R&D on Ethanol Reciprocating Engines in Brazil

Prof. José Guilherme Coelho Baêta, DSc

PUCMINAS – Belo Horizonte.

R&D on Ethanol Reciprocating Engines in Brazil

Summary:

1. What is going on around the globe concerning Ethanol?
2. Why Ethanol?
3. Brazilian R&D Ethanol Projects for Light Duty engines
4. *Ethanol PFI & DI Combustion Development for Light Duty*
   a) R&D Methodology & Workhorse Modifications
   b) Technical Results
   c) Conclusions & Lessons Learned

What is going on around the globe concerning Ethanol?

USA

MEDIUM DUTY

In This Issue

Subscribe Today!

Related Articles

2010 Green Car Vision Award Finalists: Electric Drive Rules

Want to Drive on Biofuels? A Supportive Policy Environment Can Make it Happen

Multiple Vehicle Owners Up

See All

Ethanol Direct Injection T logy Could Rival Diesel at Less Co

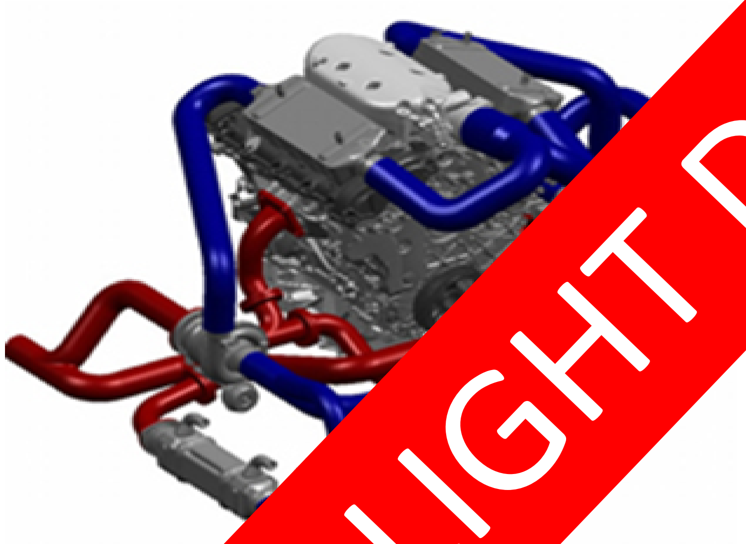
by Bill Siuru
05/13/2010

el vehicles operating nd of gasoline and l reduce the use of fossil . However, this comes with a el economy penalty of about 30 percent because of ethanol's lower energy content. This could be overcome by directly injecting ethanol and gasoline separately into the combustion chamber to optimize the use of both fuels.

Ford is developing an E85 direct injection boosting system that's combined with gasoline port fuel injection (PFI). This brings higher fuel economy because the gasoline, with its greater heating value, is primarily used during most driving modes. Directly injecting ethanol into the cylinder suppresses knock because of the evaporative cooling effect on the air-fuel mixture. Suppressing knock allows increasing compression ratio to gain ditional power, plus higher boost pressures can also be used in turbocharged or supercharged engines. These advantages allow smaller engines to provide performance equivalent to larger engines running without the technology.

What is going on around the globe concerning Ethanol?

Ricardo in Detroit is developing a similar technology it calls Ethanol Boosted Direct Injection (EBDI) to take full advantage of ethanol's best p ties – higher octane and higher heat vaporization. The EBDI project is a c n between Ricardo, Behr, Bosch, Delphi, Federal Mogul, GW d Honeywell. A prototype 3.2-liter V-6 EBDI engine can op line or up to 100 percent ethanol. By adding other advance irect injection, variable valve timing, optimized ignition, an gas recirculation, it's possible to produce more power one.



LIGHT DUTY

ardo say their ow gasoline iver performance, nd durability levels ve with diesel engines, lower price. According to do, the company is able to uce engine displacement by 5 to 50 percent while not only delivering torque that is competitive with direct-injection diesels, but fuel economy as well.

Ford's E85 DI + gasoline PFI, like modern diesel engines, features turbocharging, direct injection, struction to handle the higher pressures, and complex here are several important differences that make DI + PFI a co oach, including the fact that the DI + PFI engine requires a re xpensive conventional three-way catalyst. The E85 DI + gasoline PFI e lso uses a renewable fuel in a leveraged manner to significantly reduc petroleum consumption and total net CO^2 emissions. Likewise, Ricardo's EBDI technology relies on affordable and well-established three-way catalyst after-treatment technology to meet EPA emissions regulations.

el

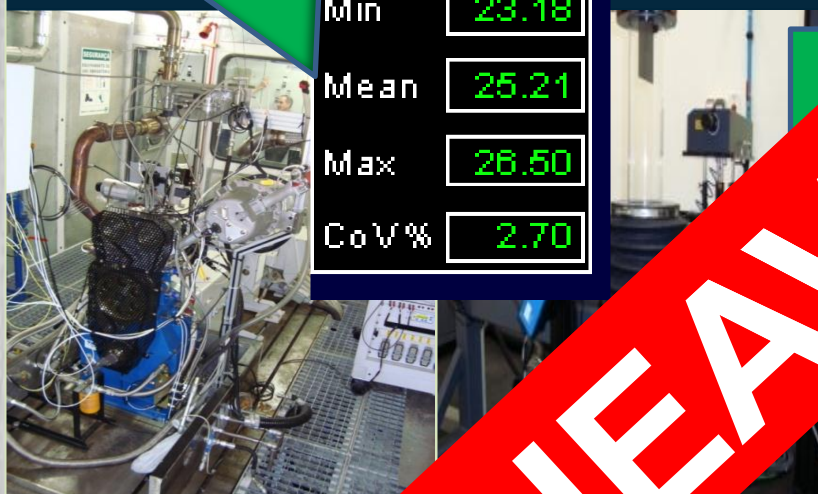
What is going on around the globe concerning Ethanol?

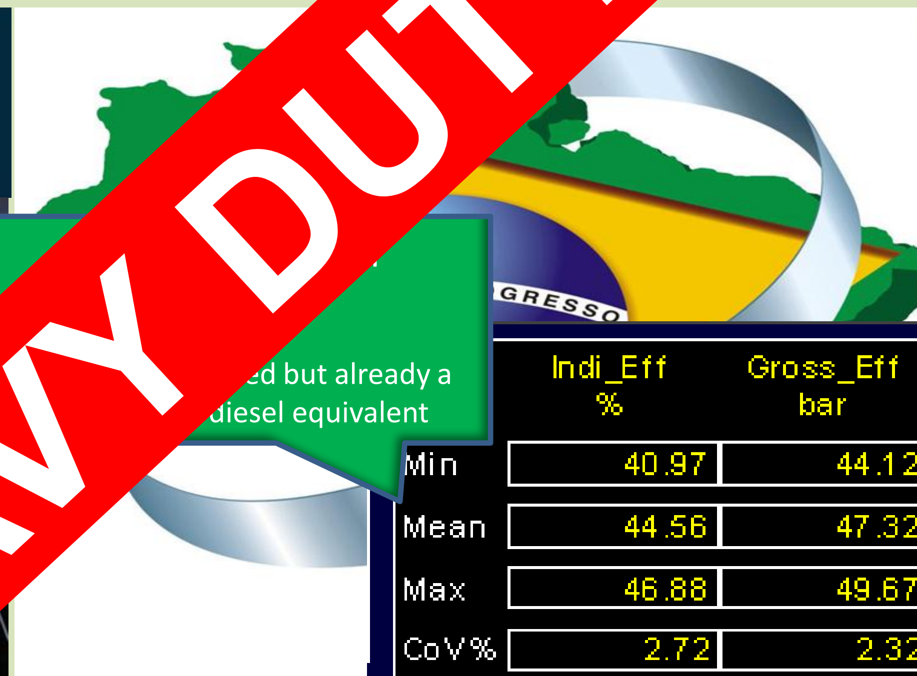
Brazil

IMEP > 25 BAR

Limited by injector maximum fuel rate but already a match for its diesel equivalent

	IMEP2 bar
Min	23.18
Mean	25.21
Max	26.50
CoV%	2.70





...ed but already a diesel equivalent

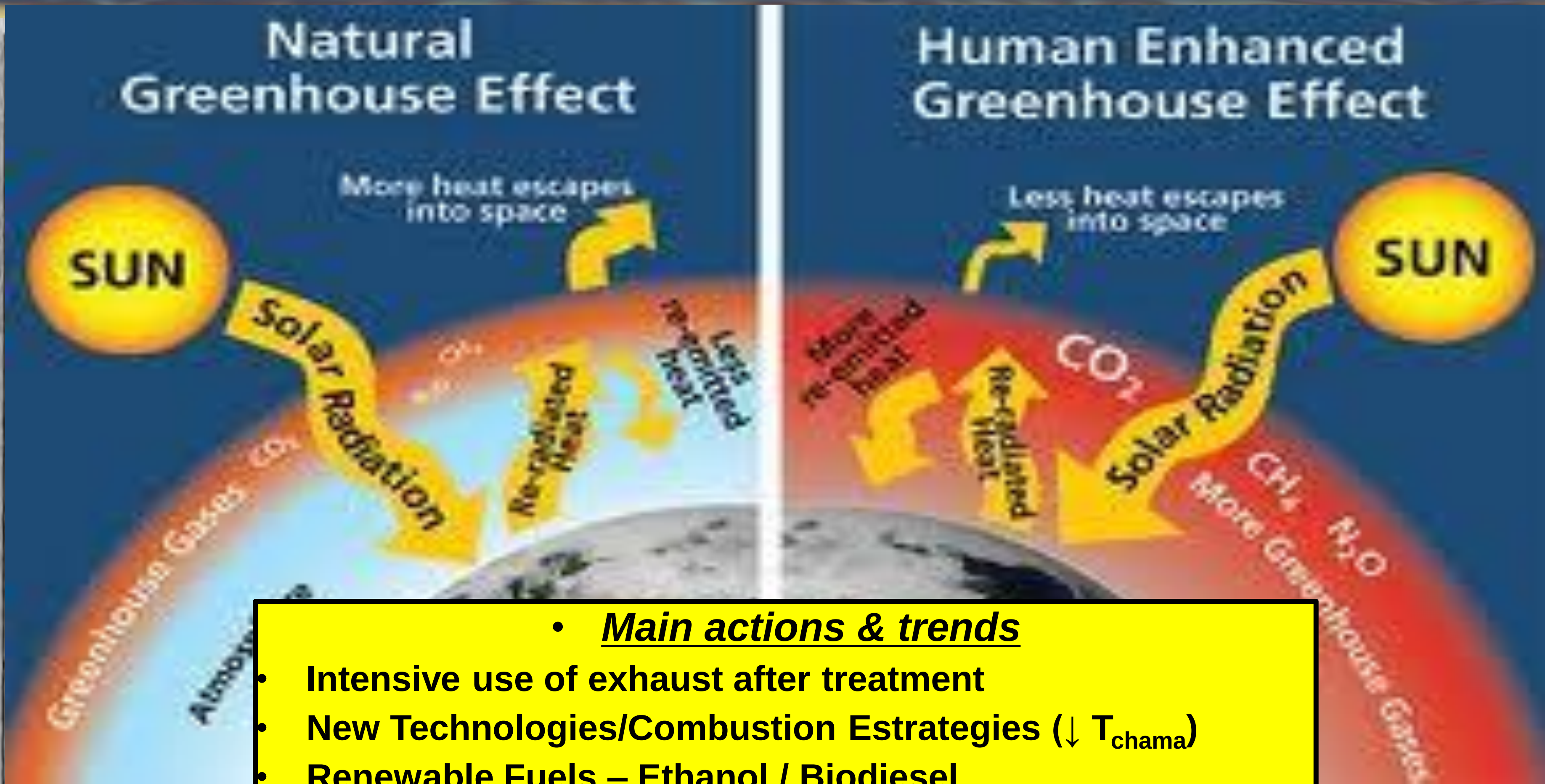
	Indi_Eff %	Gross_Eff bar
Min	40.97	44.12
Mean	44.56	47.32
Max	46.88	49.67
CoV%	2.72	2.32

HEAVY DUTY

First High Ef... ...hanol DI Engine Concept in Brazil

Fr... ...07 to 2010 - Ethanol DI – SCRE

Why Ethanol?



