MODERN SPARK IGNITION ENGINES: WHY ETHANOL CAN BECOME THE BETTER FUEL

And how this is accomplished

Dr. Ernst Winklhofer

AVL List GmbH

MODERN SPARK IGNITION ENGINES: WHY AND HOW ETHANOL CAN BECOME THE BETTER FUEL

Content of Presentation:

1. Some SI engine combustion basics

2. Technology Features for next Generation SI engines

   Legislation – Market – Technology and resources

3. Ethanol in modern SI engines

   potential benefits

   technology opportunities

4. Outlook and Conclusion

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MODERN SPARK IGNITION ENGINES: WHY AND HOW ETHANOL CAN BECOME THE BETTER FUEL

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1. Some SI engine combustion basics

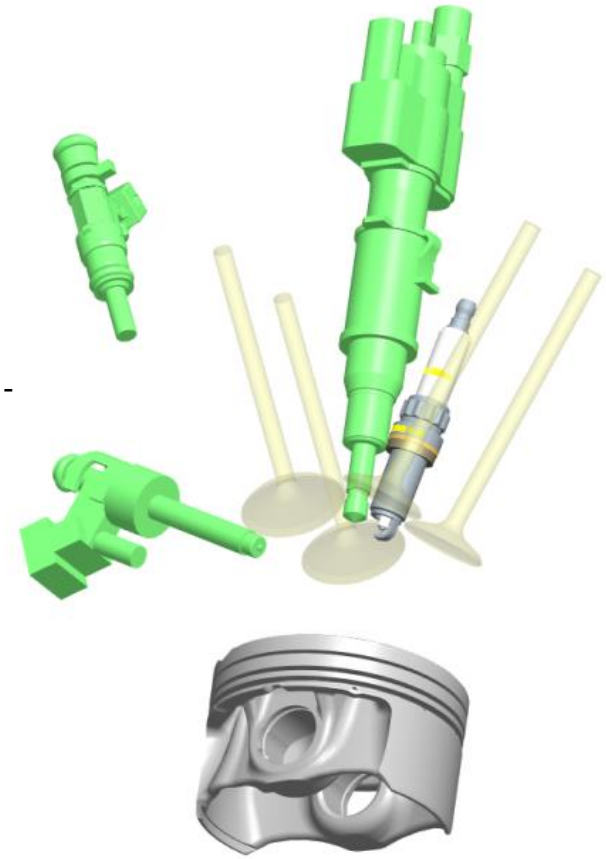
- Air intake and injection of liquid fuel in stoichiometric quantity
- Fuel evaporation and mixing with air to form a homogeneous mixture for “premixed” combustion
  - Otherwise: soot formation in “diffusion” flames

Movie 1

Options for fuel injection in an SI engine

Direct injection - central

Port fuel injection



Direct injection - side

Direct injection benefit:

we have control over mixture formation into late compression stroke

MODERN SPARK IGNITION ENGINES: WHY AND HOW ETHANOL CAN BECOME THE BETTER FUEL

1.1 Fuel injection

- PFI: port fuel injection

Movie PFI

- Direct injection

DI opportunities: controlling mixture formation up until ignition by means of injection parameters.

