USO EFICIENTE DO ETANOL VEICULAR NO BRASIL

Painel – Flex Otimizado para Etanol

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AGENDA:

- ***SPARK-IGNITION ENGINES AND ETHANOL***
- ***PROPERTIES OF ETHANOL X GASOLINE***
- ***POWERTRAIN EVOLUTION***
- ***EVOLUTION OF STRAIGHT ETHANOL VEHICLES AND FFVs***
- ***EMISSION AND MATERIALS STRENGHT CHALLENGES***
- ***OPPORTUNITIES FOR FFVs DEVELOPMENT***
- ***CONCLUSIONS AND RECOMMENDATIONS***

FUNDAMENTAL CHARACTERISTICS OF OTTO ENGINES

- Air-fuel mixture homogenous and close to stoichi-ometric ratio for flame propagation (0.8< λ< ~1.4);
- Compression of air-fuel mixture;
- Load control$\rightarrow$ throttle valve reduces the mass density of the mixture in cylinder;
- Combustion angular position is determined by spark timing;
- Combustion process by flame propagation;
- Adequate fuels should have high volatility and resistance to auto-ignition to avoid “knock”, under high compression ratios.

PROPERTIES OF ETHANOL X GASOLINE

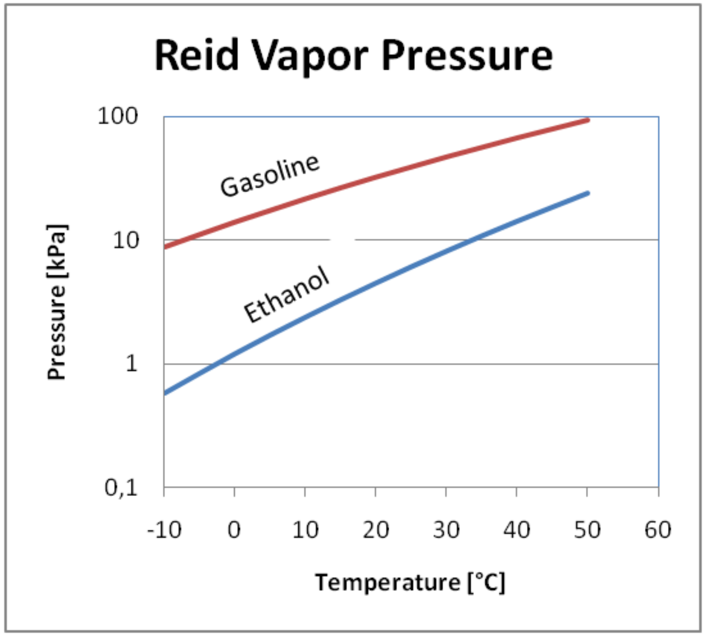
Property	Gasoline	Ethanol	E10	E85	E100 hydrous
Lower Heat Value LHV (MJ/kg)	42-44	27	41	29	25
Mass Density (kg/dm3)	0.72-0.77	0.79	0.75	0.78	0.81
Heat of Vaporization h_{lv} (kJ/kg)	310	885	366	836	970
$1000 \cdot h_{lv}/LHV$	7	33	9	27	39
Air/Fuel Stoichiometric Ratio	14.7	9.0	14.1	9.8	8.4
LHV/CO_2 Exhaust Emission (MJ/kg)	13.5	14.1	13.6	14.0	14.1
Cooling Potential of Intake Air (°C)	19	81	23	71	93
Laminar Flame Velocity @ 1 bar, 20°C (m/s)	0.33	0.41	-	-	-
Research Octane Number RON	86-98	110	+7- +3 [a]	105-109	111
Reid Vapor Pressure @ 37.8C (bar)	~ 0.6	0.16	~ 0.7	~ 0.4	~ 0.15