- ***Main actions & trends***
- **Intensive use of exhaust after treatment**
- **New Technologies/Combustion Estrategies (↓ T_{chama})**
- **Renewable Fuels – Ethanol / Biodiesel**
- **Renewable sources – Solar / Eolic**
- **Electrification/Hibridization**

Greenhouse Effect

Particulate Matte

CO: Extremely Toxic

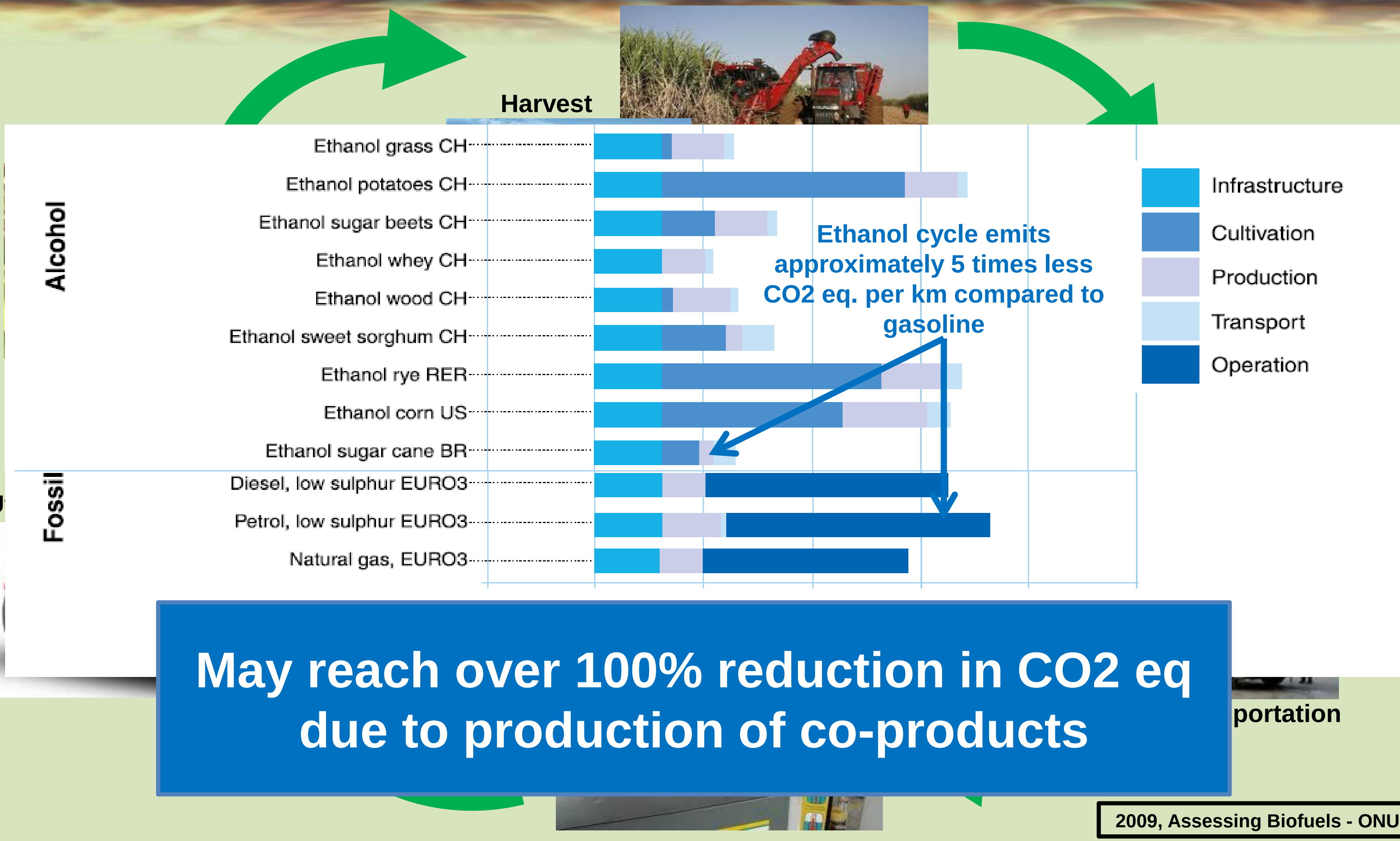
NOx: Acid rain (mainly Diesel)

Why Ethanol?

Exportation (Fossil-Fuels x Bio-Fuels)

- Oil price tends to increase in the international market;
- Oil sales abroad is not subject to government control because of concerns about inflation;
- Due to its lower energy content, the farther you need to transport ethanol (abroad) the greater the drawback of ethanol in economic terms;
- Part of the revenue from oil exports or derivatives may subsidize ethanol consumption in the country;
- Partial substitution of ethanol for gasoline and diesel will easily meet country emission targets for CO_2 reduction in years to come.
- In the coming years will increase the availability of ethanol (not instantly)

Why Ethanol?



May reach over 100% reduction in CO2 eq due to production of co-products

2009, Assessing Biofuels - ONU

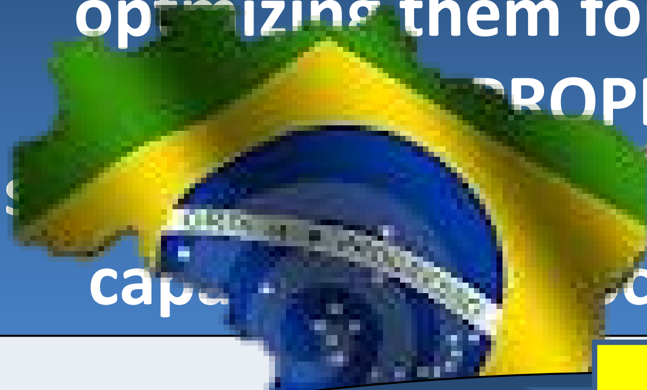
Why Ethanol?

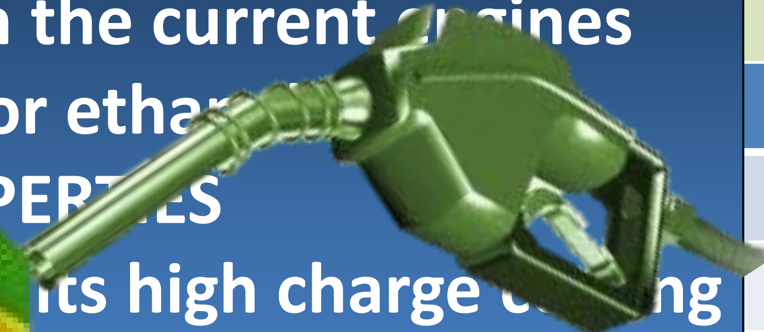
1. **Renewable Fuel (GHG Reduction)**
2. **Sup**
3. **Am**
4. **Ava**

Low CO_2 emissions due to CO_2 absorption during crop growth and reduced fossil fuel consumption for production

Opportunity to redesign the current engines optmizing them for etha PROPERTIES

Knock s ... its high charge c... ng capa ... ctane number





Tons s	
Total s	
Fiber (	
Ethanol (l/ha)	2k – 3.6k
Plantation	
Cycle	
Plantation cost/ha (R$)	

Design and calibration biased to much higher load operation (Downsizing & Downspeeding)

Why Ethanol?

Ethanol – saccharine sorghum

Saccharine Sorghum

Complementary alternative to sugar cane for ethanol production;

Fast cycle → 4 months to competitive cost due to sharing investments;

May decrease variation in the price of ethanol between harvests.

Why Ethanol ?

λ=1 Ethanol/Gasoline Engines: A Low-Cost Solution to Efficiency & Emissions Challenges?

λ=1 operation with three-way catalyst

- Low Cost
- Proven ultra-low emissions potential

SI Ethanol/Gasoline technology

- Lower cost compared to DI diesel
- Robust operation
- Boosted operation yields reasonable power density
- Reduced packaging constraints

Efficiency – SOLUTION REQUIRED

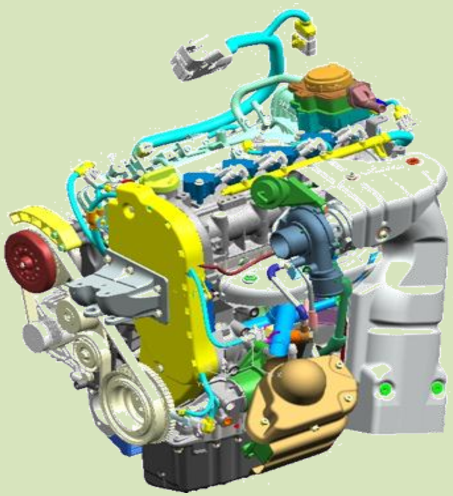
- Traditional Ethanol/Gasoline engines have r
- Knock limited performance
- Overfuelling at high loads & high speeds
- Pumping losses at partial loads
- Very high thermal loads on turbocharger

DOWNSIZED & DOWNSPEEDED ETHANOL ENGINE TECHNOLOGY

- High knock suppression capability
- Full calibration at Stoichiometric operation
- De-throttling application by WG control
- Lower thermal loads on TC by means of downspeeding & fuel properties

Brazilian R&D Ethanol Projects for Light Duty Engines

***Highly Boosted & Efficient Ethanol Engine* Concepts**



Project Challenge 2011 – 2012

The main goal was to define an engine architecture that fully exploit Ethanol Potential in order to match E22 fuel mileage with the same performance index

Ethanol & CNG DI Combustion Development for Light Duty Engines

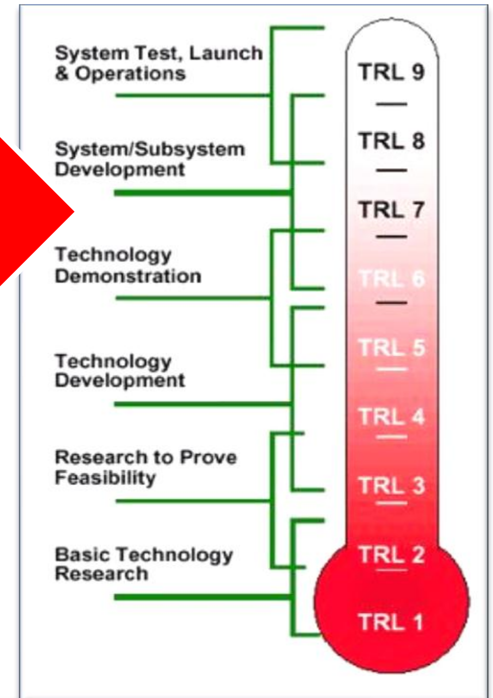
Potential Investigations for Highly efficient ICE - Technologies Approach