Benefits: emissions, BSFC, torque
Risks: many

Side injection

Movie central

Central injection

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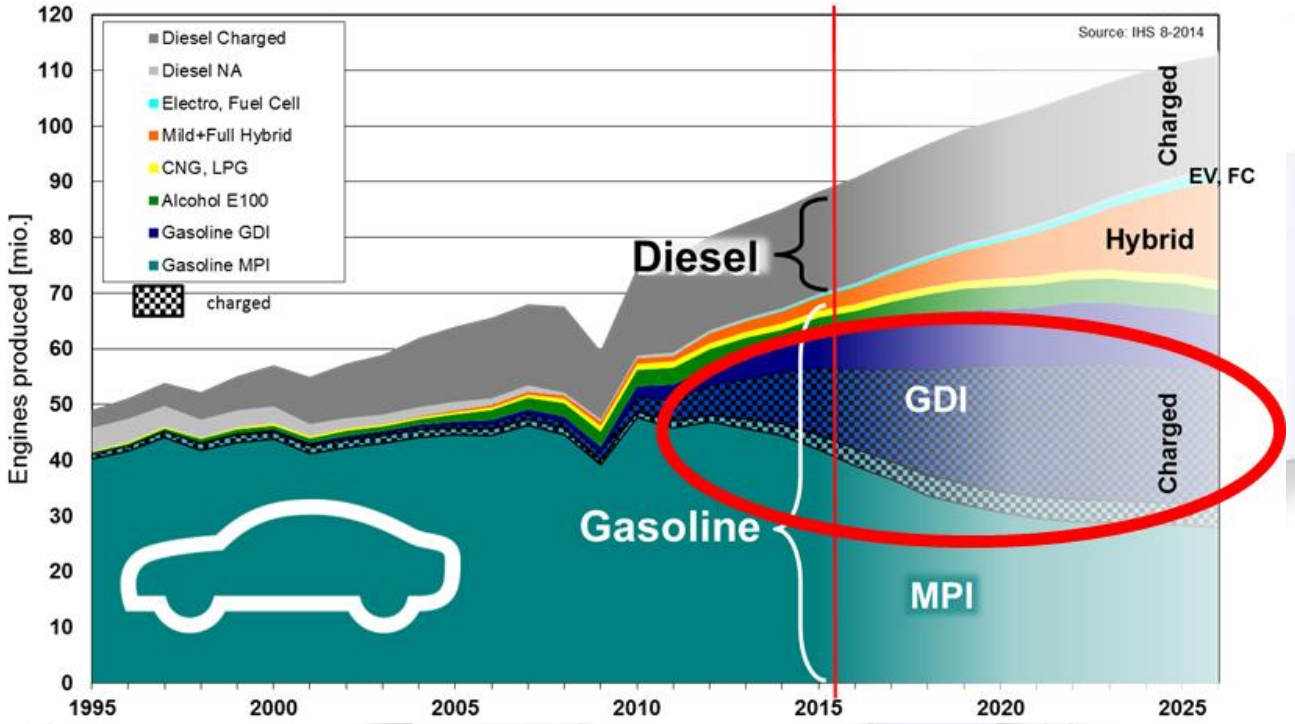
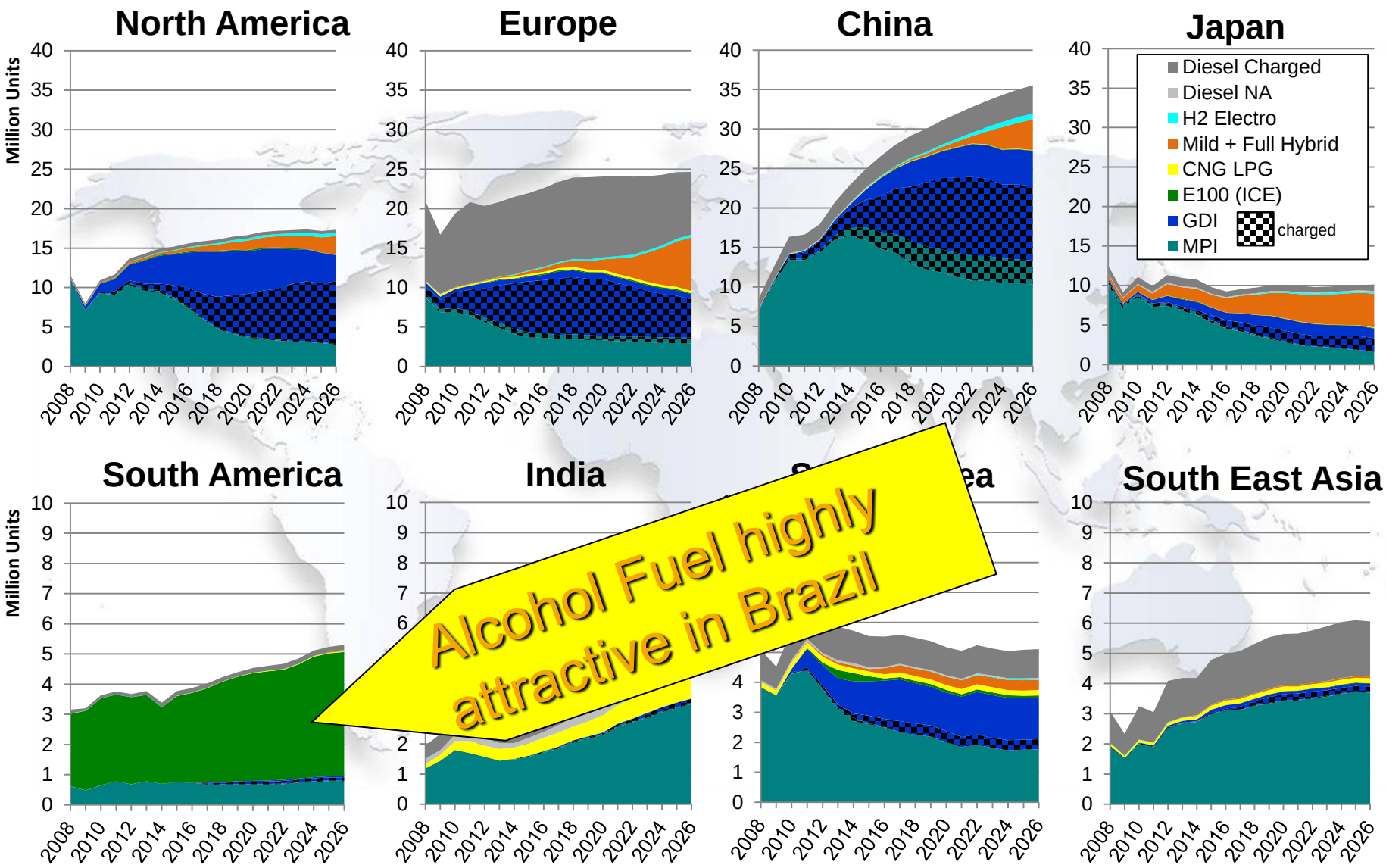
The statistics: GLOBAL PRODUCTION FORCAST
TOTAL PASSENGER CAR ENGINES



On a global scale, the ICE remains the dominating power source even beyond 2025

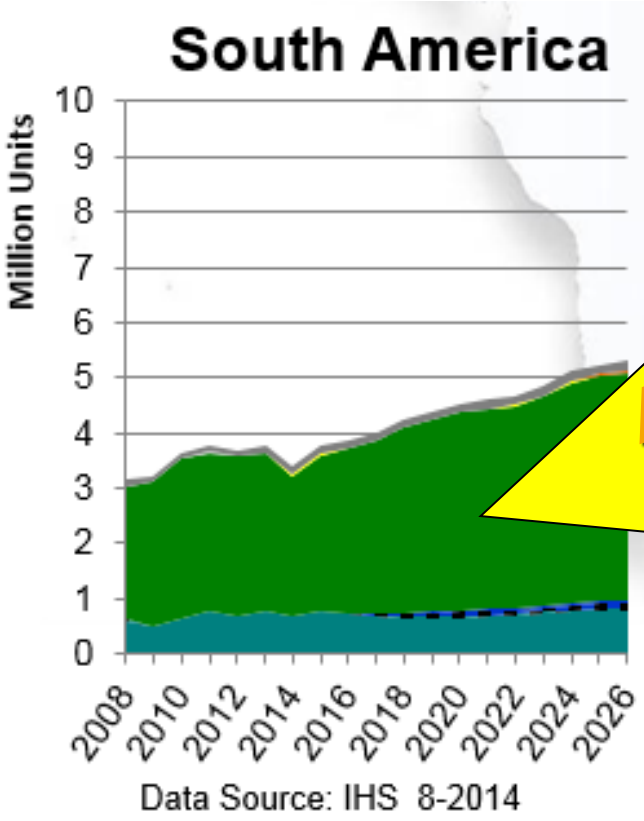
Today the GDI engine is the fastest growing engine type

LOCAL ENGINE PRODUCTION PER TECHNOLOGY - PASSENGER CARS



Data Source: IHS 8-2014

Brasil has a unique fuels and infrastructure situation



Alcohol Fuel highly attractive in Brazil

But you compromise Ethanol's benefits in PFI flex fuel engines!