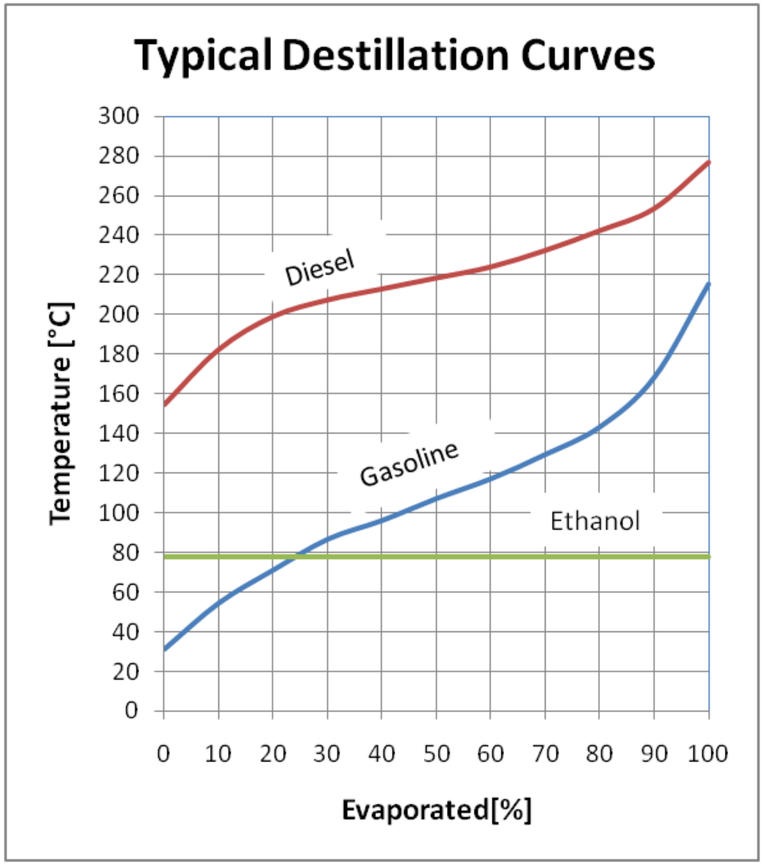
a – Incremental values of research octane number over clear gasoline for splash blending

Data obtained mainly from Kasseris E. “Knock limits in spark ignited direct injected engines using gasoline/ethanol blends” Ph.D Thesis – MIT, 2011; from Larsen U., Johansen T., Schramm J. “Ethanol as a fuel for road transportation” IEA-AMF Report, May 2009; and from “Determination of the potential property ranges of mid-level ethanol blends” API Final Report, April 2010.

VOLATILITY – ETHANOL X GASOLINE

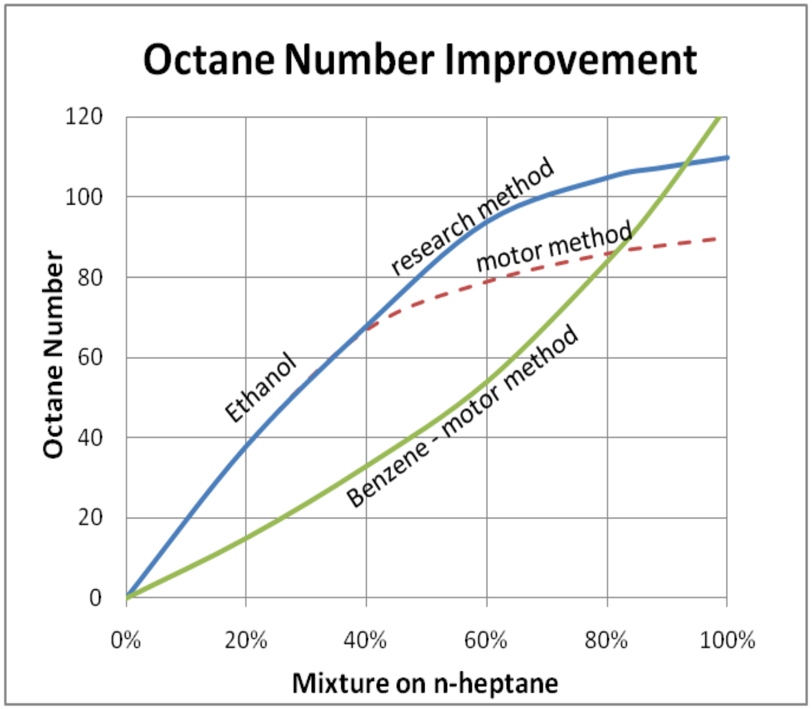
Difficult cold-start and cold-drivability, but less tendency of lub-oil contamination with warm engine