Technology Strategy

Mature Technologies → Advanced Technologies → Breakthrough

40% | Lower efficiencies | 42 – 43 % | 45 - 47% | Higher efficiencies

Lower risks ⟷ Higher risks



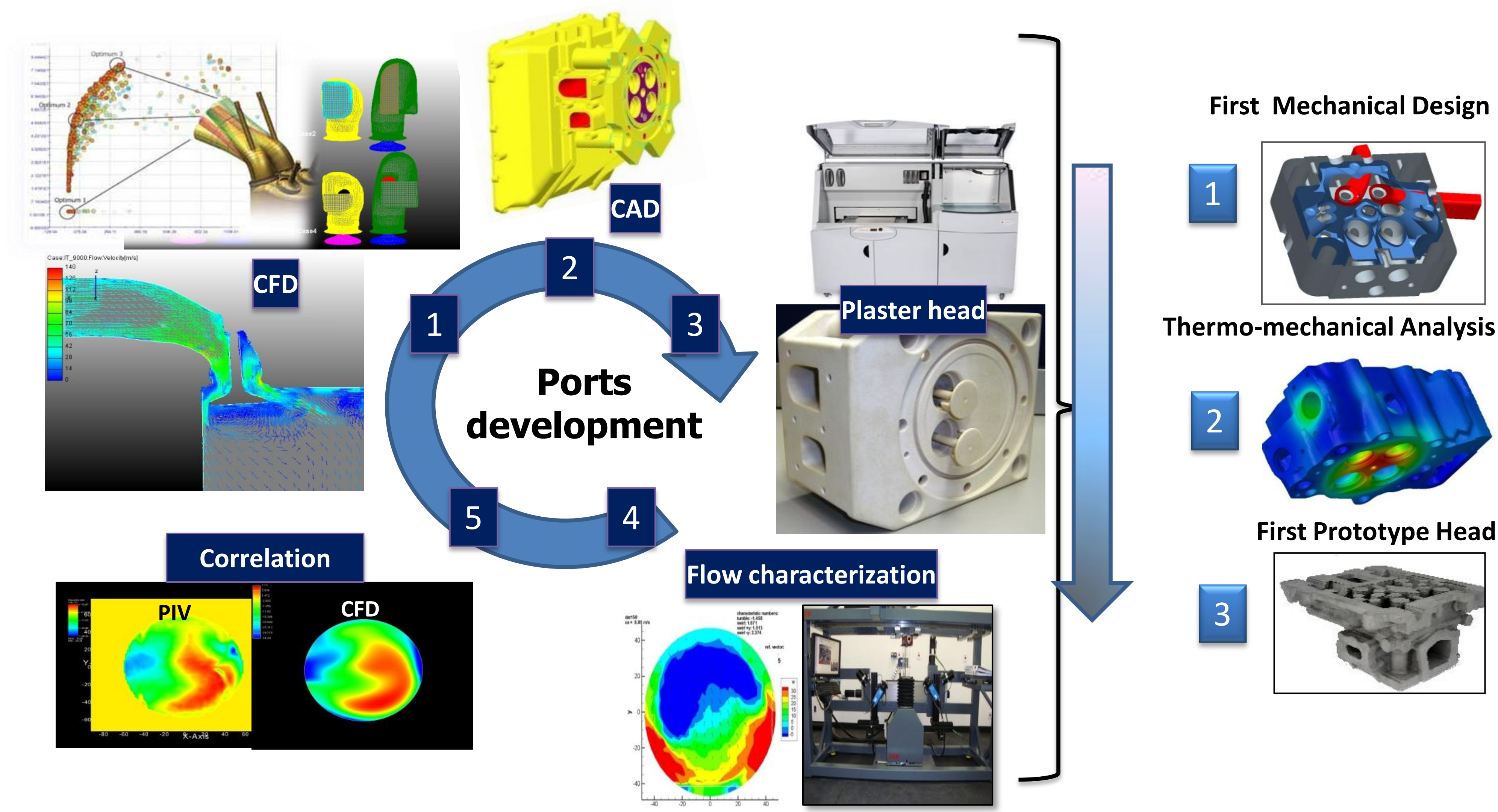
- Liquid Direct Injection
- Air-assisted Direct Injection
- Massive cooled EGR
- High Energy Ignition

- Advanced Combustion Chamber
- Dedicated to DI ethanol application
- Fuel Stratification
- Advanced Miller Cycle
- Flex DI combustion chamber

- Extended Stratification
- CNG-assisted Ethanol DI
- Ethanol 2 stroke CAI
- New supercharging methods

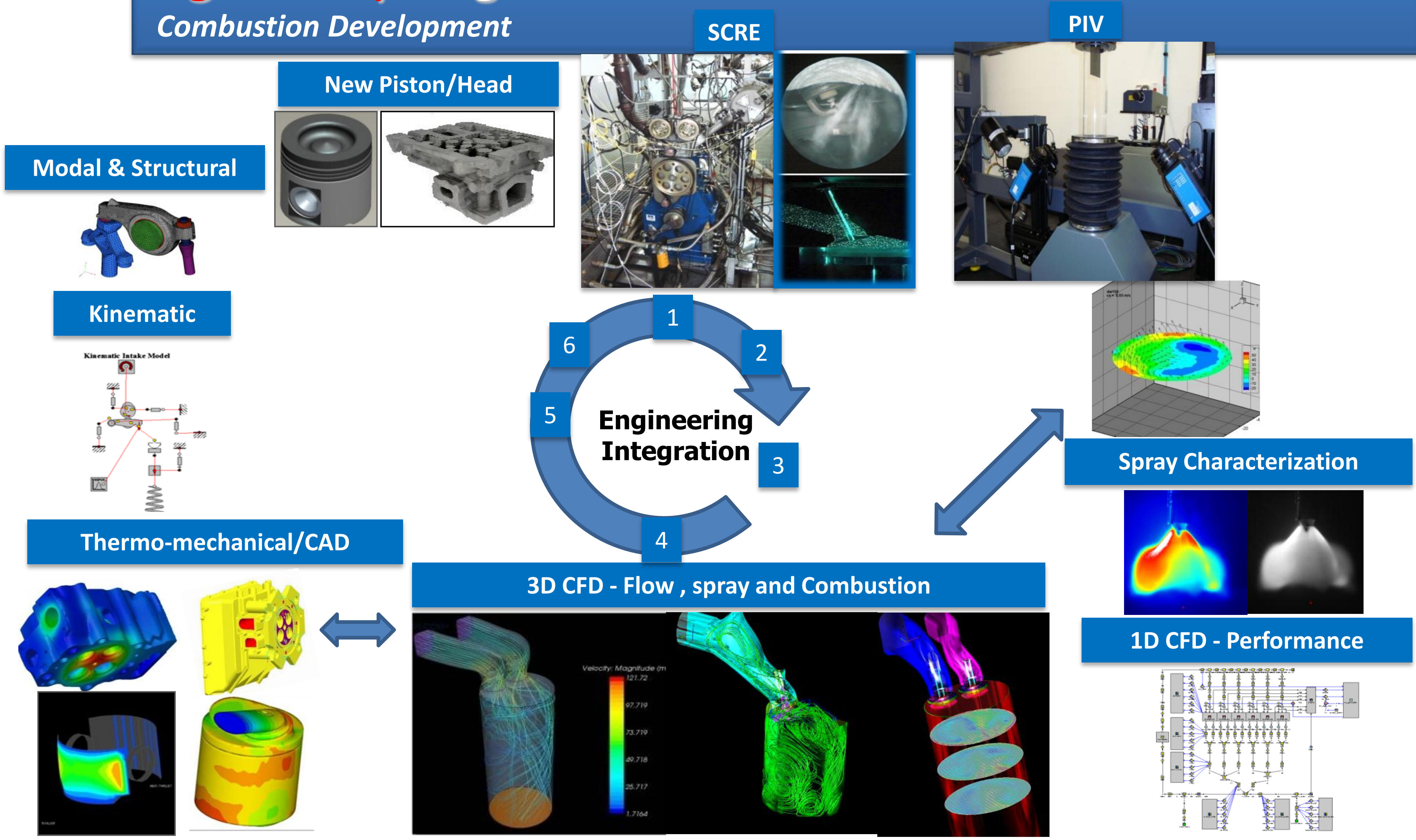
Ethanol & CNG DI Combustion Development for Light Duty Engines

Intake ports flow Pre-design



Ethanol & CNG DI Combustion Development for Light Duty Engines

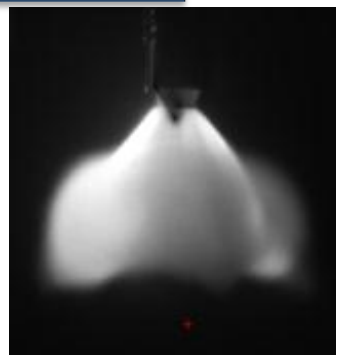
Combustion Development



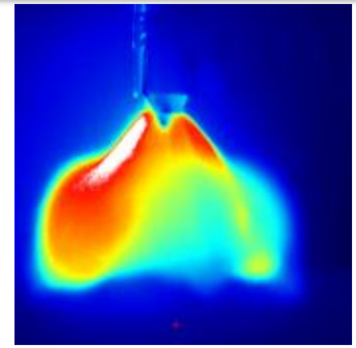
Ethanol & CNG DI Combustion Development for Light Duty Engines

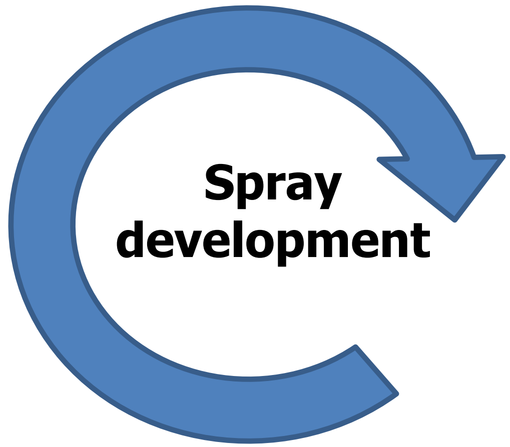
DI characterization & pre-design

SPRAY CHARACTERIZATION

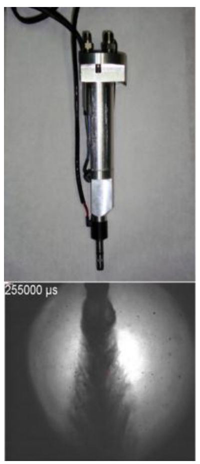


CFD CALIBRATION MODEL

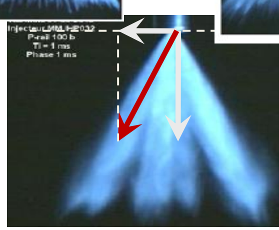




air-assisted

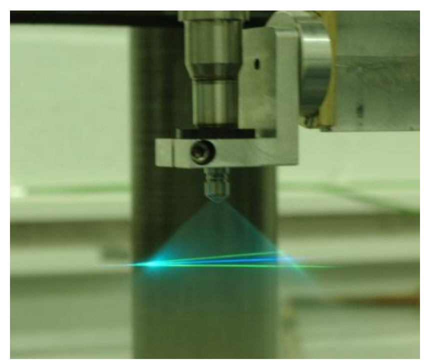


Bosch HDEV4



Continental

Magneti Marelli

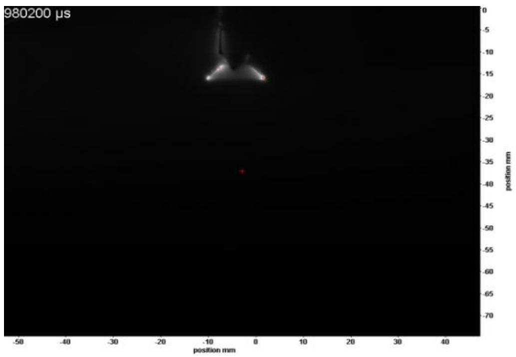


MAIN FEATURES

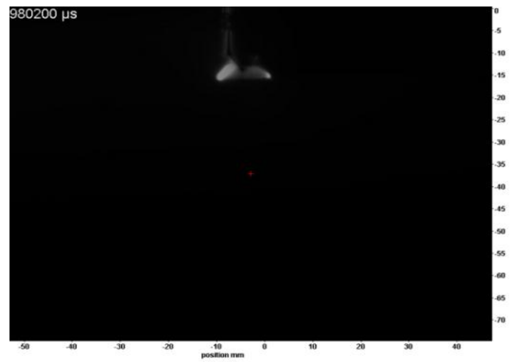
- Cone angle
- Droplet distribuition
- Droplet sizes
- Spray velocity
- Wetted foot print
- Spray asymmetry
- Spray penetration
- Spray diameter