Data Source: IHS 8-2014

Fuel features

		Gasoline	Ethanol
Chemical Formula	(-)	C_7H_{15}	C_2H_6O
Molecular Weight	(-)	99	46
Carbon Content	(%m)	84.9	52.2
Hydrogen Content	(%m)	15.1	13.0
Density Liquid at 20°	(kg/l)	0.740	0.790
Oxygen Content	(%m)	0	34.8
Lower Heating Value	(MJ/kg)	42.5	26.8
Heat of Evaporation	(kJ/MJ)	≈ 8.0	33.8
Octane Rating RON	(-)	95	>100
T evaporation	(°C)	25 - 210	78
Vapor pressure	(hPa)	60 - 90	17
Ignition temperature	(°C)	400	425

Ethanol chances

Heating Value	inject 1,5 liter Ethanol for 1 liter Gasoline
Evaporation	Ethanol yields better charge cooling
	Ethanol has much higher risk at cold start
Octane number - RON	is a most attractive Ethanol feature

Ethanol risks

Self (pre) ignition
Engine start
Oil dilution and deposits
Soot formation

Gasoline – Ethanol comparison:

Ethanol has promising as well as challenging features

1. How will such fuel features influence engine operation?
2. What does it need to exploit fuel advantages?
3. What is required to overcome the risks?

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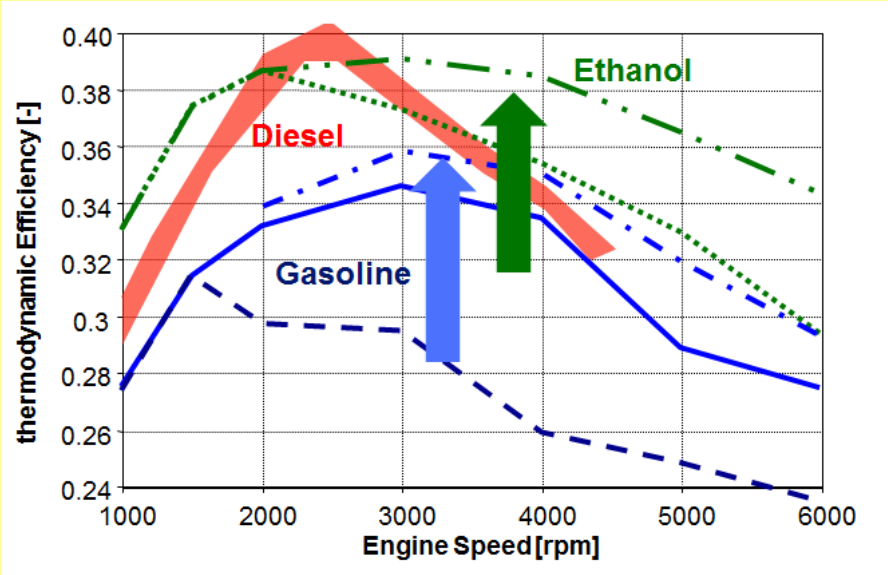
Full Load Efficiency with direct injection and turbocharging

Diesel - Gasoline – Ethanol (E85)



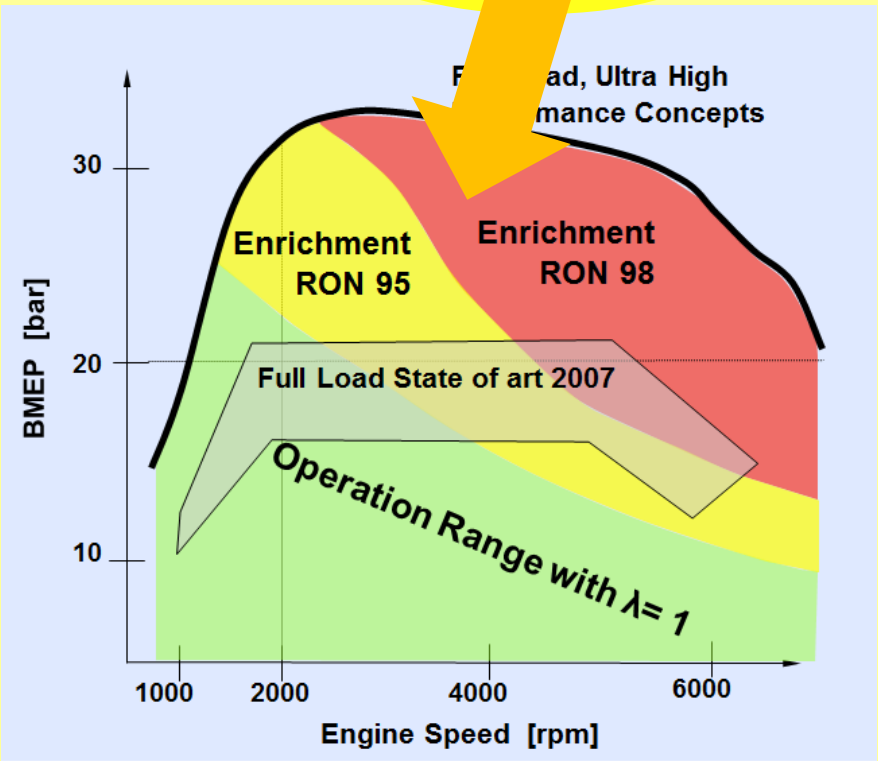
Ethanol is most attractive in high load operation

thermodynamic efficiency of a modern Ethanol engine (here on E85) is in good company with best Diesel engines

How to develop an Ethanol DI combustion system ?

