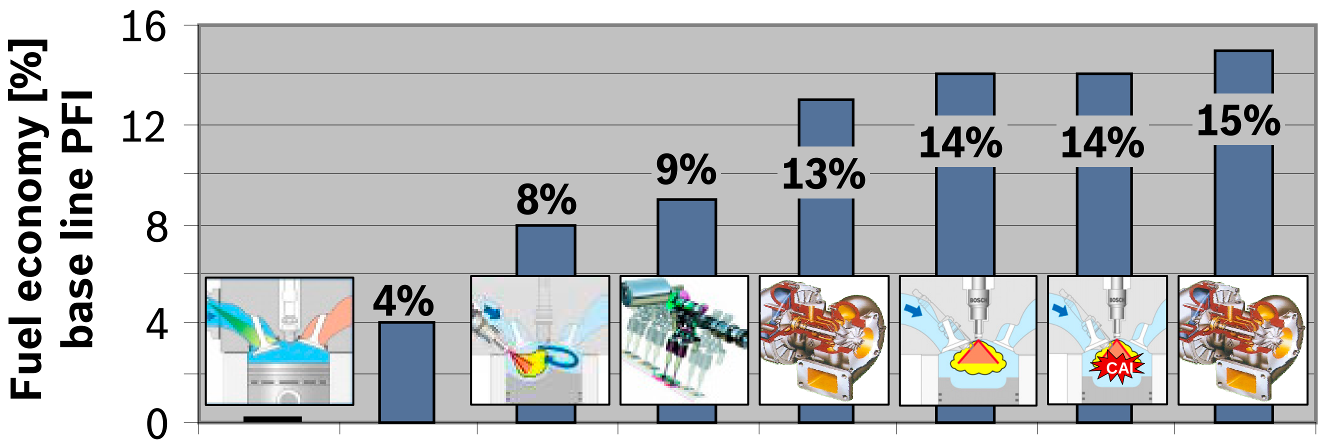
Advanced FFV – Gasoline Direct Injection Benchmarking



Combustion concept	PFI	DI	DI	DI	DI	DI	HCCI	DI
Lambda	1	1	> 1	1	1	>1		1
Side/central mounted injector	-	s/c	s	s/c	s/c	c	s/c	s/c
Turbocharged downsizing					TC-DS			TC-DS
Inlet variable valve train		x	x	x	x	x	x	x
Outlet variable valve train				x		x	x	x
Variable valve lift				x			x	
Cylinder pressure sensor							x	

Advanced FFV – Downsizing with DI-TC-VVT

Fuel economy

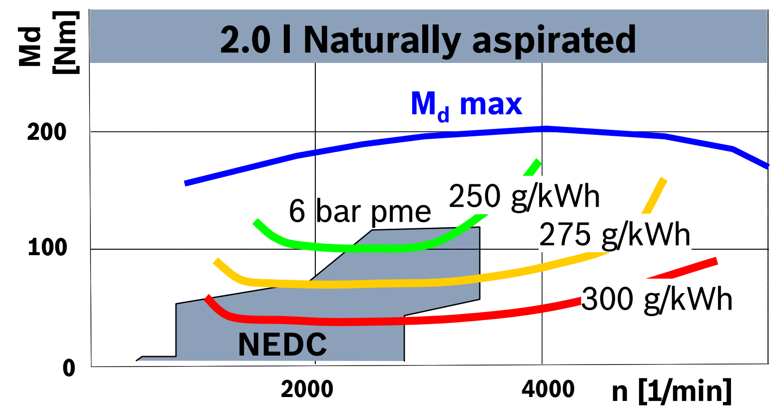
- Shift of operating points towards better fuel consumption
- Benefit 5 - 15 % (downsizing ratio)

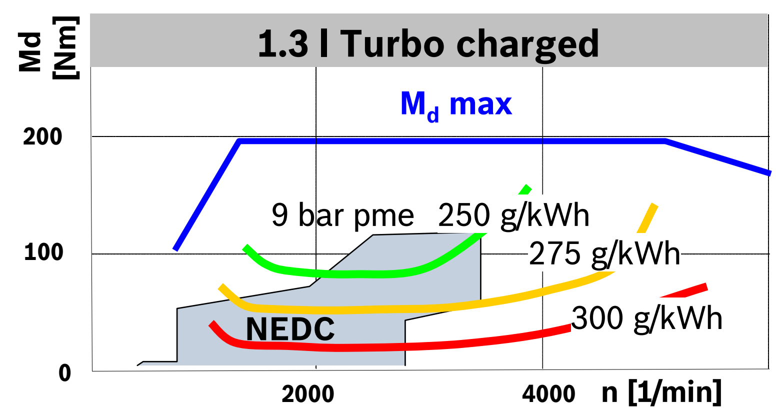
Perfect synergy of DI + TC + VVT

- Enables high scavenging rates
  - reduced knock
  - higher charge
  - better dynamic

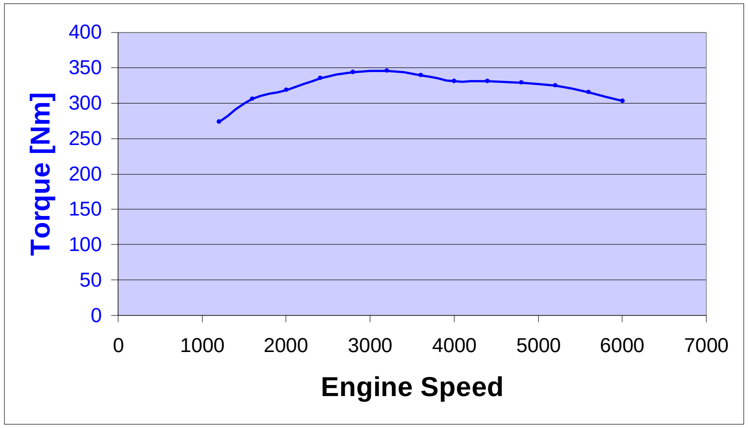
  } up to +50% Torqu w rp vs. PFI
- Charge cooling
  - Higher compression (+1) vs. PFI