Ethanol & CNG DI Combustion Development for Light Duty Engines

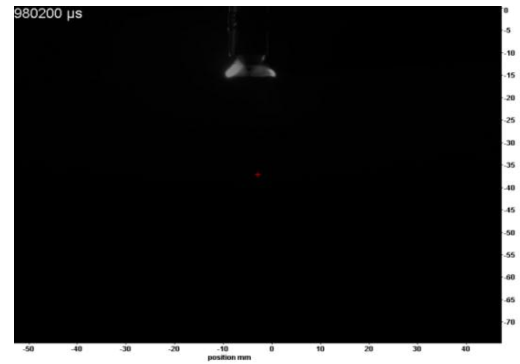
DI characterization & pre-design (counter pressure)



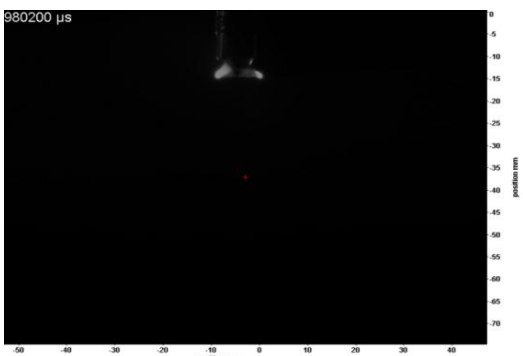
0 bar



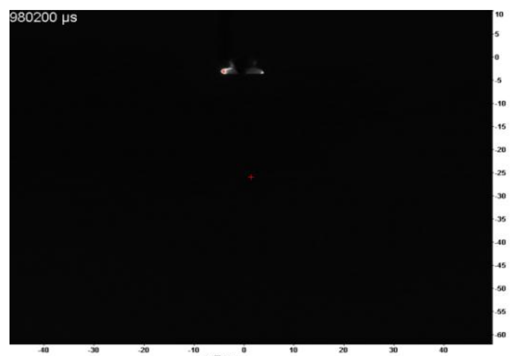
10 bar



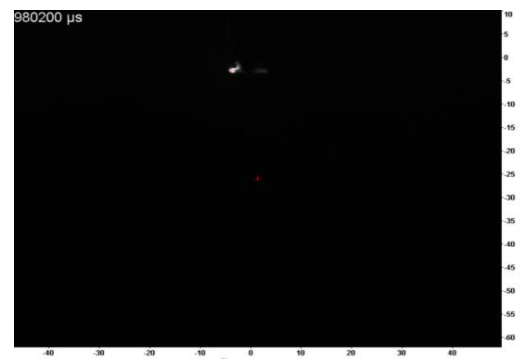
20 bar



30 bar



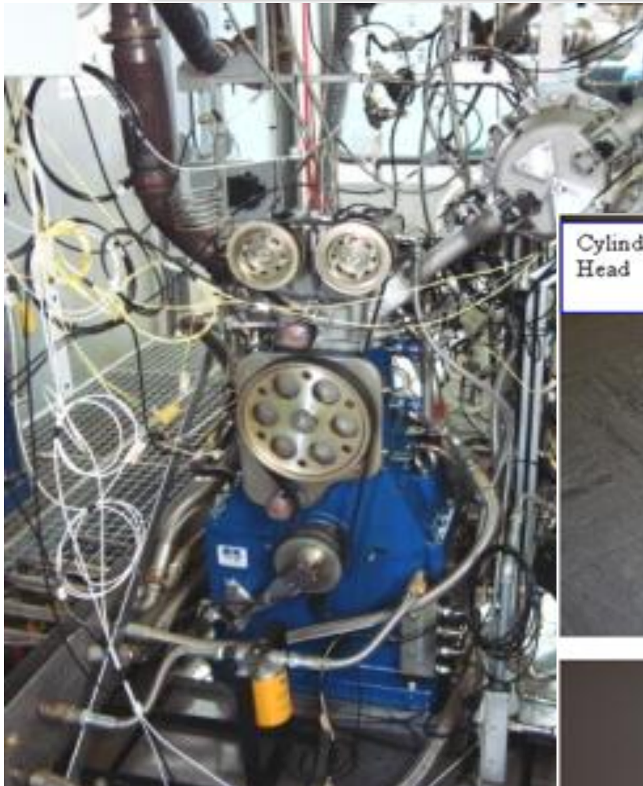
40 bar



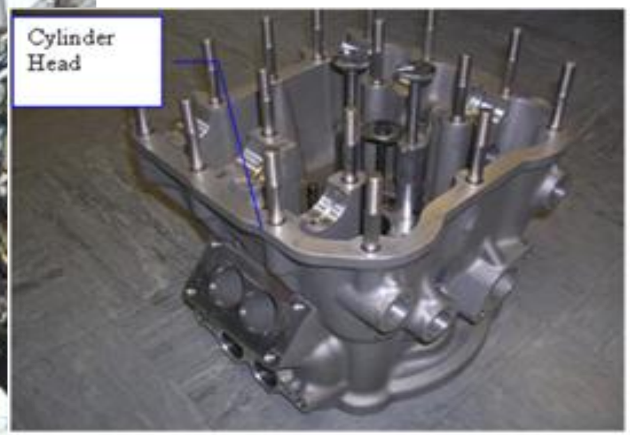
50 bar

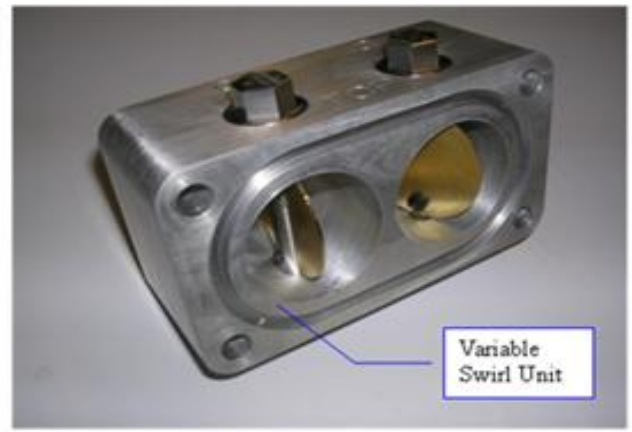
Ethanol & CNG DI Combustion Development for Light Duty Engines

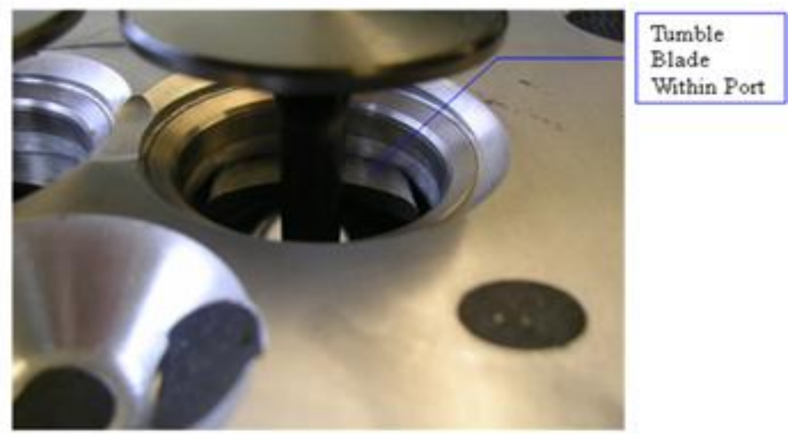
Flow, Mixture Formation, Combustion & Emission Integration