Ethanol opportunities

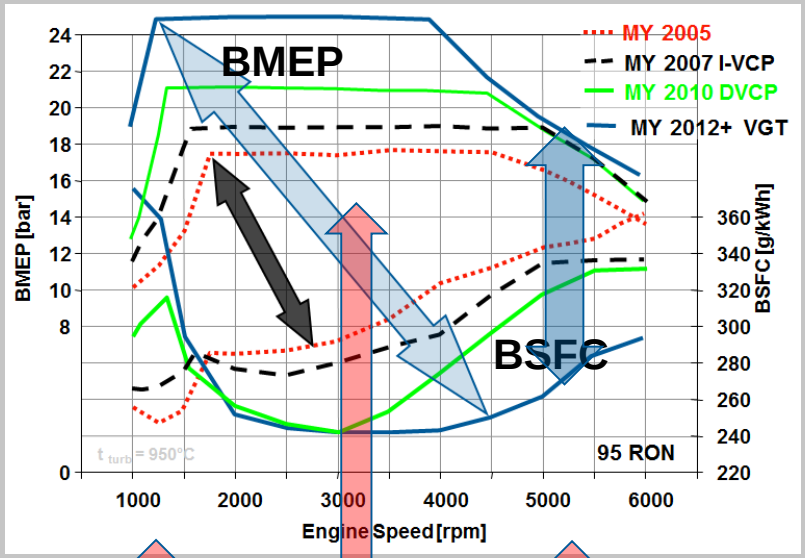
Heating Value	inject 1,5 lit[illegible] Gasoline
Evaporation	Ethan[illegible] yields better charge cooli[illegible]g
	Ethanol has [illegible] higher risk at cold start
Octane number - RON	is a most attractive Ethanol fe[illegible]ture



GDI high load operation:
the need for fuel enrichment is a desaster for BSFC

RON and heat of evaporation:
is most attractive in high load operation

The challenge is heat balance:
An effective engine will use exhaust gas cooling, cooled EGR, high temperature materials for spark plugs and valves



PN - soot

Pre-ignition

Knock and temperature

<u>Spray – wall interaction</u>:

…oil dilution, PN-soot, deposits

…engine start

<u>Temperature</u>:

…spark plug, valves and piston

…pre-ignition, knock, run-away knock

Ethanol provides opportunities - they need to be developed:

RON and heat of evaporation: is most attractive in high load operation

Oxygen in fuel: supports soot free combustion

The risks :

Spray – wall interaction: needs fuel injection tuning

Combustion chamber temperature: needs cooling, components selection, ECU safeguard procedures

Ethanol DI - TC
Today‘s technology opportunities

TODAY'S OPPORTUNITIES – OUR TOOLS AND PROCEDURES

Air intake and injection of liquid fuel in stoichiometric quantity

- With or without Turbocharger, port design and valve details: is standard engine engineering task

  Fuel injection: central or side injector, injection pressure up to 350 bar (2015)

- **Injection development**: is central part of engine development with targets for spray – wall interaction in engine start, part load, high load, and transients.

- Thermal development: is standard engine engineering task with specific Ethanol requirments

- **Engine and vehicle calibration for driveability and legislative targets**: we use special procedures for DI engine combustion analysis

- **Exploiting the limits of a combustion system:** knock, pre-ignition, transients, cold start… is a routine calibration process and includes tuning of injection modes to specific engine operation

TODAY'S OPPORTUNITIES – SELECTING THE FUEL INJECTION MODULES

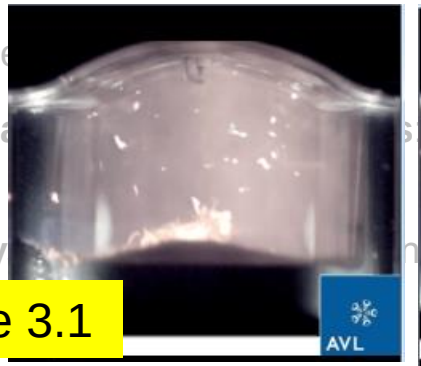
Air intake and injection of liquid fuel in stoichiometric quantity

- Turbocharger, port design and valve details: is standard engine engineering
- Fuel injection: central or side injector, injection pressure up to 350 bar (2015)
- **Injection development**: is central part of engine development with targets for spray – wall interaction in engine start, part load, high load, and transients.
- Thermal development: is standard
- **Engine and vehicle calibration fo** …es for DI engine combustion analysis
- **Exploiting the limits of a combus**

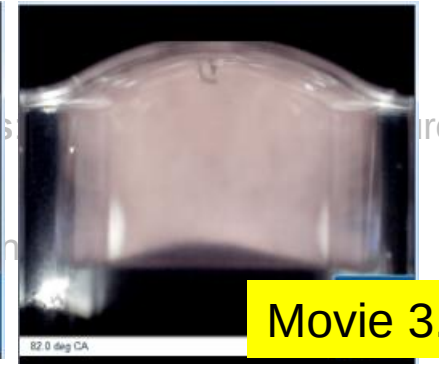
TODAY'S OPPORTUNITIES – AN EXAMPLE ON E85 COMBUSTION

Air intake and injection of liquid fuel in stoichiometric quantity

- Turbocharger, port design and valve details: is standard engine engineering
- Fuel injection: central or side injector, injection pressure up to 350 bar (2015)
- **Injection development**: is central part of engine development with targets for spray – wall interaction in engine start, part load, high load, and transients.
- Thermal development: is standard engine
- **Engine and vehicle calibration for drive** ures for DI engine combustion analysis
- **Exploiting the limits of a combustion sy**