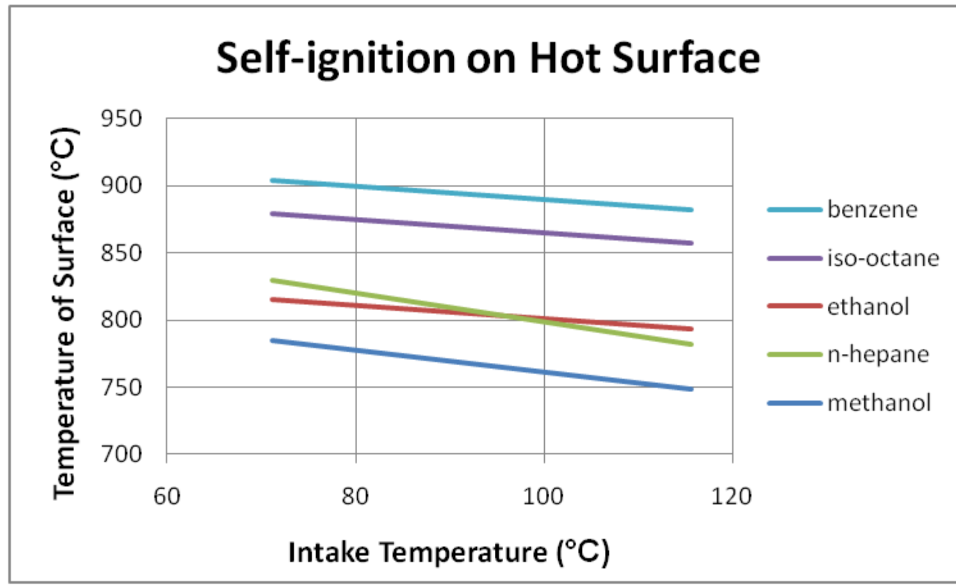




KNOCK RESISTANCE – ETHANOL X GASOLINE

Allows use of higher compression ratios (higher thermal efficiency), but is very sensitive to hot surfaces

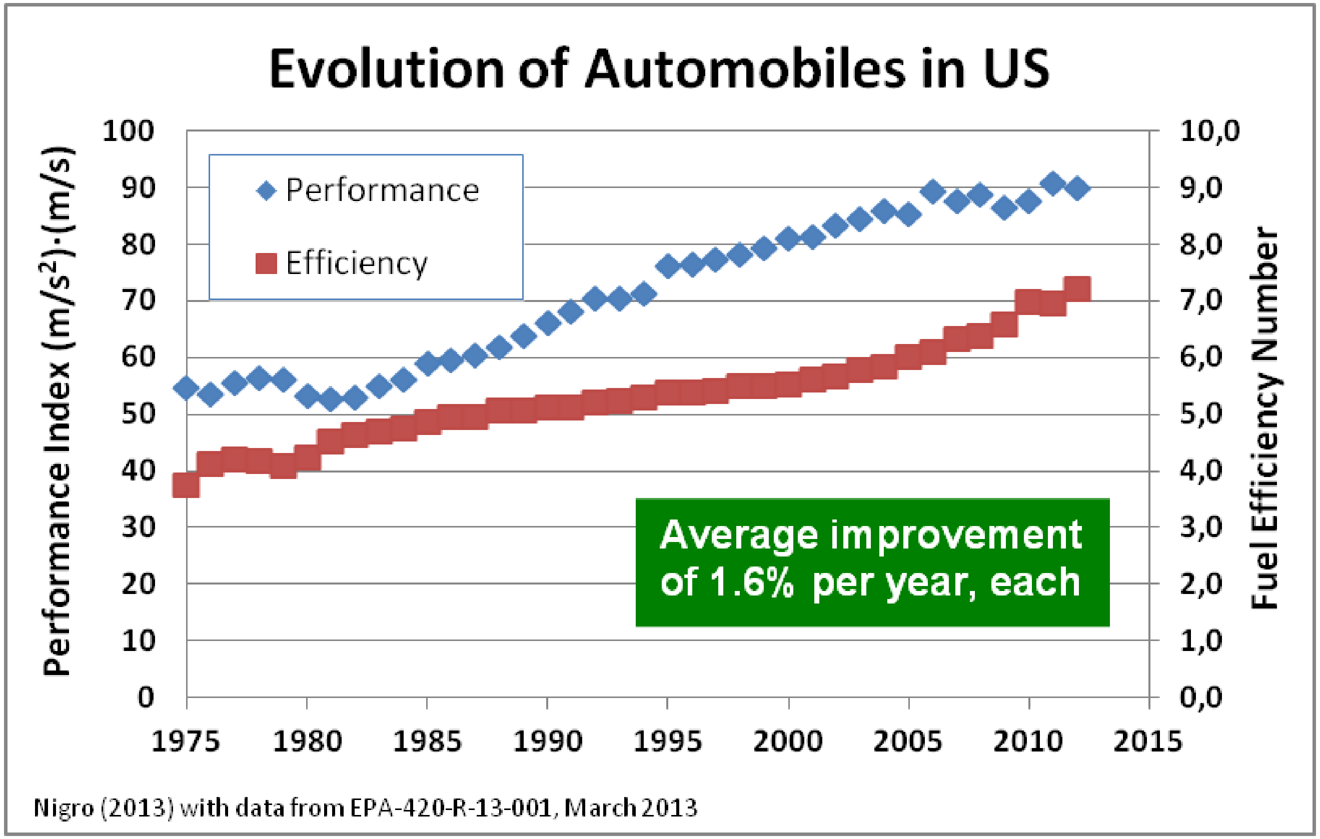




Adapted from Taylor C.F.“The Internal-Combustion Engine in Theory and Practice”