Single Cylinder Research Engine



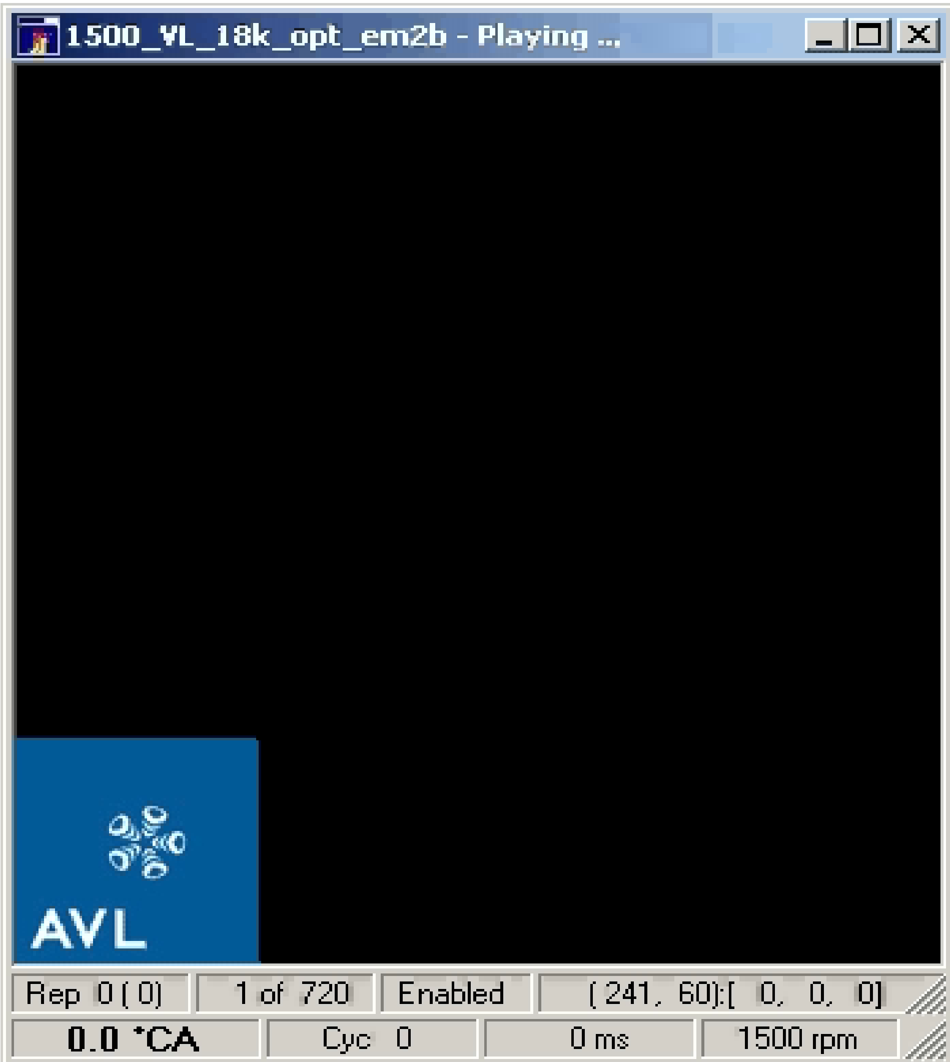


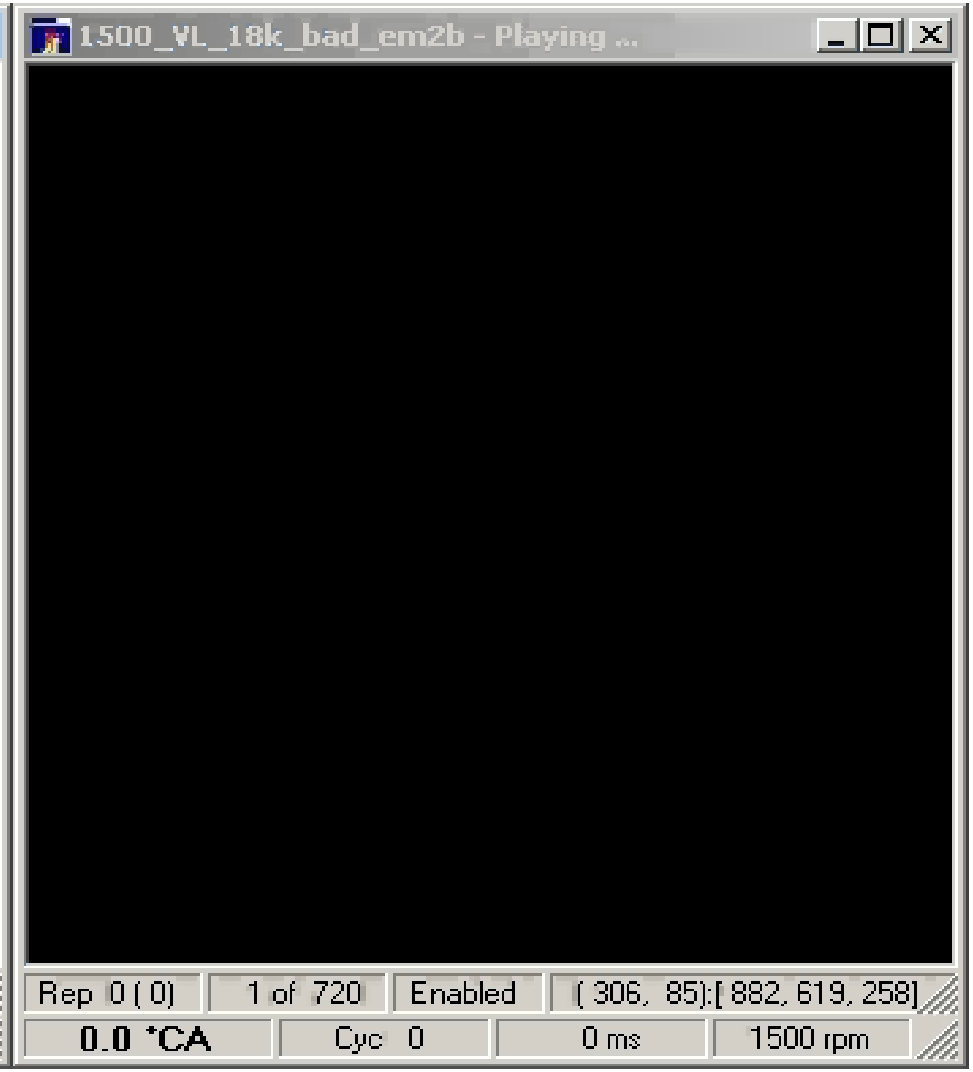


Ethanol & CNG DI Combustion Development for Light Duty Engines

Flow, Mixture Formation, Combustion & Emission Integration

Single Cylinder Research Engine

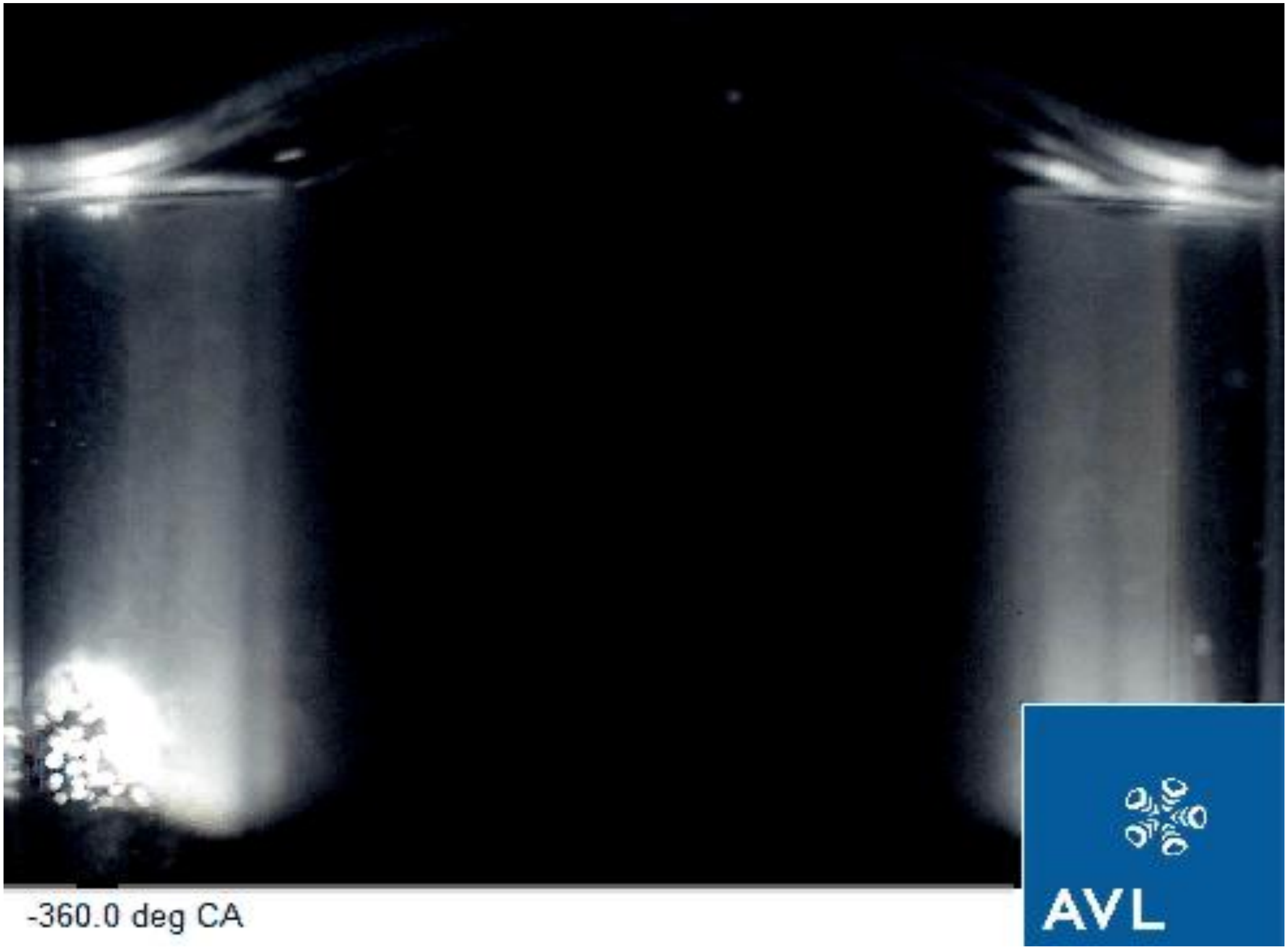




Ethanol & CNG DI Combustion Development for Light Duty Engines

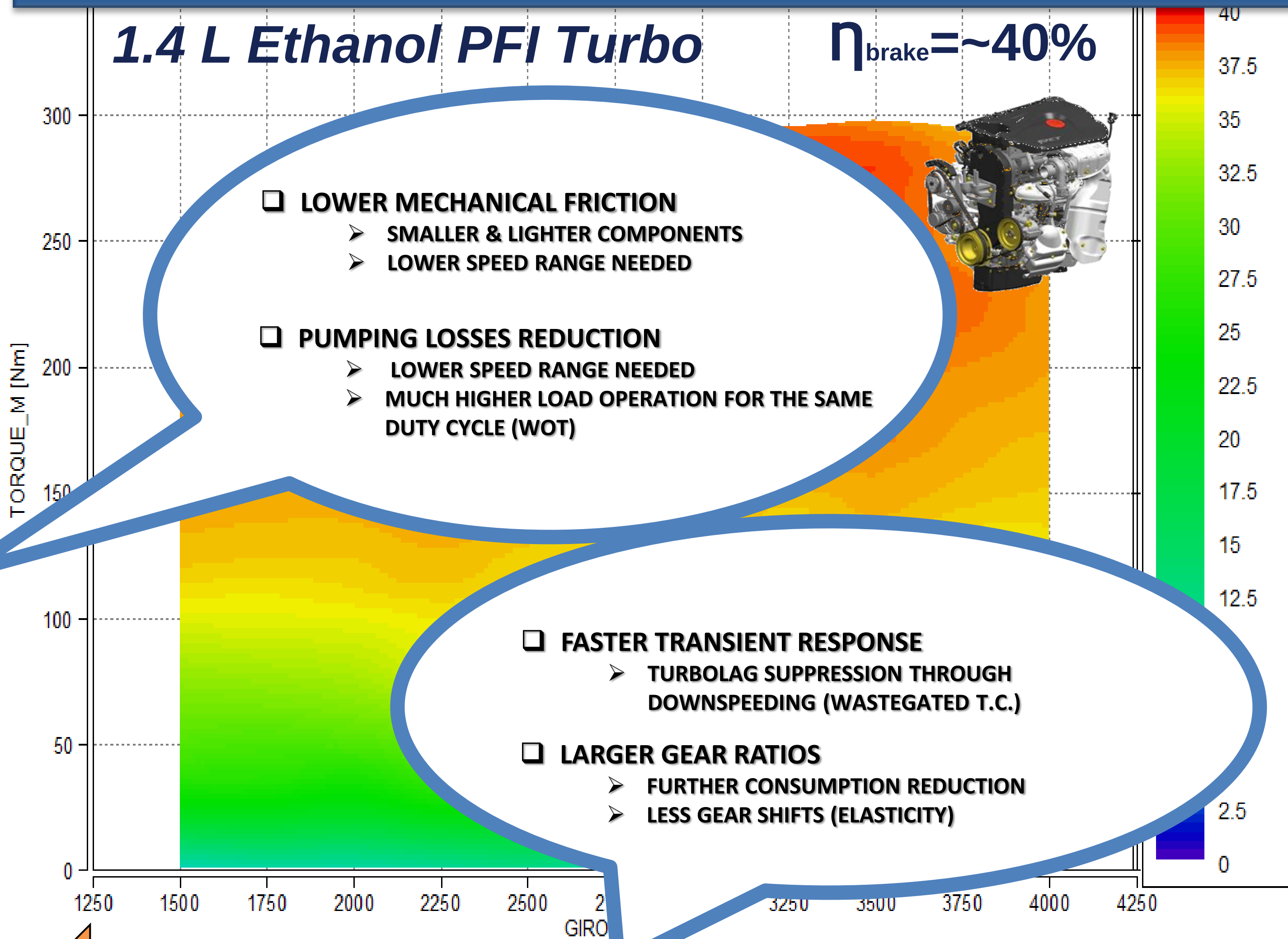
Flow, Mixture Formation, Combustion & Emission Integration