2. Generation DI
Fuel economy + Fun2drive





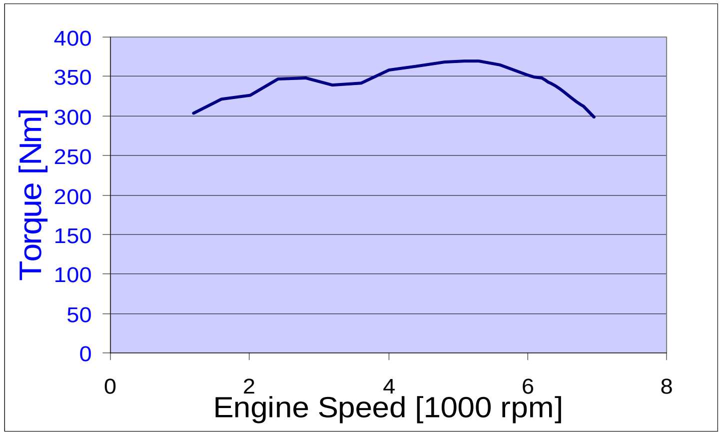
Cadillac CTS 3.6 L V6 Port Fuel Injection (PFI)



Model:	**MY08 CTS PFI**
Engine:	**3.6L PFI V6 DOHC VVT**
Horsepower:	**266 HP (199 kW) @ 6200 rpm**
Torque:	**256 lb-ft (346 Nm) @ 3100 rpm**
Transmission:	**6-speed AT**
Consumption:	**18/26 mpg**

Baseline Enhanced PFI System

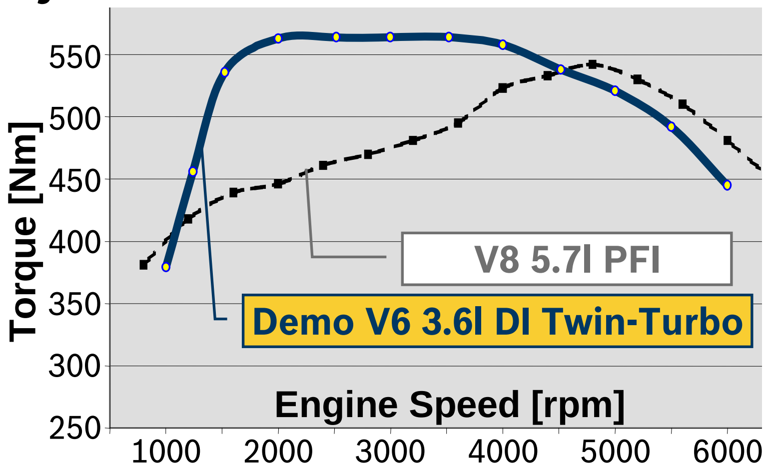
Cadillac CTS 3.6 L V6 Direct Injection (DI)



Model:	MY08 CTS PFI	→	MY08 CTS SIDI
Engine:	3.6L PFI V6 DOHC VVT	→	3.6L DI V6 DOHC VVT
Horsepower:	266 HP (199 kW) @ 6200 rpm	→	307 HP (229 kW) @ 6400 rpm
Torque:	256 lb-ft (346 Nm) @ 3100 rpm	→	277 lb-ft (376 Nm) @ 5200 rpm
Transmission:	6-speed AT	→	6-speed AT
Consumption:	18/26 mpg	→	18/26 mpg

40 HP more with same Fuel Efficiency Compared to PFI

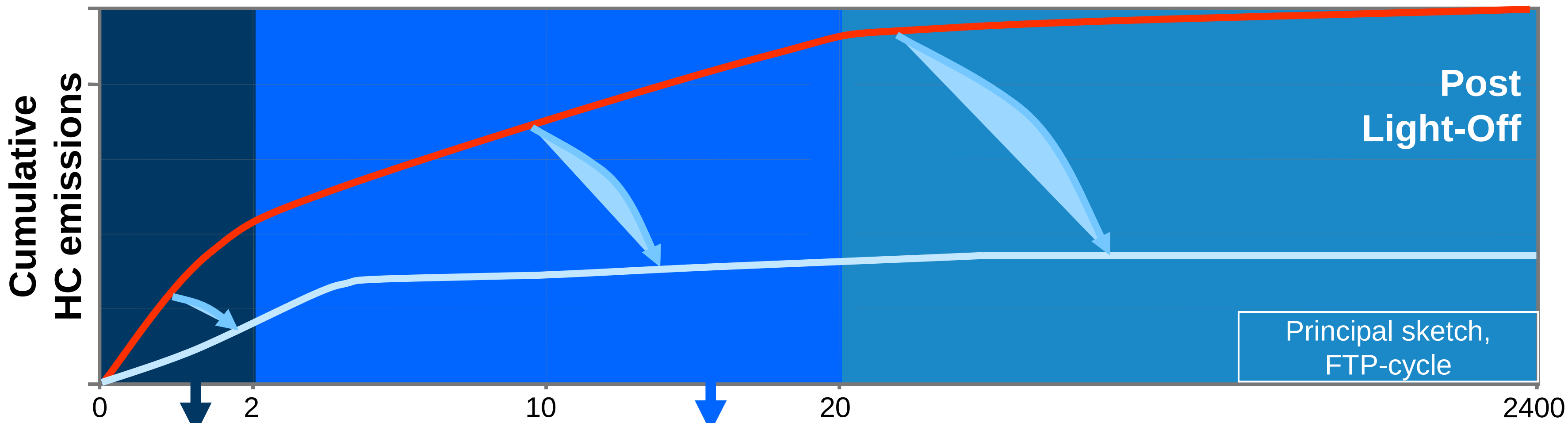
Cadillac CTS 3.6 L V6 Direct Injection w/ Twin Turbo