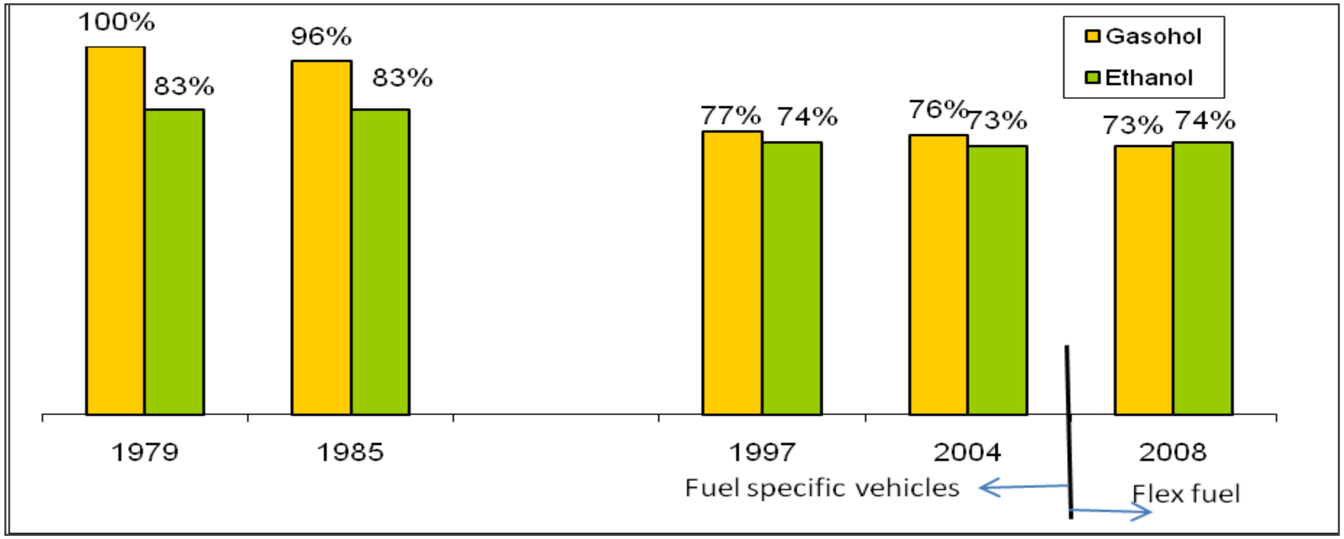
POWERTRAIN EVOLUTION - ENGINEERING PERSPECTIVE

Compromise between Performance and Fuel Efficiency



- F.E.Number = η_{tot}/μ_{mov} ~ thermo-mechanical total efficiency/moving resistance factor (tonne · km/MJ)
- Performance Index $(m/s^2) \cdot (m/s)$ ~ capacity to accelerate at a given velocity (kW/tonne)