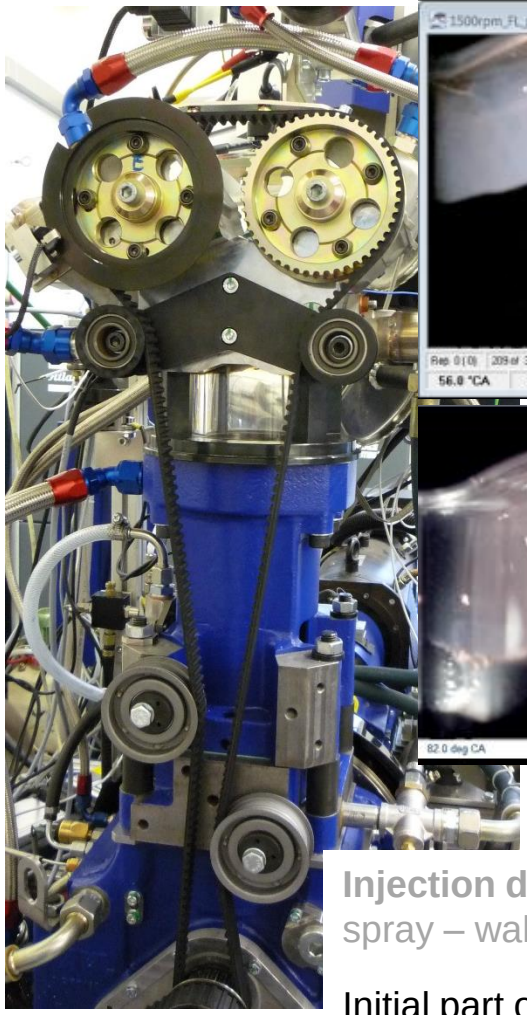


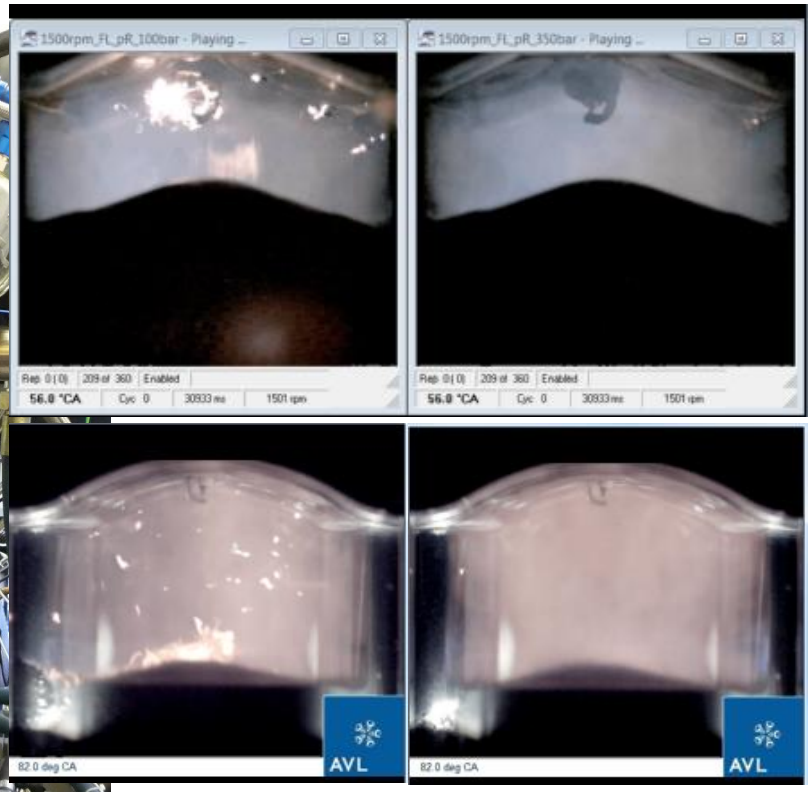
Movie 3.1



Movie 3.2

Ethanol (E85) example shows piston wetting effect. Solution is better injection tuning

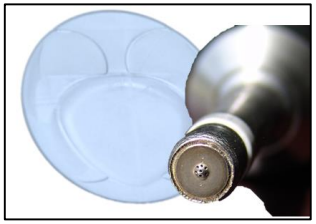




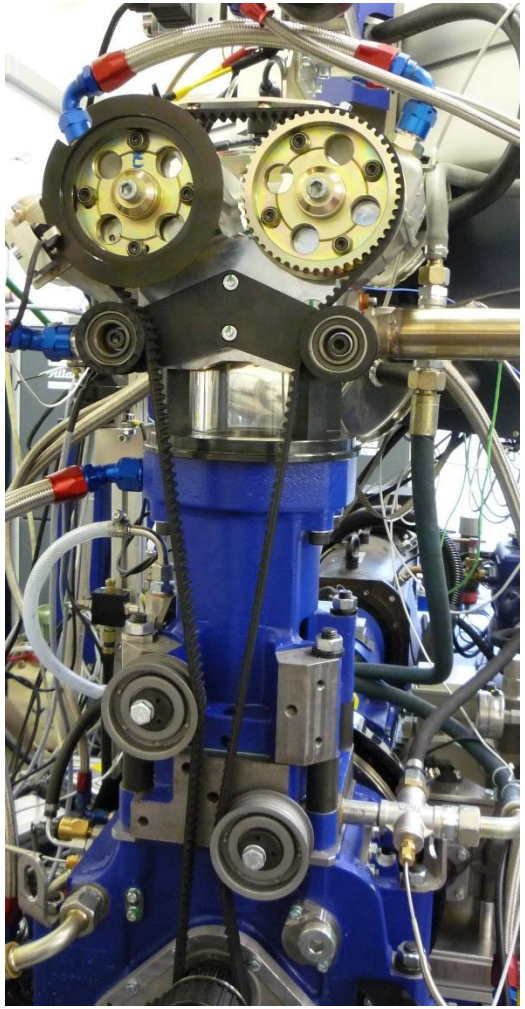
OUR TOOLS AND PROCEDURES

Injection development: is central part of engine development with targets for spray – wall interaction in engine start, part load, high load, and transients.

Initial part of injection development is done on transparent engine with full view of sprays and combustion.



Result: selection of best suited injectors and definition of optimum injection parameters

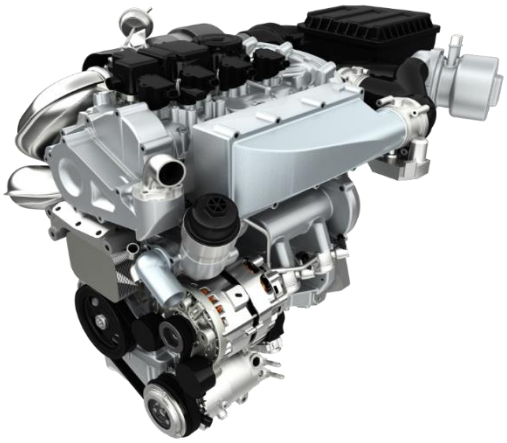


OUR TOOLS AND PROCEDURES

Optical Engine

We use the luxury of a full view into the combustion chamber to decide on best injector selection.

But there are limits to how we can use it: high speed, high load and transient operation is part of multicylinder engine development



OUR TOOLS AND PROCEDURES

Optical Engine

We use the luxury of a full view into the combustion chamber to decide on best injector selection.