	V6 DI BOOST	V8 PFI
Acceleration 0 – 60 mph	5.68 sec	5.65 sec
50 – 70 mph (6th gear)	8.7 sec	10.0 sec
Acceleration ¼ mile	14.2 sec @ 102.6 mph	14.0 sec @ 107.6 mph
Fuel Economy	mpg	mpg
City (FTP75)	18.3 ← + 14%	16.0
Highway	31.0	30.8
Combined	23.2 ← + 10%	20.4

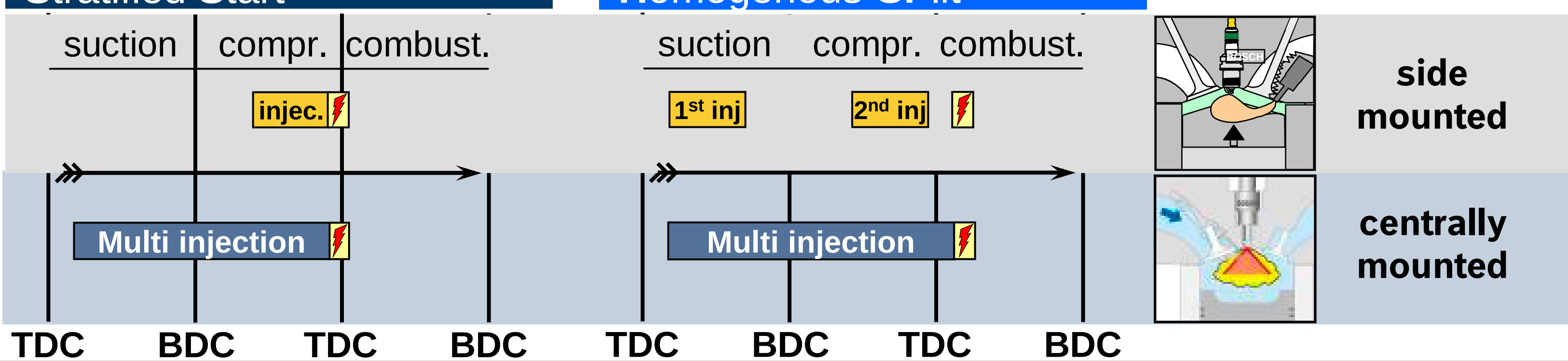
Performance of V8 PFI Engine reached w/ 14% FE benefit