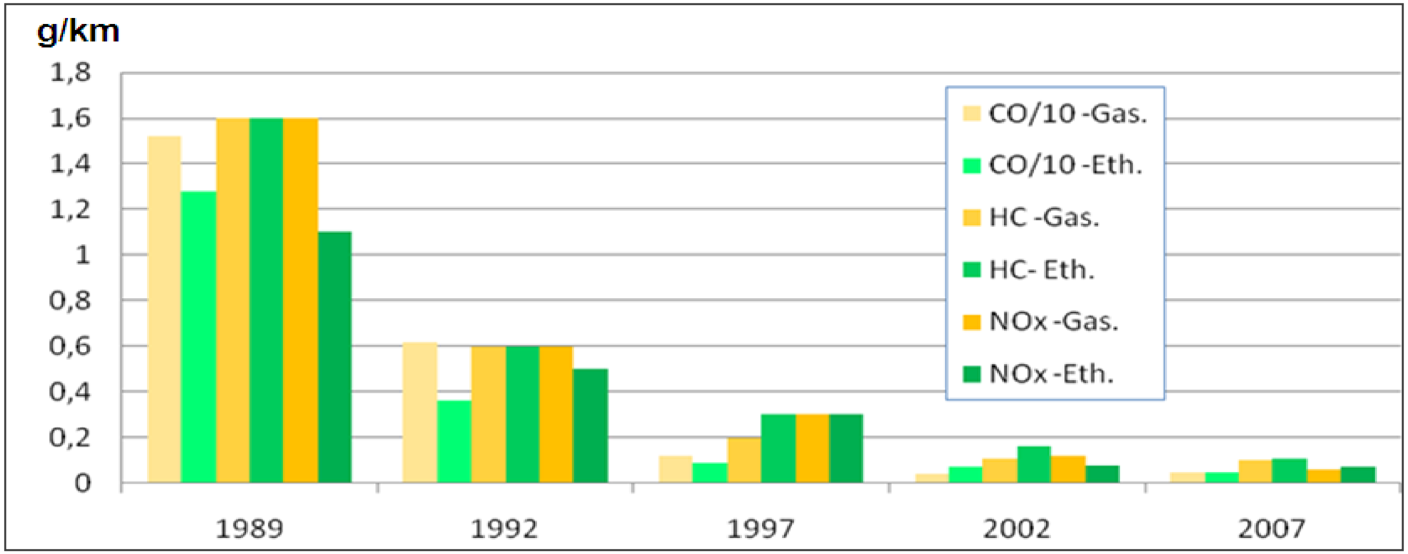
RELATIVE ENERGY CONSUMPTION BY BRAZILIAN CARS



Nigro, F.; Swarcz, A. "Ethanol as Fuel" in book "Ethanol and Bioelectricity: Sugarcane in the Future of the Energy Matrix"; – UNICA, 2010

- **1979 – Total emphasis on fuel economy (Rc 7.5 → 11:1, full-load lean mixture, intake air heating, poor drivability)**
- **1985 – Torque gain → engine down-speeding (Rc 8.5 → 12:1, materials compatibility, lean mixture, performance)**
- **1997 – 3 way-catalyst (λ = 1, Rc 10 → 13:1, torque gain → performance bonus)**

EXHAUST EMISSIONS OF GASOHOL & ETHANOL AUTOS



Average data on new sold cars after Cetesb (Report of Air Quality in State of Sao Paulo (in Portuguese) – 2007

- **After the advent of 3 way-catalyst, ethanol lost lean-burn advantage (need of EGR)**
- **Cold phase of cycle dominates total emissions (R,D&I)**
- **Unburned ethanol is important for VOC emissions (ozone forming potential)**

EVOLUTION OF FLEX FUEL TECHNOLOGY IN BRAZIL

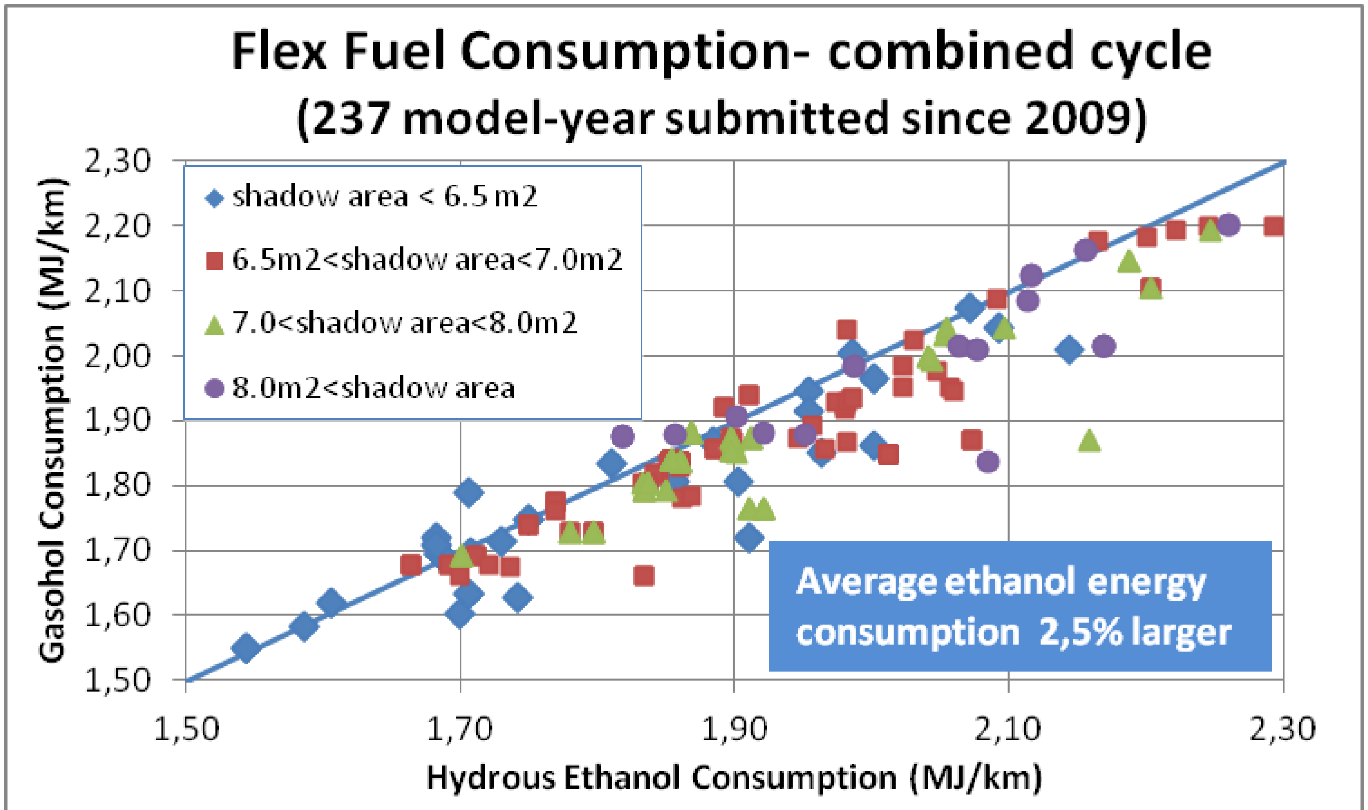
Generation	Market entry	Engine compression ratio	Power gain with ethanol	Torque gain with ethanol	Mileage loss with ethanol	Cold start with gasoline
1st	2003	10.1 – 10.8	2.1%	2.1%	25% - 35%	Yes
2nd	2006	10.8 – 13.0	4.4%	3.2%	25% - 35%	Yes
3rd	2008	11.0– 13.0	5.6%	9.3%	25% - 30%	Yes
4th	2009	11.0 – 13.0	5.6%	9.3%	25% - 30%	No