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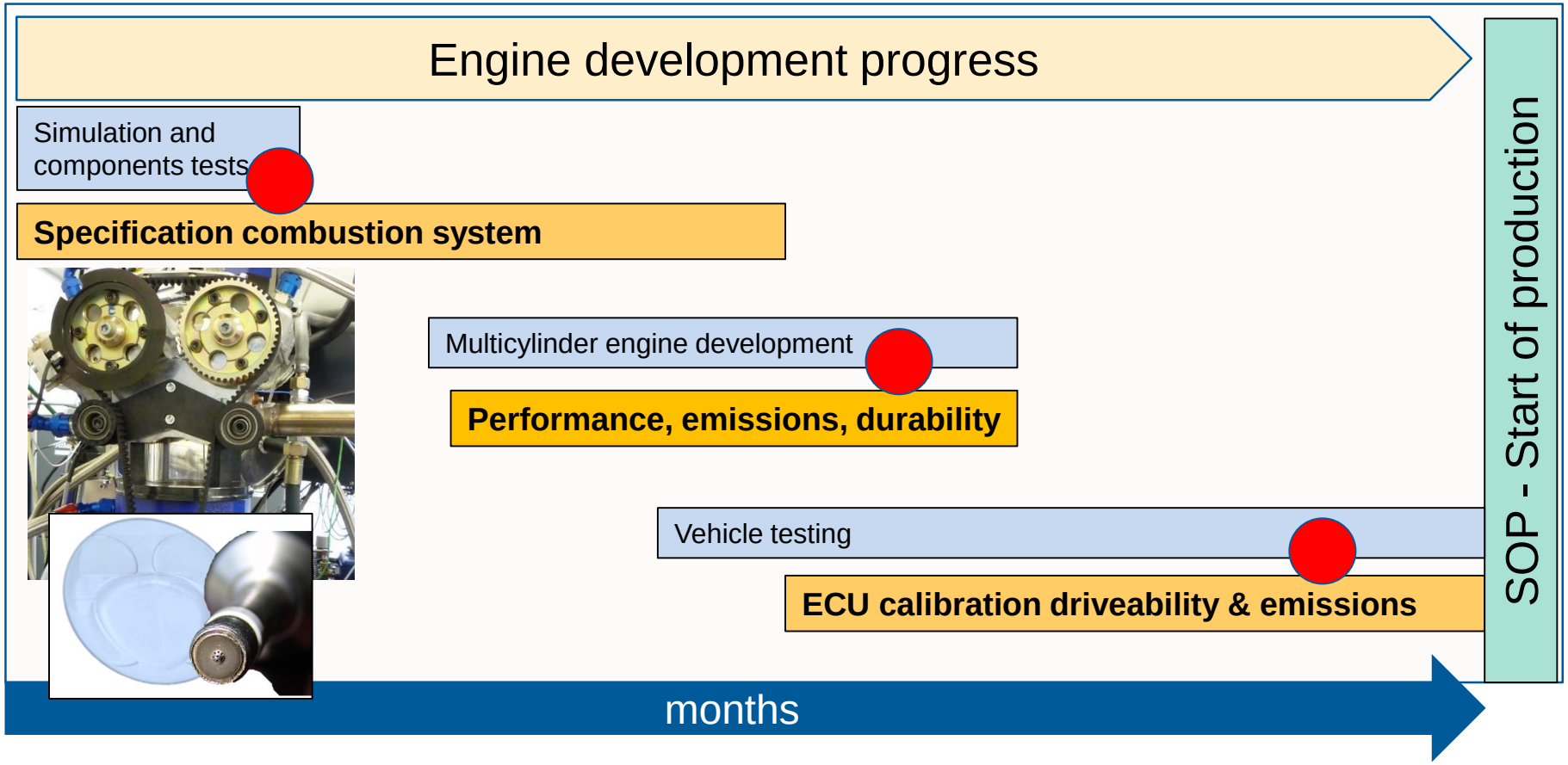
THE WORKFLOW IN ENGINE DEVELOPMENT