Advanced FFV – DI Strategy for SULEV/PZEV

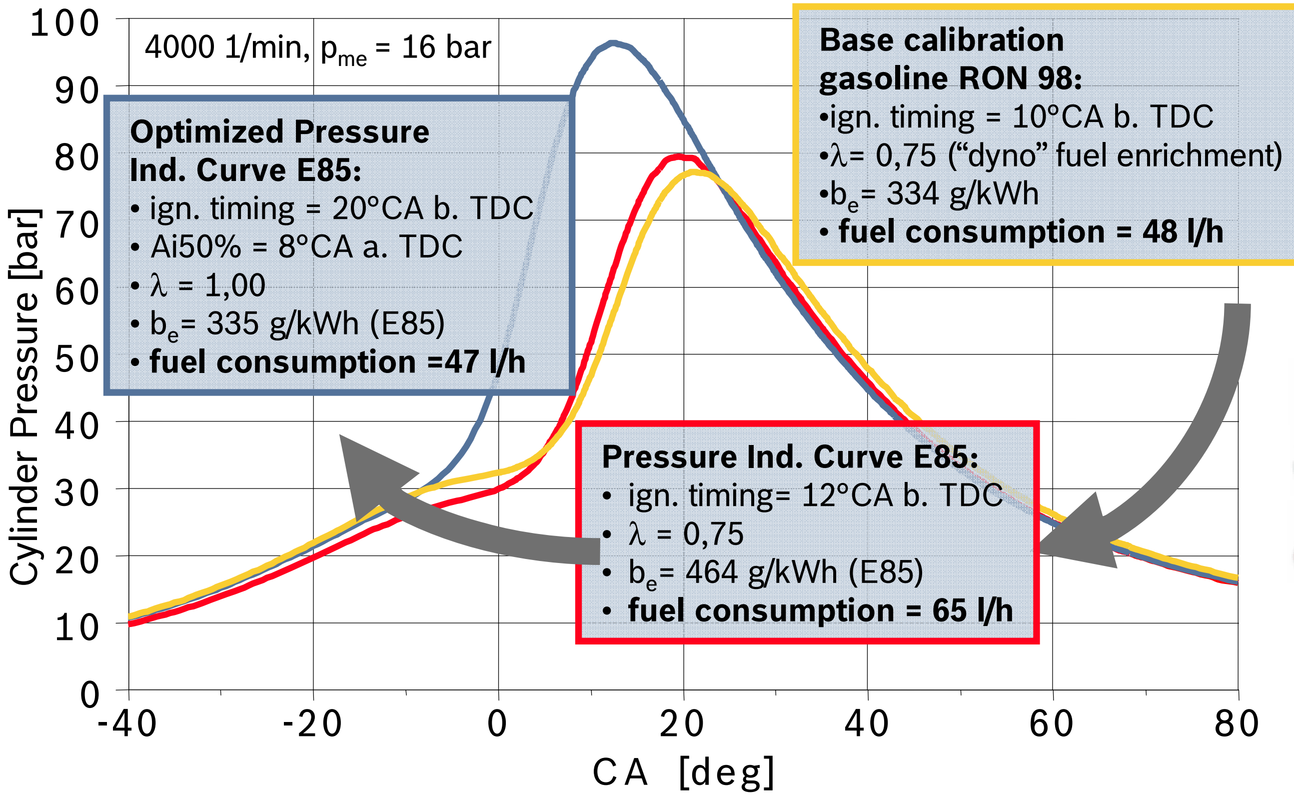


Start → High-Pressure Stratified Start

Catalyst-Heating → Homogenous-SPlit

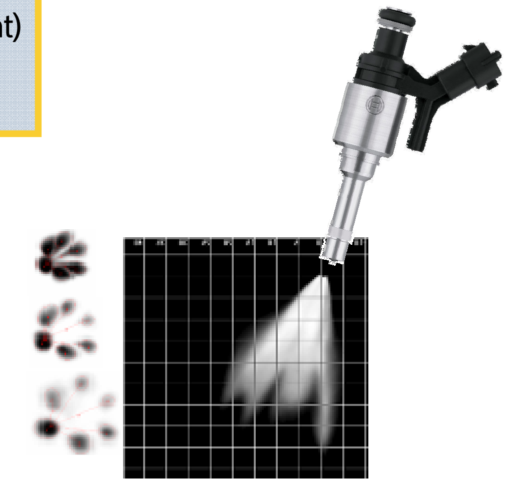


Advanced FFV – Ethanol Fuel with DI Technology



Injectors: HDEV 5.1

6-Hole, Q_{stat} = 15 ccm/s

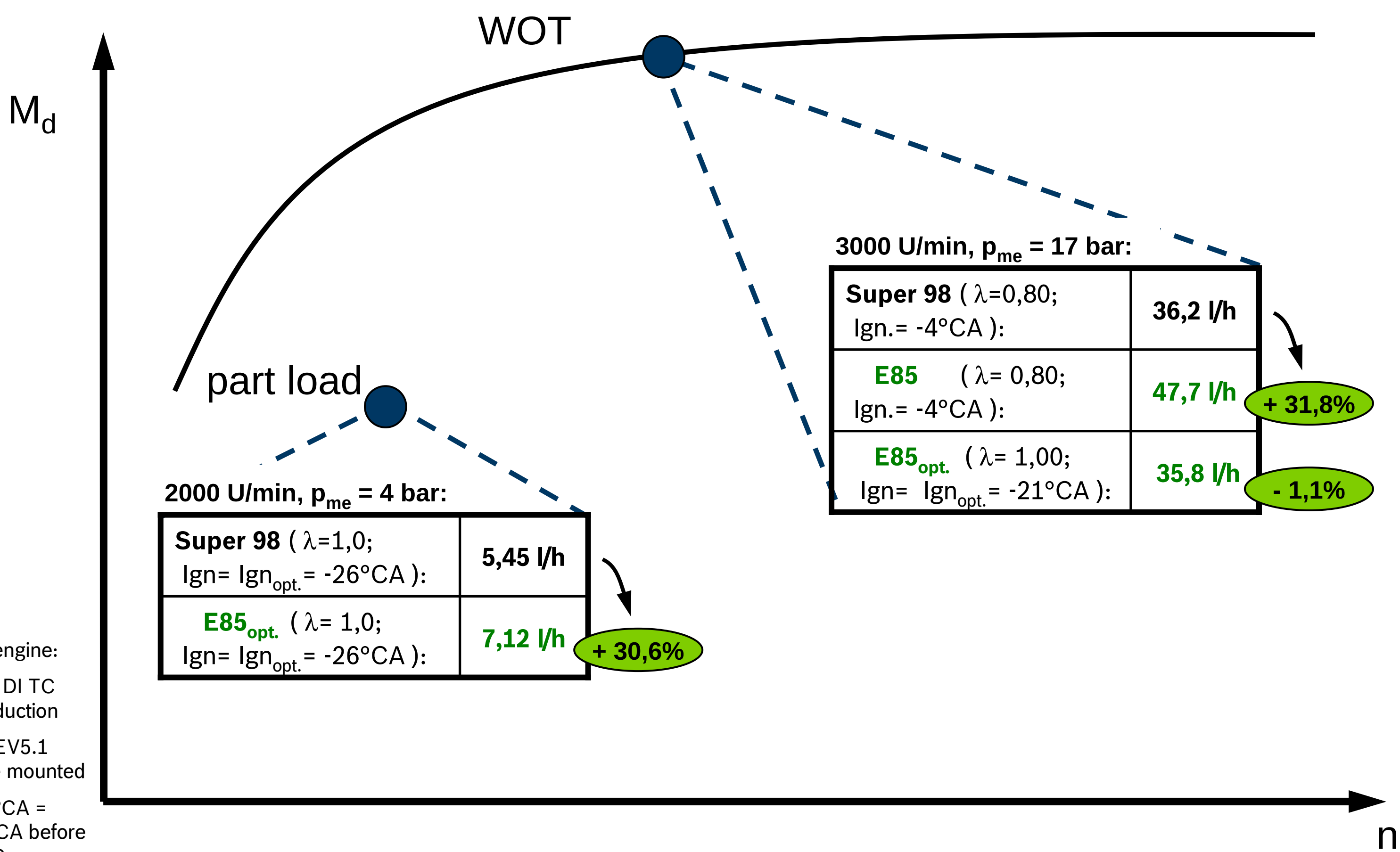


Test engine:

- 2.0l DI TC production
- HDEV5.1 side mounted

Combination of Flex Fuel & DI → Potential for optimizing combustion efficiency

Advanced FFV – Ethanol Fuel with DI Technology



2000 U/min, p_{me} = 4 bar:

Super 98 (λ=1,0; Ign= $Ign_{opt.}$= -26°CA):	**5,45 l/h**
E85$_{opt.}$ (λ= 1,0; Ign= $Ign_{opt.}$= -26°CA):	**7,12 l/h**

+ 30,6%

3000 U/min, p_{me} = 17 bar:

Super 98 (λ=0,80; Ign.= -4°CA):	**36,2 l/h**
E85 (λ= 0,80; Ign.= -4°CA):	**47,7 l/h**
E85$_{opt.}$ (λ= 1,00; Ign= $Ign_{opt.}$= -21°CA):	**35,8 l/h**