JOSEPH Jr., H. "New Advances in Flex-fuel Technology". Panel at Ethanol Summit 2009, São Paulo, June, 2009

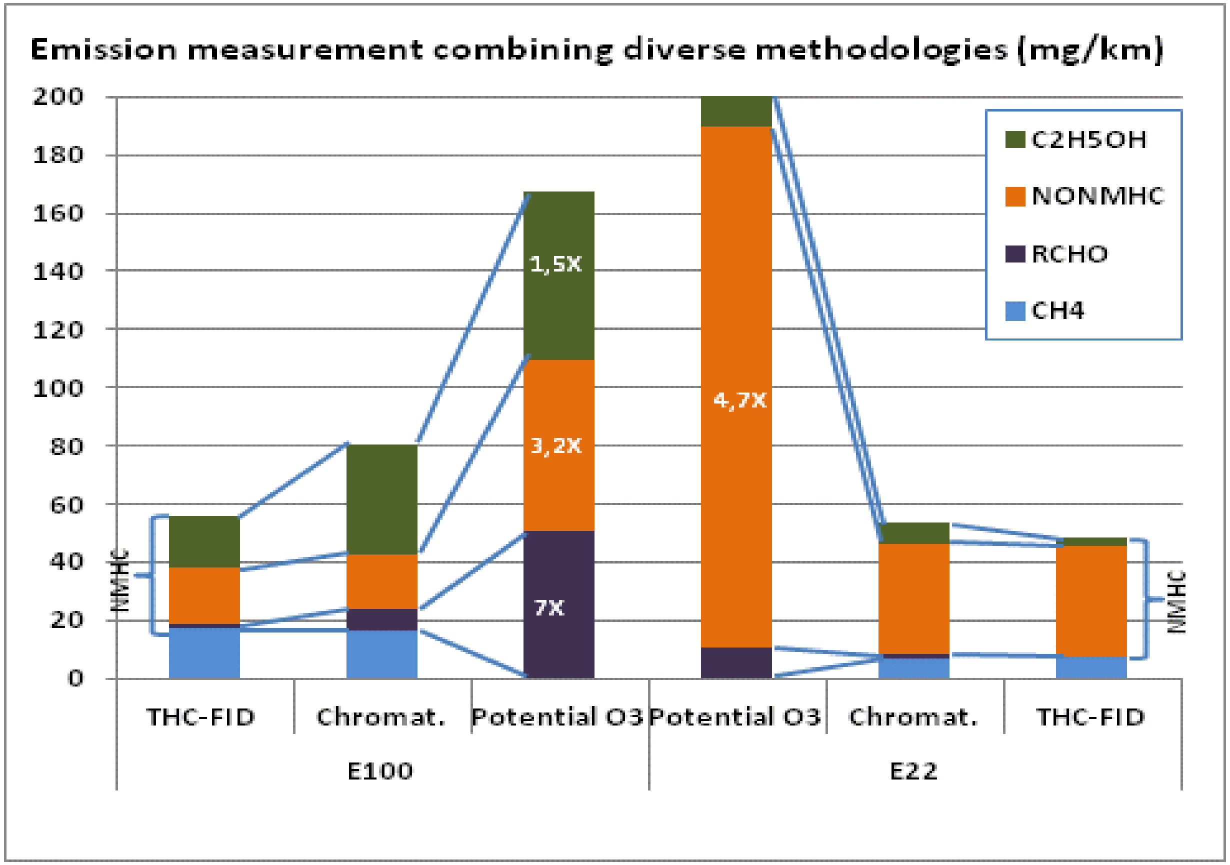
- Cold start and heating with gasoline injection (small gasoline tank)
- 4th generation with heated injectors or fuel gallery (no gasoline tank)