supported by advanced combustion measurement techniques

OUR COMBUSTION ANALYSIS TOOLS FOR NORMAL ENGINE OPERATION

The work environment

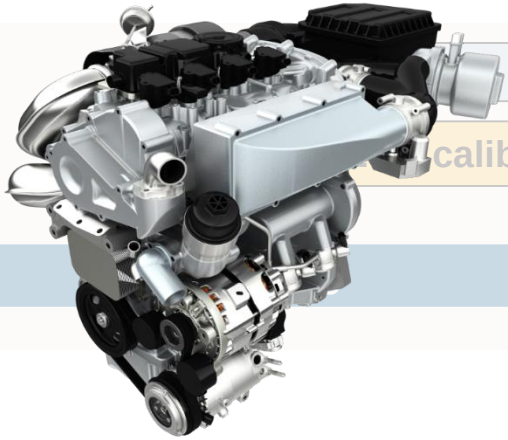
Cylinder pressure

Flame radiation

Engine development progress

Multicylinder engine development

Performance, emissions, durability



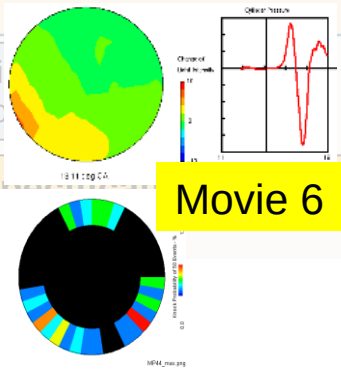
calibration driveability & emissions

SOP - Start of production

THE WORKFLOW IN ENGINE DEVELOPMENT

The work environment

EXPLOITING THE KNOCK LIMIT

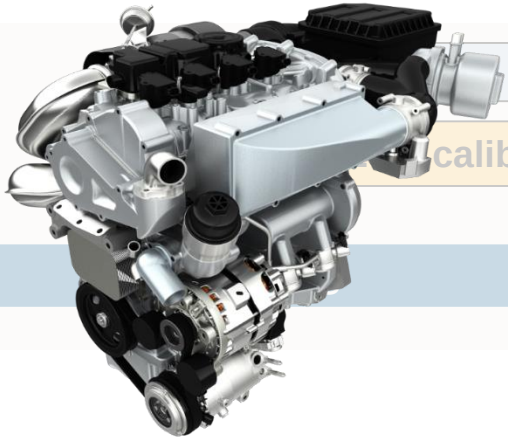


Movie 6

Engine development progress

Multicylinder engine development

Performance, emissions, durability



calibration driveability & emissions

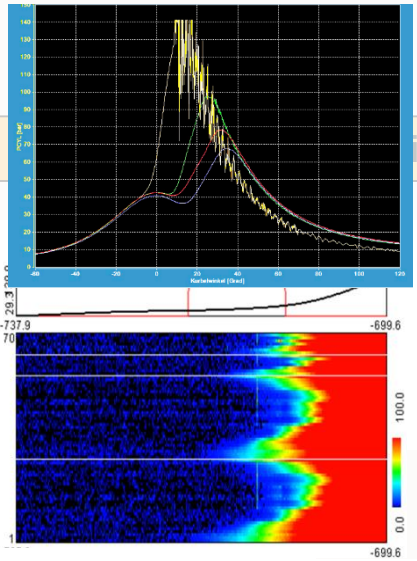
SOP - Start of production

Movies show tools applications to gasoline engines

THE WORKFLOW IN ENGINE DEVELOPMENT

HANDLING THE PRE-IGNITION LIMIT

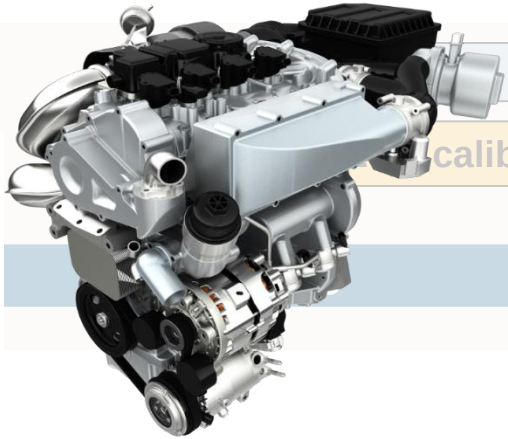
Engine development progress



ion system

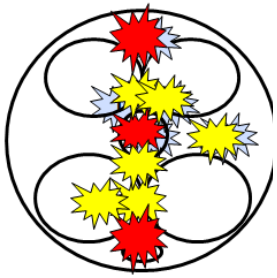
Multicylinder engine development

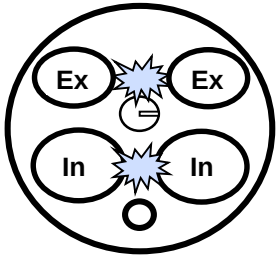
Performance, emissions, durability



calibration driveability & emissions

SOP - Start of production





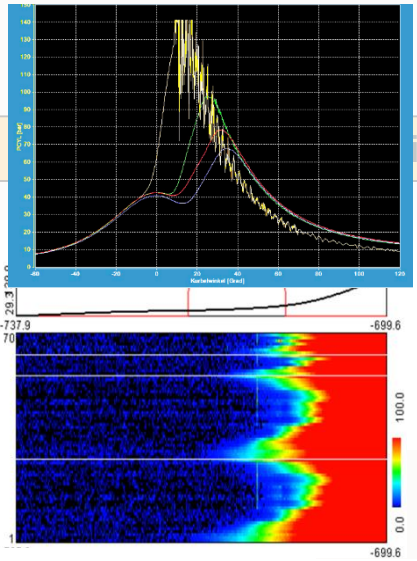
Movies show tools applications to gasoline engines