+ 31,8% (E85 vs. Super 98); **- 1,1%** (E85$_{opt.}$ vs. Super 98)

Test engine:

- 2.0l DI TC production
- HDEV5.1 side mounted
- -26°CA = 26°CA before TDC

Advanced FFV – Project Highlights

Base Engine:

- 2.0 L 4 Cylinder Engine
- Gasoline Direct Injection, Variable Valve Timing, Turbo Charging

Proposed Technologies:

- In-Cylinder Pressure Sensor (CPS) for Ethanol Content Detection, Closed Loop Control of Boost, VVT, Throttle Valve, Injection and Ignition
- Optimized Effective Compression Ratio with Boost control and VVT
- Transmission Shift Pattern Optimization for Ethanol Content in Fuel

Targets:

- Similar Fuel Economy with Gasoline and E85
- Higher Performance with E85 → Promotes Ethanol Fuel
- Closed loop cycle based control of Combustion Event
- Minimized additional calibration effort for different fuel blends

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Advanced FFV – Project Status

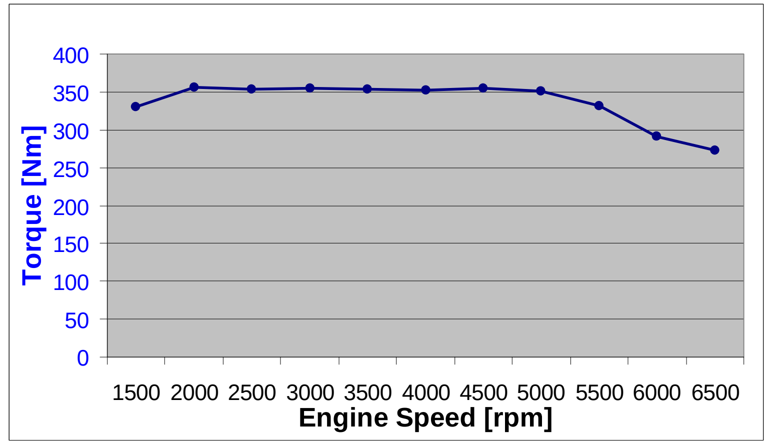
Experimental Work
- 2.0 L TC DI engine was instrumented and prepared for dynamometer at Ricardo
- Engine dynamometer work started in January 2008

Engine Modeling for Control Strategies
- Modeling of the engine is in progress at University of Michigan and BOSCH
- Control strategies and ethanol content detection methods are being investigated

Performance Model Simulation
- 1-D engine simulation model is 80% completed by Ricardo for analysis of thermodynamic behavior

Engine Control Unit Development
- Bosch MED 17 Controller with in-cylinder pressure sensor interface is in development
- System design for flex-fuel base software is completed, software integration in progress

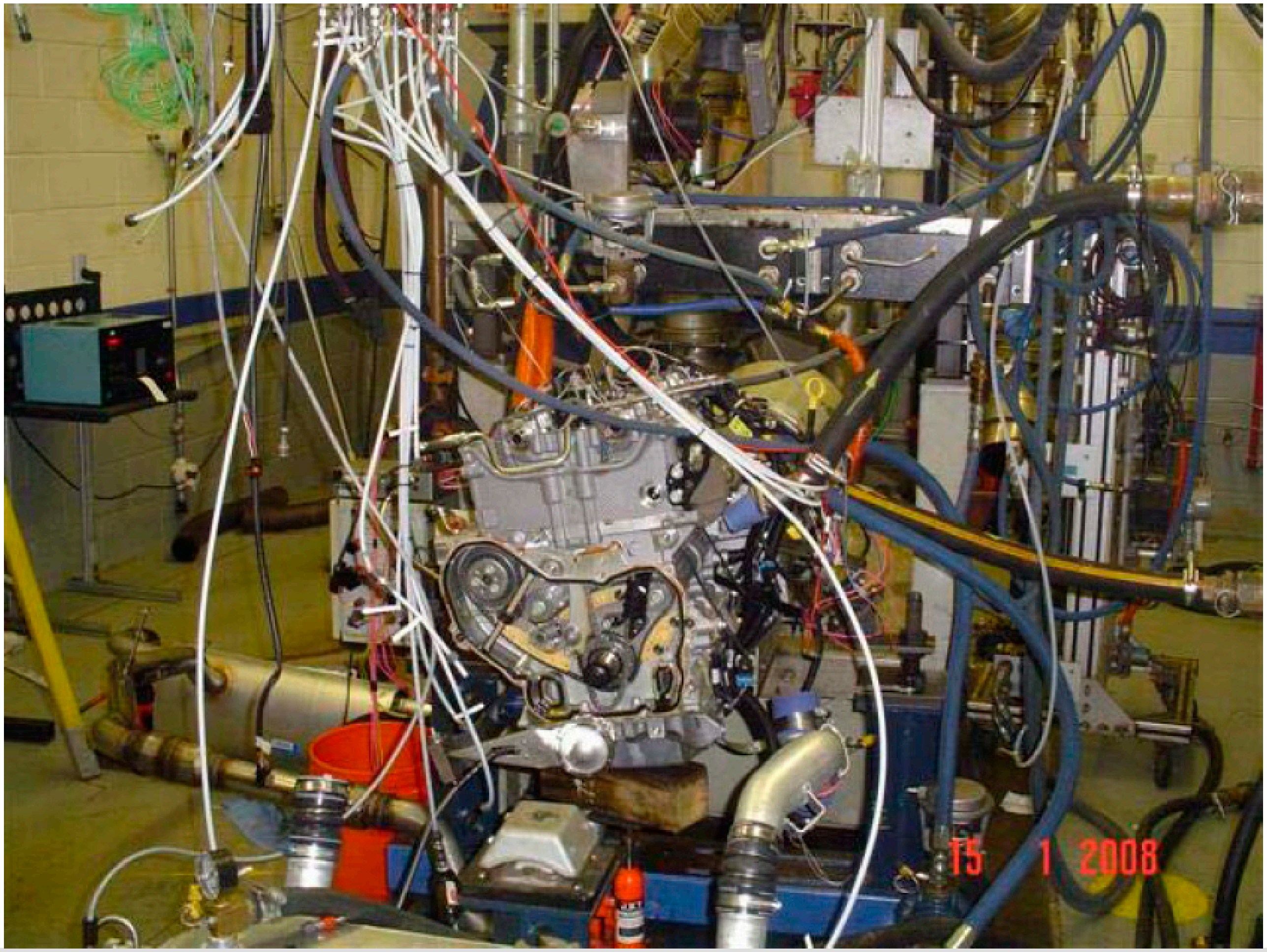
Advanced FFV – Base Platform 2.0 L I4 DI-TC-VVT