Single Cylinder Research Engine



Ethanol PFI & DI Combustion Development for Light Duty Engines

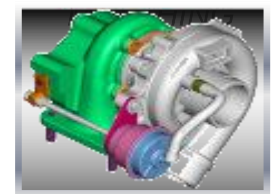
1.4 L Ethanol PFI Turbo η_{brake}=~40%



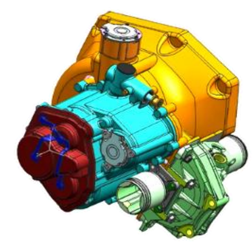
- LOWER MECHANICAL FRICTION
  - SMALLER & LIGHTER COMPONENTS
  - LOWER SPEED RANGE NEEDED
- PUMPING LOSSES REDUCTION
  - LOWER SPEED RANGE NEEDED
  - MUCH HIGHER LOAD OPERATION FOR THE SAME DUTY CYCLE (WOT)

- FASTER TRANSIENT RESPONSE
  - TURBOLAG SUPPRESSION THROUGH DOWNSPEEDING (WASTEGATED T.C.)
- LARGER GEAR RATIOS
  - FURTHER CONSUMPTION REDUCTION
  - LESS GEAR SHIFTS (ELASTICITY)

PERFECT TURBO



LARGER GEAR RATIOS



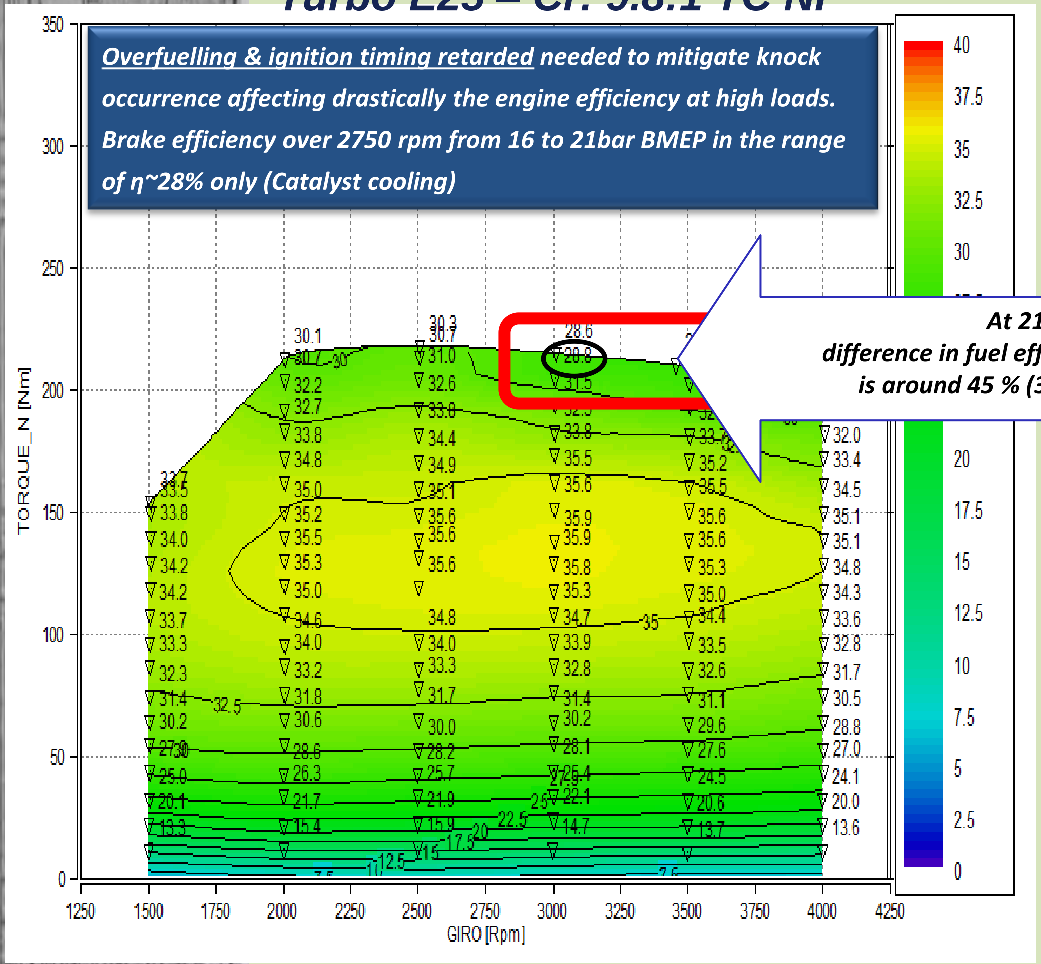
~50% Downsizing Capability

~38% Downspeeding Capability

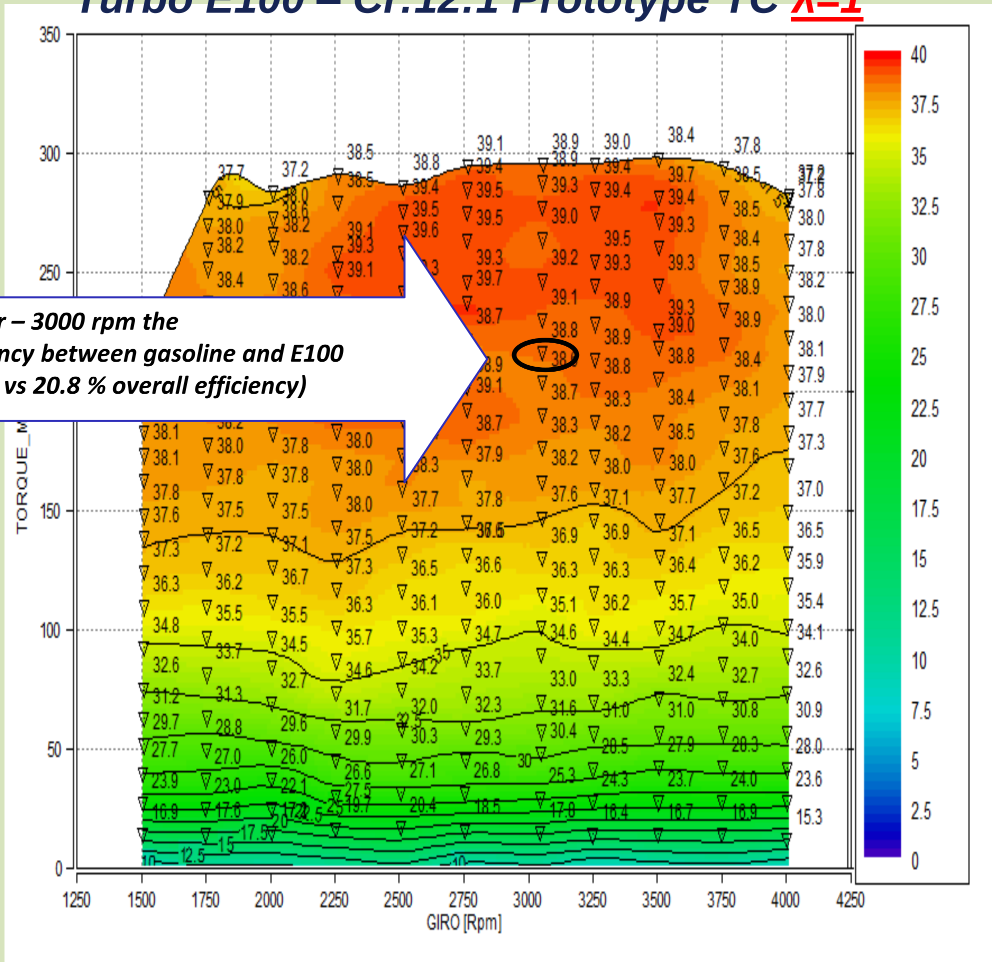
Ethanol PFI & DI Combustion Development for Light Duty Engines

- Technical Results

Turbo E25 – Cr: 9.8:1 TC NP



Turbo E100 – Cr:12:1 Prototype TC λ=1

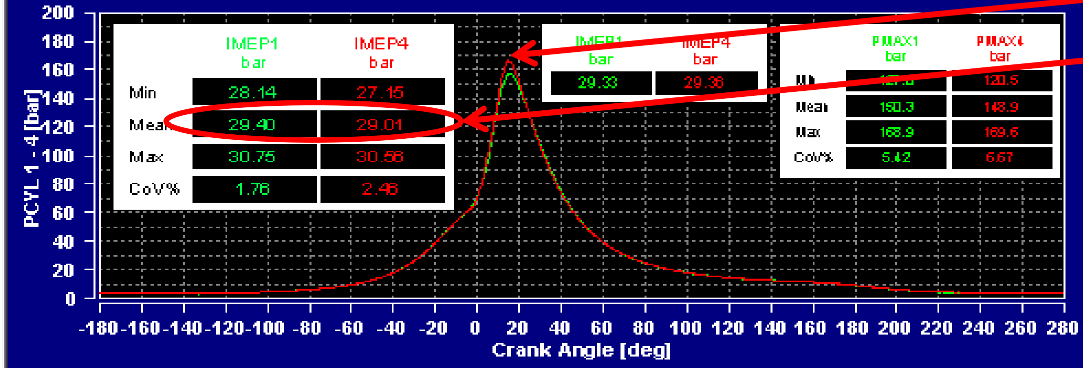


At 21 bar – 3000 rpm the difference in fuel efficiency between gasoline and E100 is around 45 % (39% vs 20.8 % overall efficiency)

Technical Results

PxV | Heat Release x MBF | MFB per Cycle | apresentação | MFB Average

Burn time 90-10_cyl1 ms	Burn time 90-10_cyl4 ms
1.07	1.06



	IMEP1 bar	IMEP4 bar
Min	28.14	27.15
Mean	29.40	29.01
Max	30.75	30.56
CoV%	1.76	2.46

IMEP1 bar	IMEP4 bar
29.33	29.38

	PMAX1 bar	PMAX4 bar
Min	[illegible]	120.5
Mean	150.3	148.9
Max	168.9	169.6
CoV%	5.42	6.67