THE WORKFLOW IN ENGINE DEVELOPMENT

The work environment

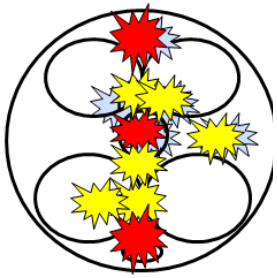
HANDLING THE PRE-IGNITION LIMIT

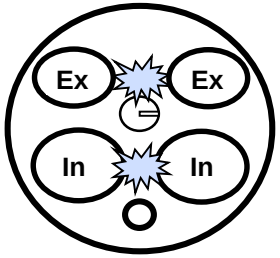
Engine development progress

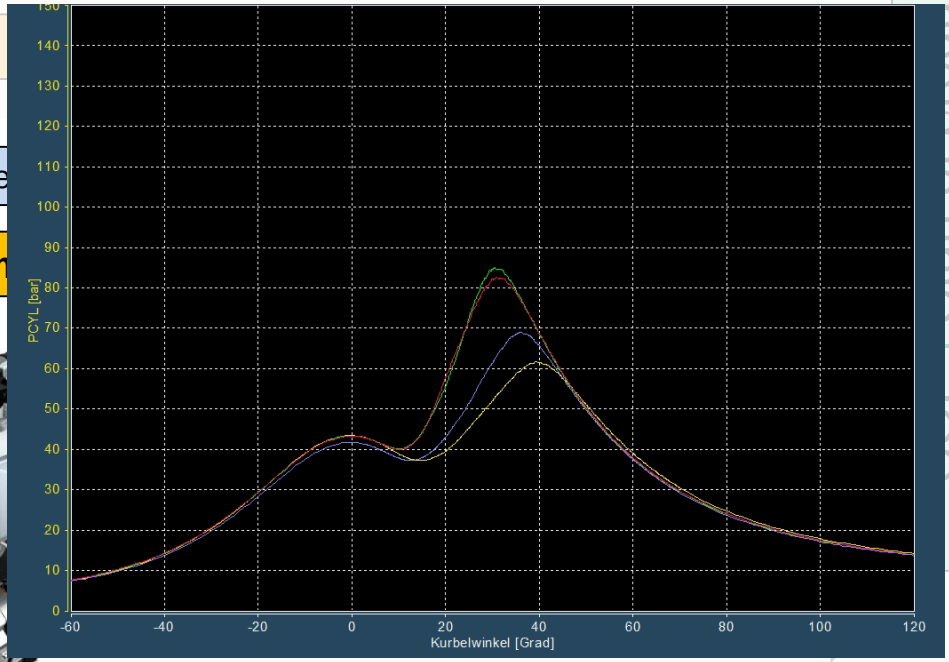


Multicylinder engine de

Performance, em







Movies show tools applications to gasoline engines

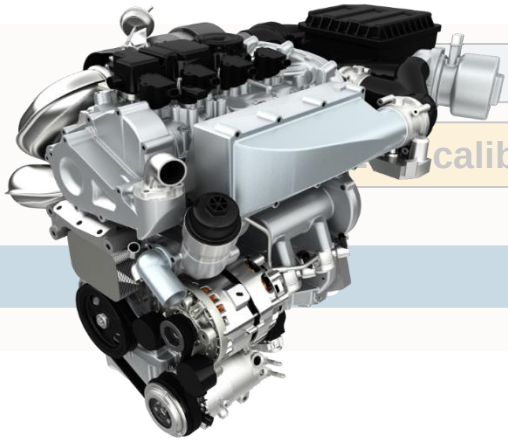
THE WORKFLOW IN ENGINE DEVELOPMENT

Engine development progress

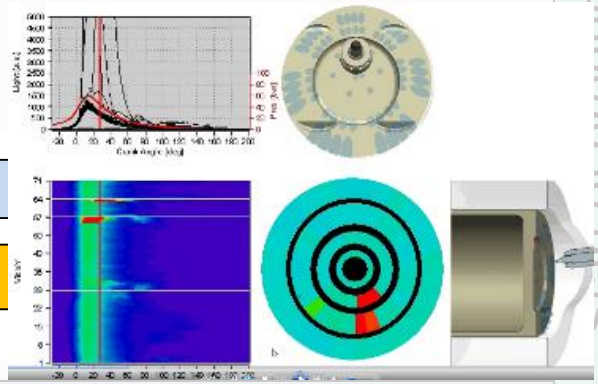
Specification combustion system

Multicylinder engine development

Performance, emissions, durability



UNDERSTANDING SOOT EMISSIONS SOURCES



Movie 5

calibration driveability & emissions

SOP - start of production

Movies show tools applications to gasoline engines

WHY AND HOW ETHANOL CAN BECOME THE BETTER FUEL

SUMMARY

Fuel features

The Ethanol impact on combustion

Heating Value	inject 1,5 liter Ethanol for 1 liter Gasoline
Evaporation	Ethanol yields better charge cooling
	Ethanol has much higher
Octane number - RON	is a most attractive Ethan

Some risks
- Self (pre) ignition
- Oil dilution and deposits
- Soot formation
- Engine start

RON and heat of evaporation:

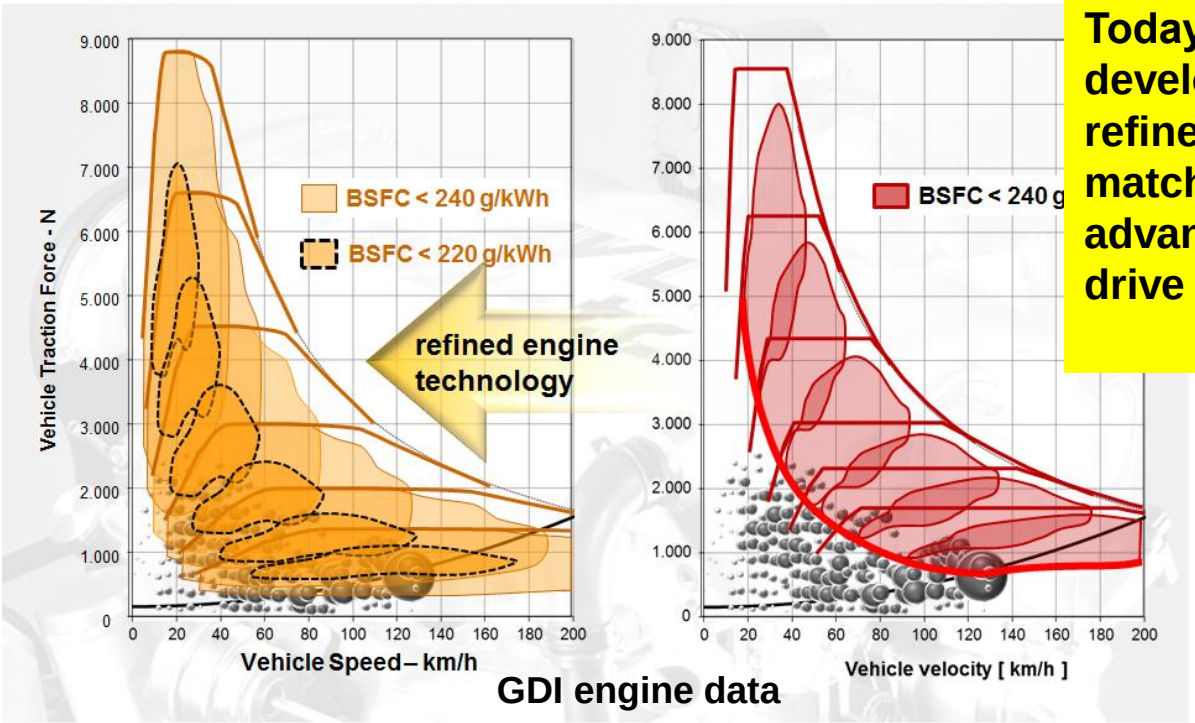
BSFC benefits from high CR and from stoichiometric operation in high load.

- Engineering:
  In high load: Cooling of components and exhaust gas
- Combustion system management:
  start, part load, high load, emissions **benefit from direct injection as we maintain control over mixture formation until start of combustion**.
- Development tools:
  are all available from GDI development

Why Ethanol is the better fuel:

RON and heat of evaporation:
is most attractive in high load operation

…but in real world drive situtions, part load operation is in the driver‘s focus



GDI engine data

Today‘s combustion system development techniques together with refined engine technologies make the match between Ethanol‘s high load advantage and the mass markets real drive requirements

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And how this is accomplished

Dr. Ernst Winklhofer

AVL List GmbH

Thank You