ENERGY EFFICIENCY WITH ETHANOL IS POOR

At least on FTP combined cycle



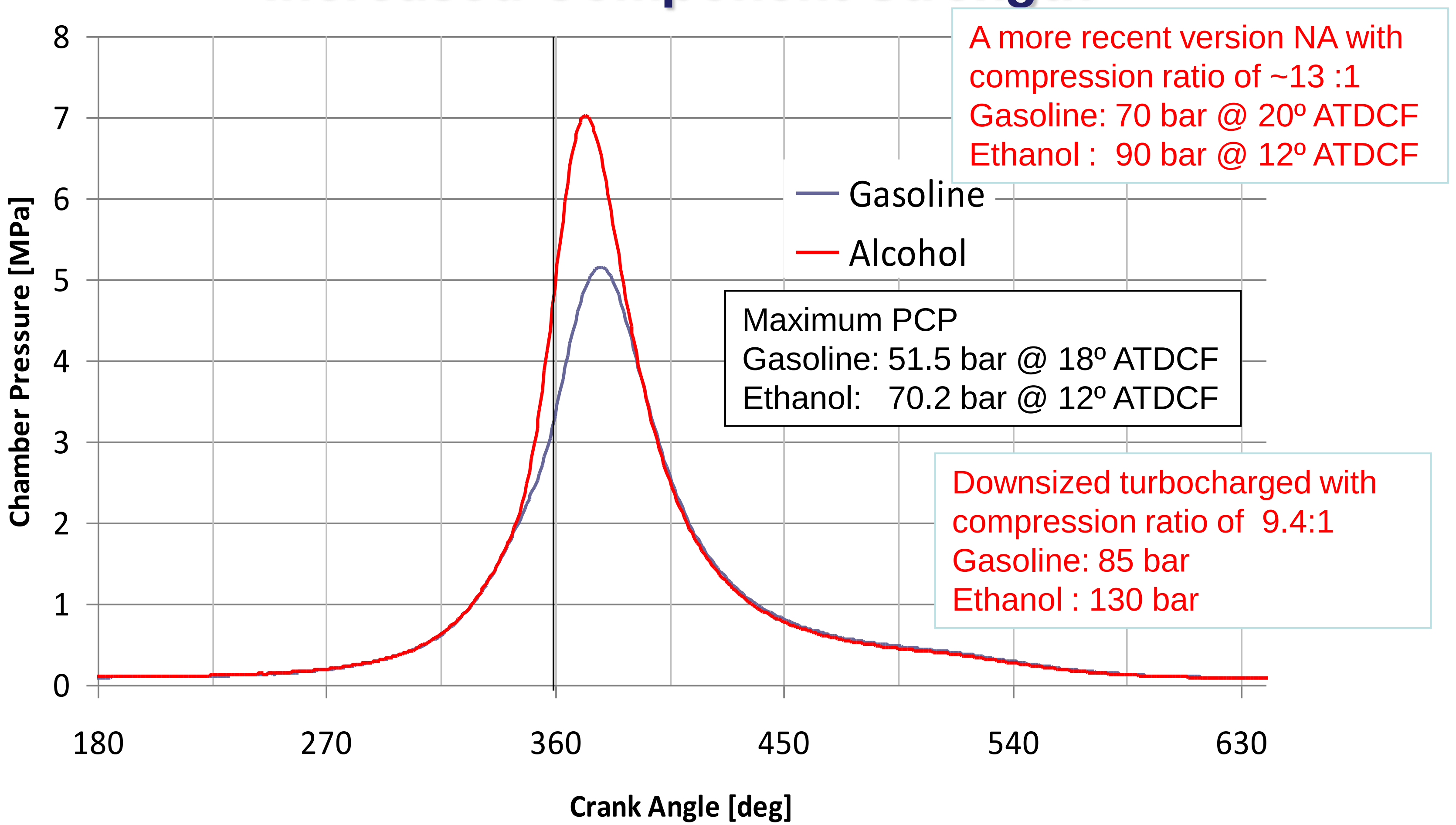
EXHAUST VOC OF FFV (4th Gen) ON GASOHOL & ETHANOL