3500rpm

Pmax – 160bar

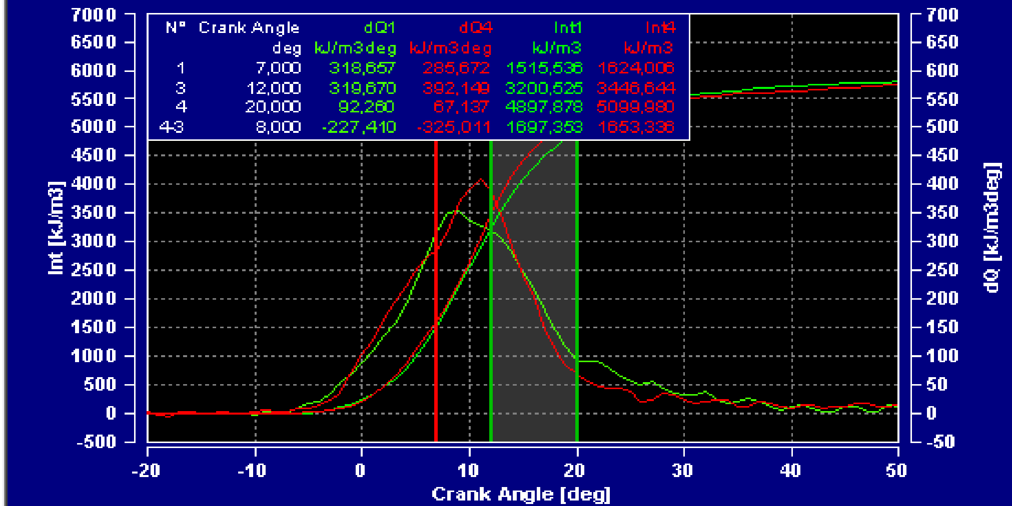
IMEP=29 bar

ITorque=32 kgf.m

	MBF50%1 deg	MBF50%4 deg
Min	9.50	9.70
Mean	12.88	13.27
Max	17.60	18.05
CoV%	12.39	12.12

MBF50%

MBF50%1 deg	MBF50%4 deg
11.20	10.75



N°	Crank Angle deg	dQ1 kJ/m3deg	dQ4 kJ/m3deg	Int1 kJ/m3	Int4 kJ/m3
1	7,000	318,657	285,672	1515,536	1624,006
3	12,000	319,670	392,149	3200,525	3446,644
4	20,000	92,260	67,137	4897,878	5099,980
4-3	8,000	-227,410	-325,011	1697,353	1653,336

MBF5010cyl1 deg	MBF5010cyl4 deg
8.25	8.05

MBF9050cyl1 deg	MBF9050cyl4 deg
14.25	14.30

MBF9010cyl1 deg	MBF9010cyl4 deg
22.50	22.35

	MBF5010cyl1 deg	MBF5010cyl4 deg	MBF9050cyl1 deg	MBF9050cyl4 deg	MBF9010cyl1 deg	MBF9010cyl4 deg
Min	7.45	7.40	10.70	12.45	20.00	20.90
Mean	8.81	8.95	13.61	15.71	22.43	24.66
Max	10.60	11.15	16.00	20.10	25.20	28.20
CoV%	6.91	8.01	7.84	9.45	4.50	5.23

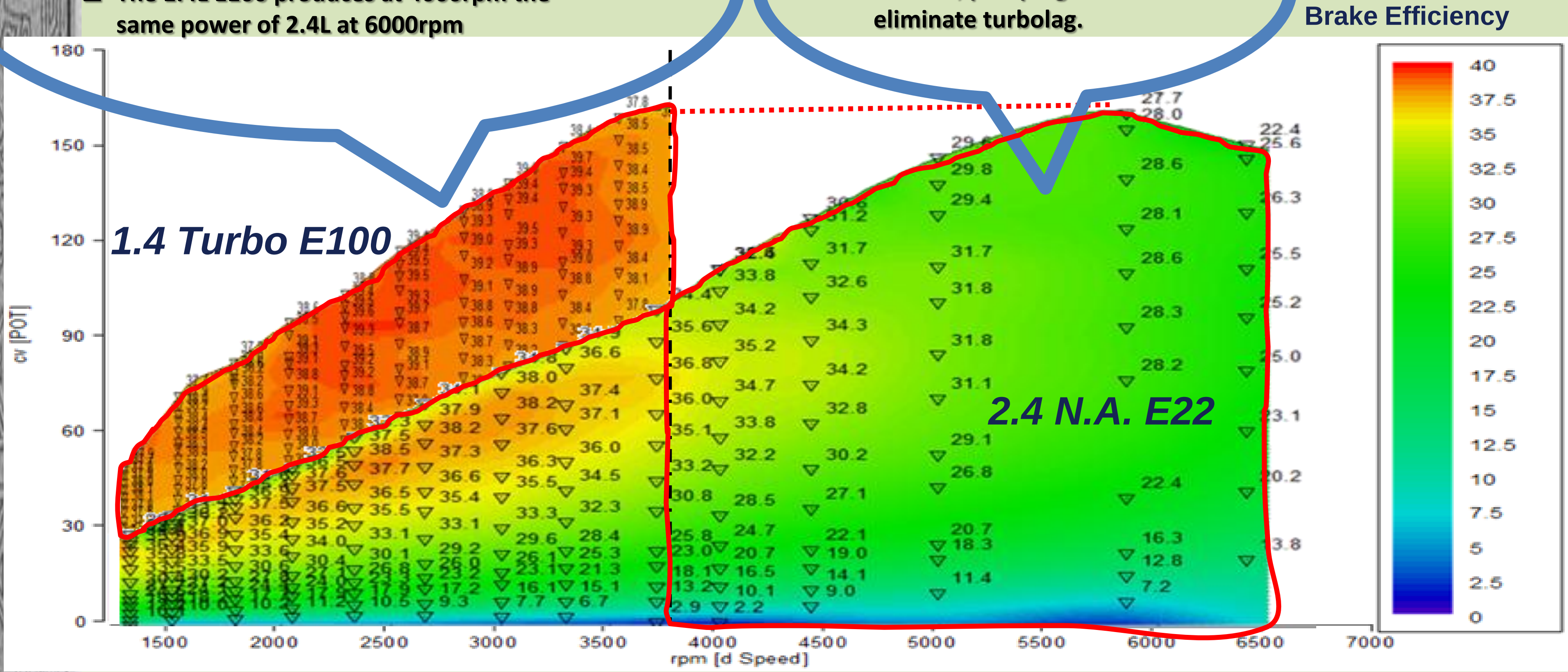
Fast Combustion
24 CAD MFB 10-90%

Ethanol PFI & DI Combustion Development for Light Duty Engines

- Technical Results

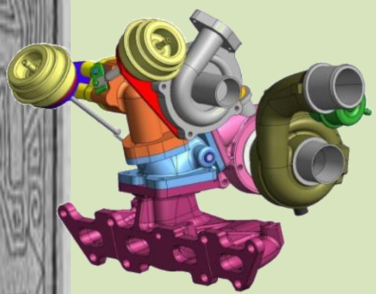
- Much Higher Brake Efficiency
- Plenty room for Gear Ratios Enlargement
- Much Higher torque Availability
- The 1.4L E100 produces at 4000rpm the same power of 2.4L at 6000rpm

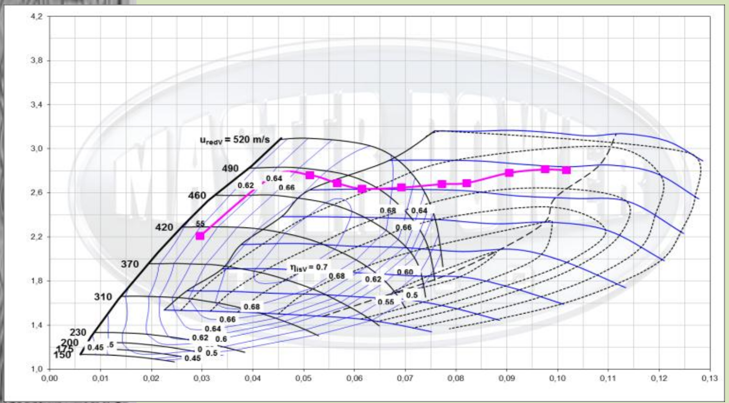
- Engine speed over 4000rpm is avoided in order to reduce Friction, pumping losses & to eliminate turbolag.

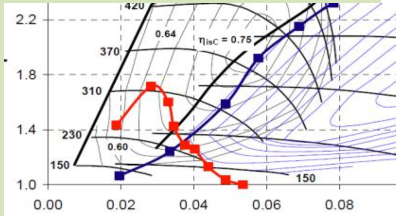


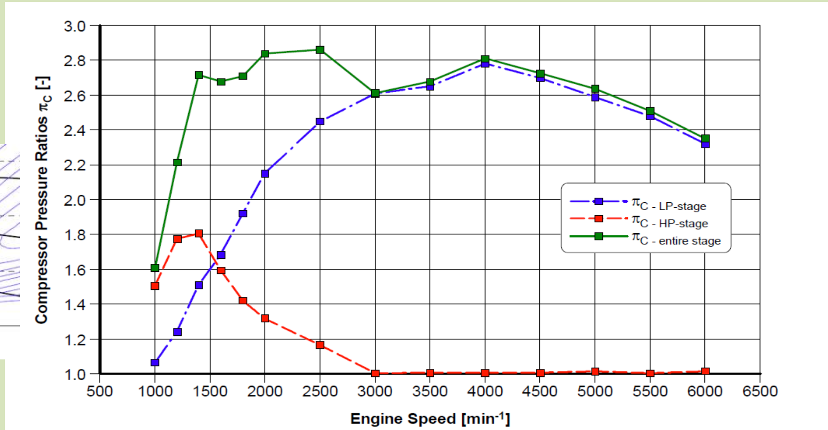
Ethanol PFI & DI Combustion Development for Light Duty Engines

- Downsizing boundaries:
  - Twin Stage Turbo set in order to double engine power output range to evaluate downsizing capability