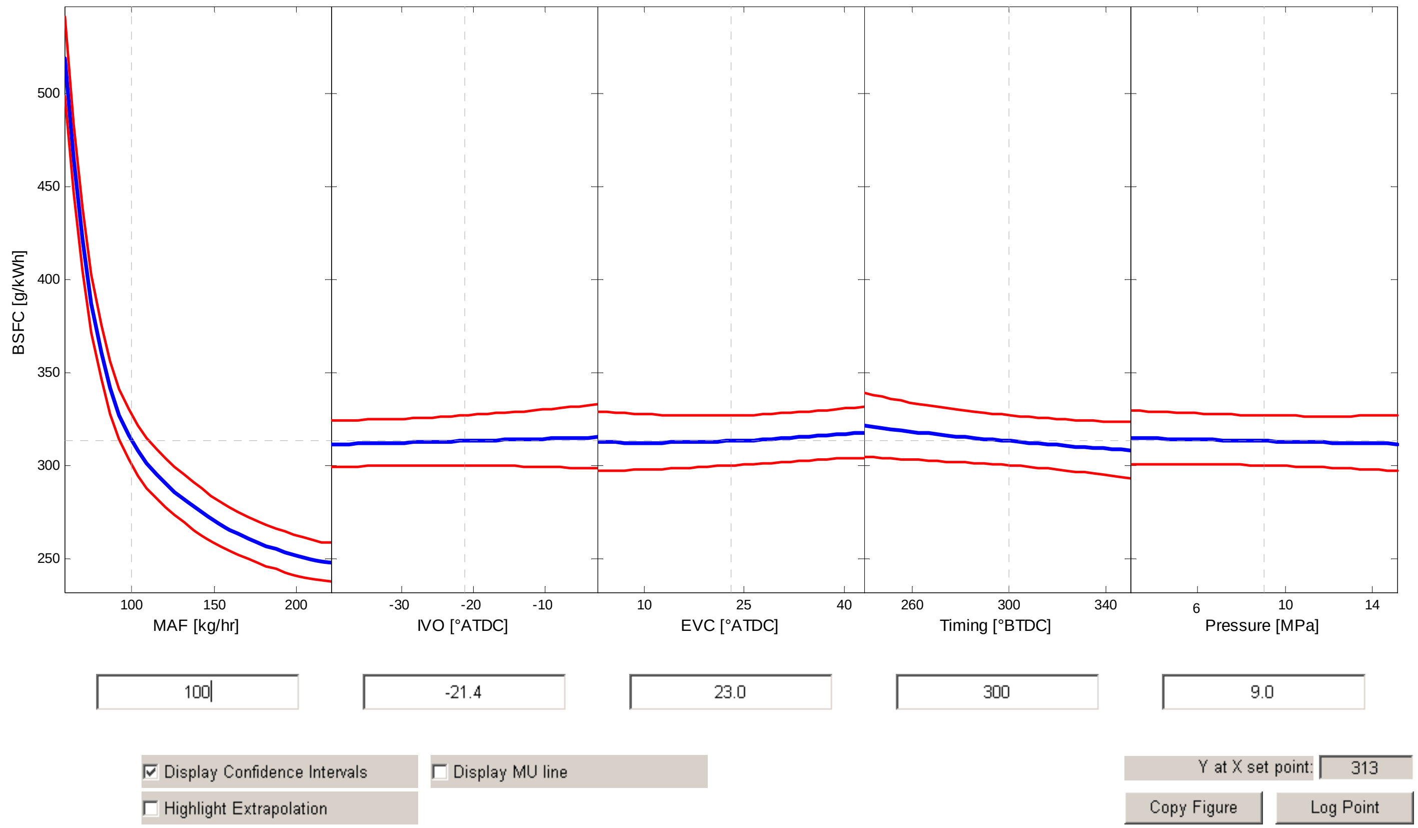
Model:	**MY07 Pontiac Solstice**
Engine:	**Turbo ECOTEC 2.0L I4 DOHC VVT**
Horsepower:	**260 HP @ 5300 rpm**
Torque:	**351 Nm @ 2500-5250 rpm**
Compression Ratio:	**9.2:1**
Drive-Train:	**RWD**
Consumption:	**19/28 mpg**