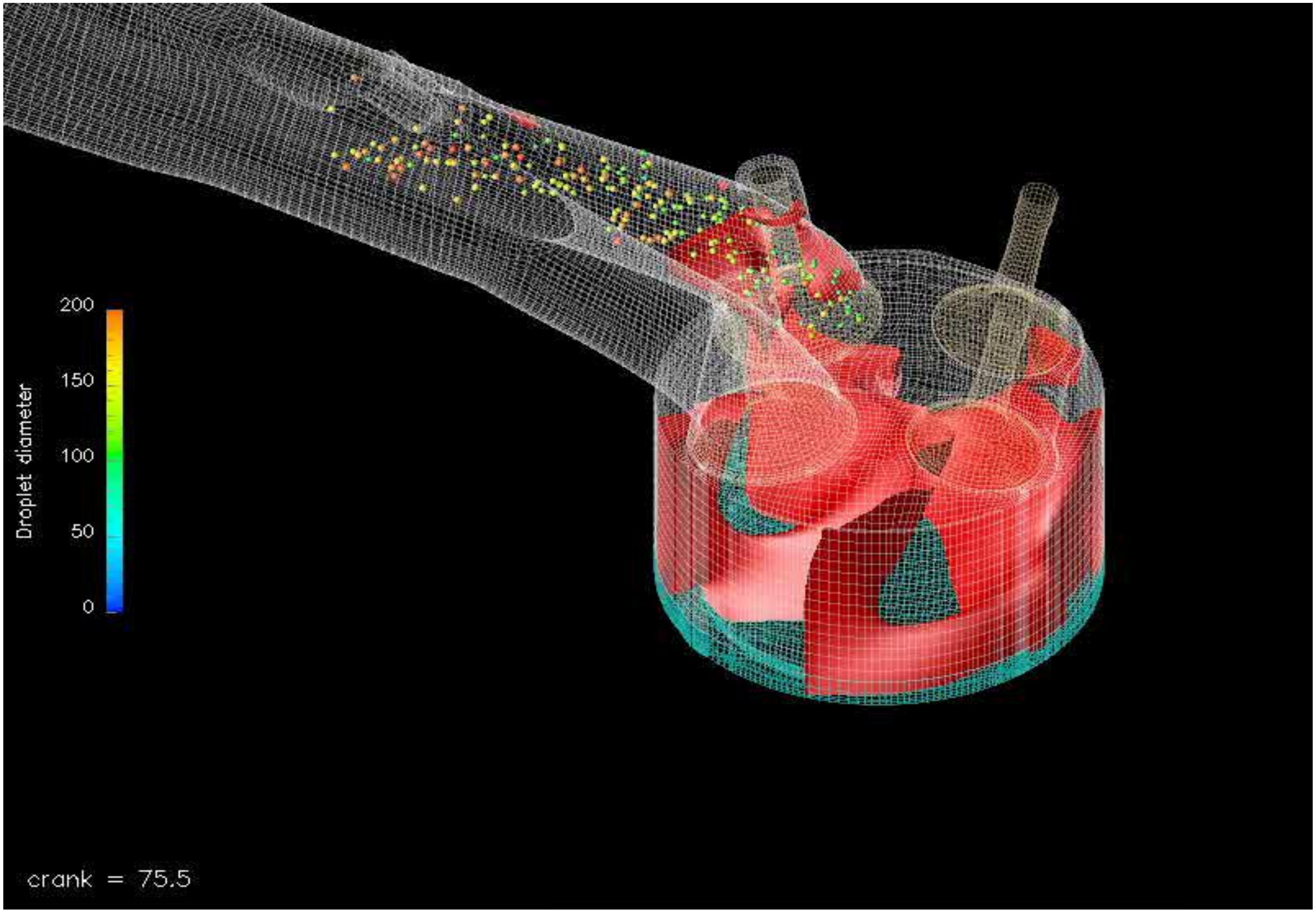




Ethanol PFI & DI Combustion Development for Light Duty Engines

- Technical Results

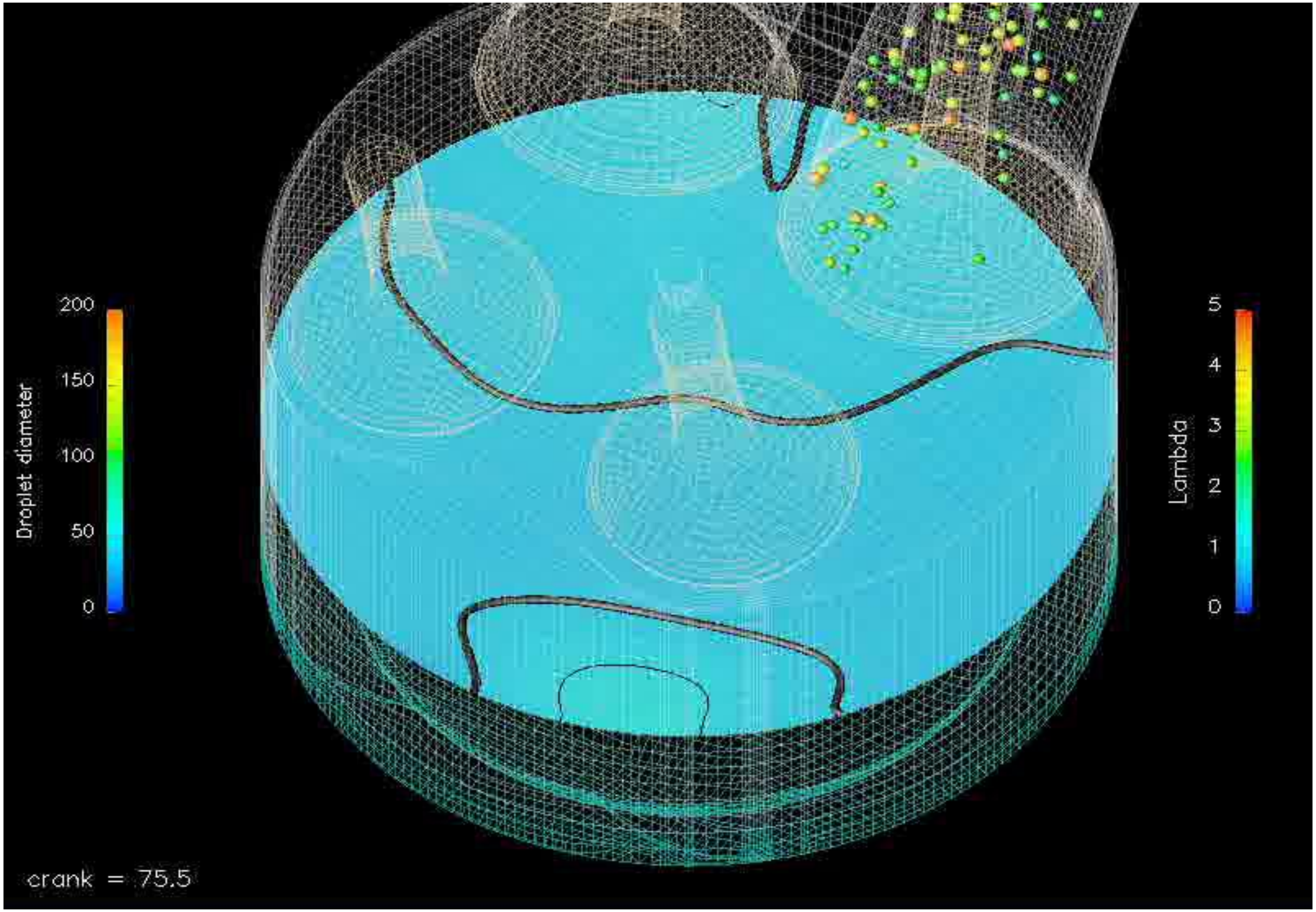
Dropplet Diameter



Ethanol PFI & DI Combustion Development for Light Duty Engines

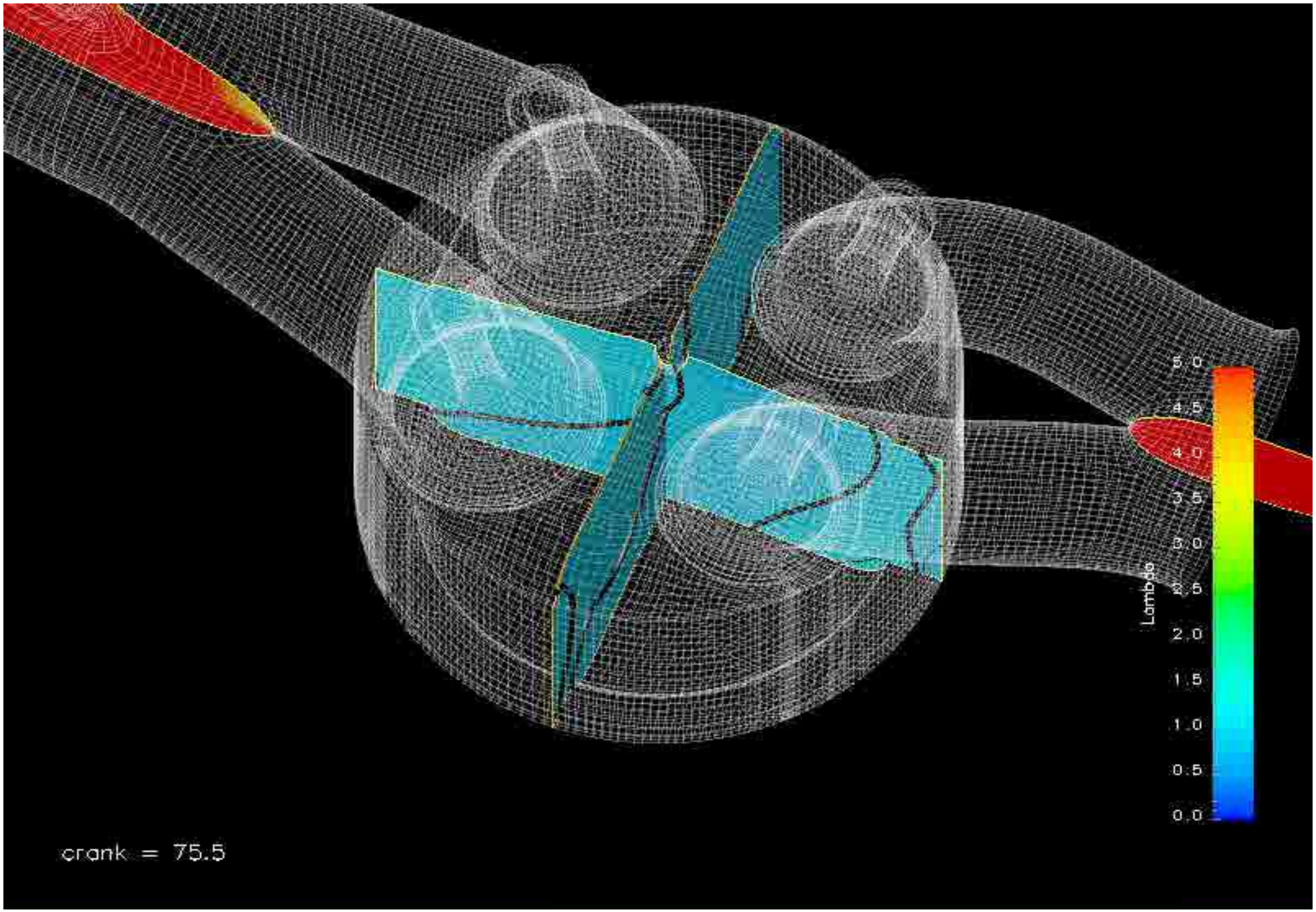
- Technical Results

Lambda Swirl (horizontal Plan)



Ethanol PFI & DI Combustion Development for Light Duty Engines *- Technical Results*

Lambda 2 (vertical) tumble Plans



Ethanol PFI & DI Combustion Development for Light Duty Engines

Conclusions & Lessons Learned

1. *There is an ample room to optimize the use of brazilian fuel energy matrix by means of the development of new "national" engine technologies ;*
2. *Ethanol fuel properties make possible to match diesel efficiency in an Otto highly Boosted Engine by means of downsizing & downspeeding techniques implementation ;*
3. *Test results demonstrate feasibility of this engine technology concept. A more robust workhorse engine is needed to fully exploit the boundaries of the ethanol properties. The diesel engine hardware would be a promissing choice.*
4. *Highly Boosted Downsized Ethanol Engines can match E22 fuel mileage;*
5. *The DI implementation could lead to an extra fuel consumption reduction increasing the downsizing capability. In other words, the downsizing needed of 50% for a PFI could be in the range of 42% if the E100 DI is implemented. (Additional benifit to justify DI implementation - The E22 cold start system can be suppressed!)*

Ethanol PFI & DI Combustion Development for Light Duty Engines

Conclusions & Lessons Learned

6. *Cooled EGR implementation makes possible E22 implementation mitigating its performance losses for a flex fuel investigation.*

7. *Literature and previous investigation show that swirl flow structure seems to be promising for efficiency optimization & further cost reduction (2 valves/cylinder) & it is recommended to be carefully investigated. (Synchronized dissipation is still an issue)*

THANK YOU