V6 Performance with 4 Cylinder Engine

Advanced FFV – Project Status – Engine Test Stand

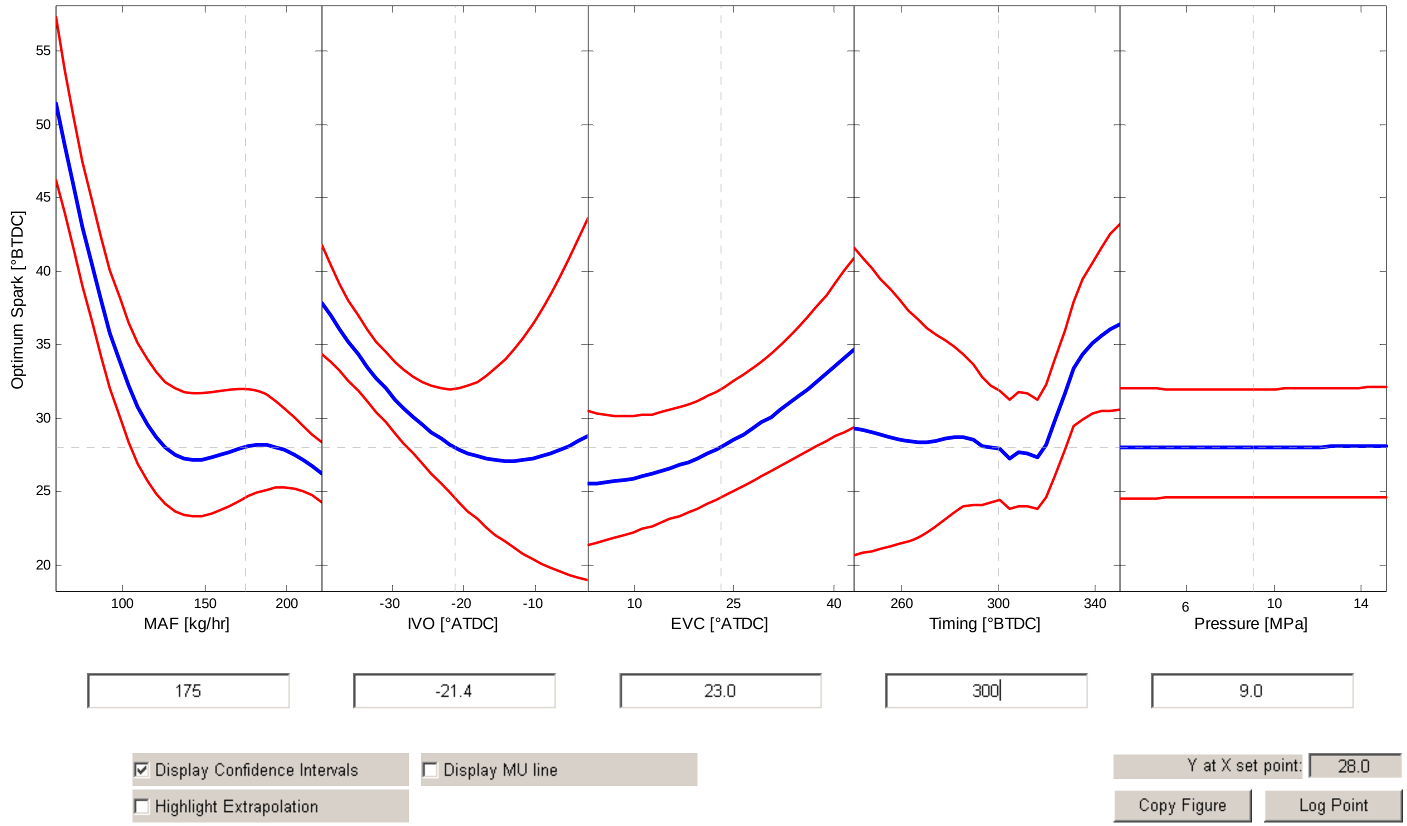


Advanced FFV – Project Status – Engine Simulations



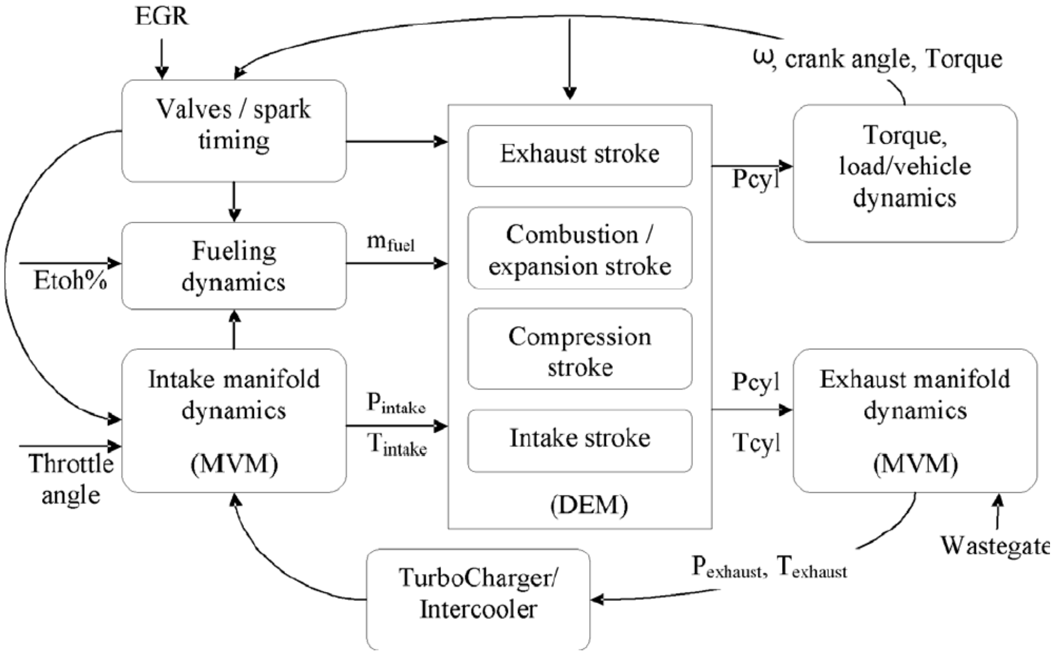
BSFC Model – 3500 RPM: Trends show slight improvement in BSFC with increased exhaust valve closing and decreased injection timing advance.

Advanced FFV – Project Status – Engine Simulations



Optimum Spark Model – 3500 RPM: Trends show improved optimum spark timing with increased valve overlap and increased injection timing advance

Advanced FFV – Project Status – Engine Modeling

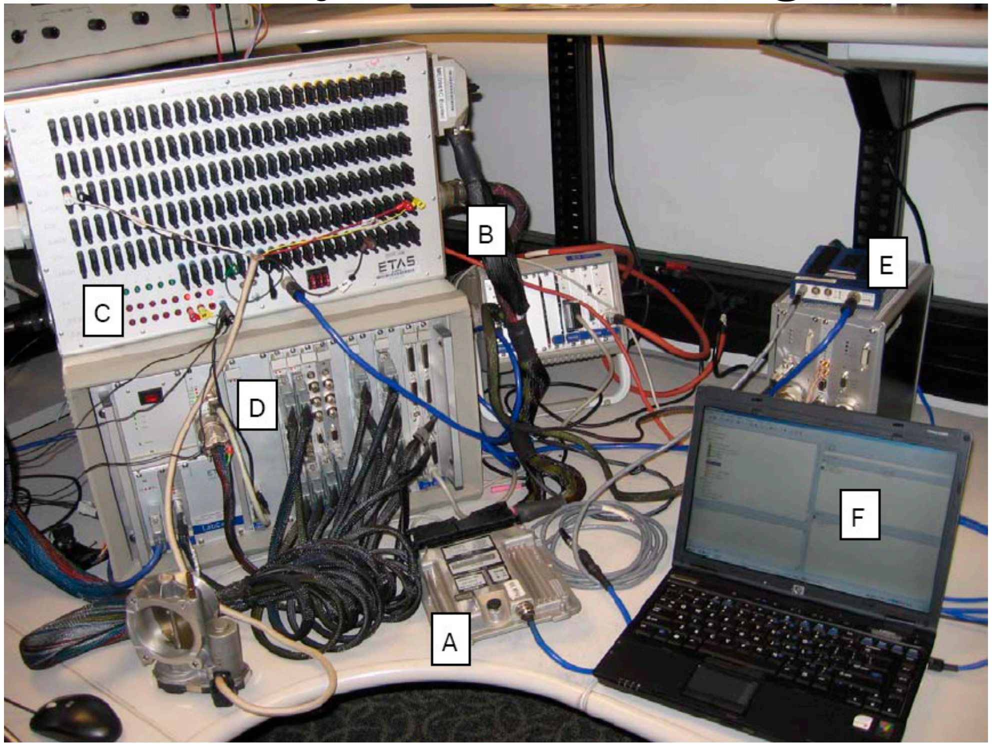


High level block diagram of the engine model for control system development

- Nonlinear with causal dynamics
- Based on physics (minimize the use of look-up tables)
- Parameterized with dynamometer steady-state and transient data
- Model structure 75% complete
- Matlab-Simulink environment

MVM: Mean Value Model
DEM: Discrete Event Model

Advanced FFV – Project Status – Engine Controls



Real Time Control System Simulation Set Up

Bosch ECU (A) is connected with a harness (B) to the LabCar engine simulator (D) through a breakout box (C). The Labcar receives actuator signals from the ECU and simulates engine operation and sends back sensor signals to the ECU. Variables and calibration parameters inside the ECU are measured through the ETAS data acquisition system (E) and are recorded using the computer (F).

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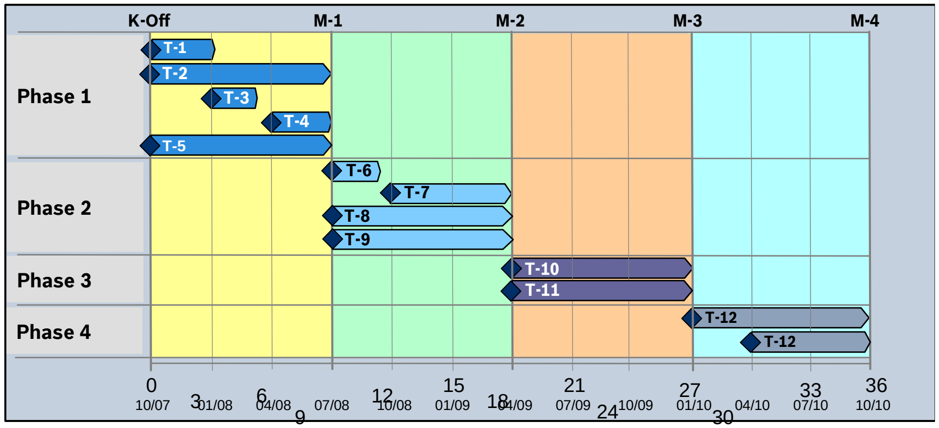
Advanced FFV – Project Tasks



Task 1 – Combustion Concept Design
Task 2 – Modeling for Control Strategies
Task 3 – Performance Model Simulation
Task 4 – Vehicle Simulation Study
Task 5 – Base Level Engine Control Unit Integration
Task 6 – System Specification
Task 7 – Design of Modified Engine Components
Task 8 – Development of Base Engine and Powertrain Management Systems
Task 9 – Base Level Vehicle Platform Development
Task 10 – Procurement and Adaptation of Hardware
Task 11 – Control Strategies for Engine and Powertrain Management System
Task 12 – Engine Management Software Development
Task 13 – Base Engine Application

Advanced FFV – Phase 1 Milestones

Phase 1 Milestones (October 1st 2007 – June 31st 2008):

- Combustion characterization engine test data
- Control oriented model that predicts the trends and dynamic behavior of the flex-fuel engine system
- Simulink models, physical equations used in modeling, model simulation results and correlation with experimental data
- WAVE simulation results, Flex Fuel System Proposal for prototype engine
- Vehicle level fuel economy prediction as a function of fuel blend
- Demonstration of BOSCH MED 17 ECU with proposed engine platform and Labcar simulation environment

Questions?

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