- Branco, G.M., Nigro, F. et al "Emission control of organic compounds based on their ozone forming potential" (in Portuguese) XXI SIMEA – São Paulo – August 2013
- Graner, L.; Garcia, I.S. & Joseph Jr, H. "Comparative qualification of non-methane hydrocarbons in the exhaust gas of a flex fuel vehicle fuelled by E22 and E100)" (in Portuguese) - XXI SIMEA – São Paulo – August 2013

TECHNOLOGICAL CHALLENGES

Increased Component Strength



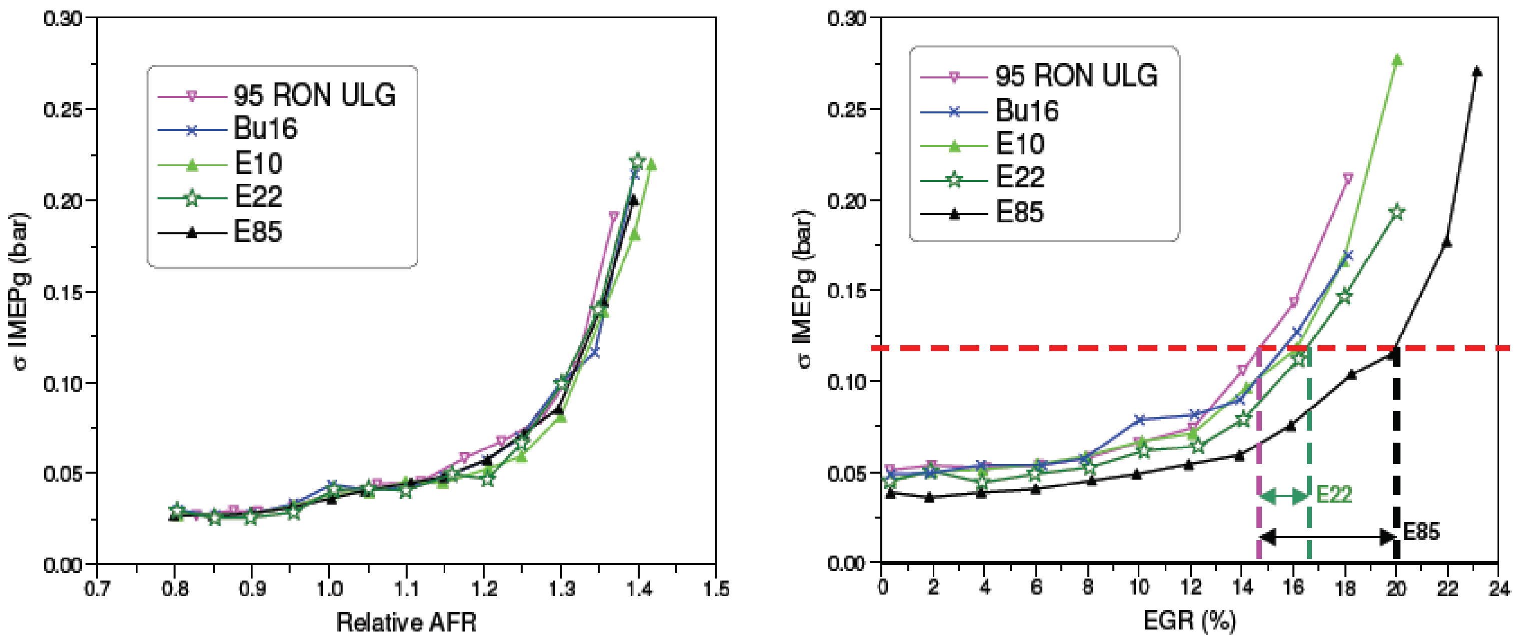
Neil Fraser– Simpósio SAE Brasil Powertrain ago/2009

FUTURE STEPS IN THE DEVELOPMENT OF FLEXIBLE-FUEL ENGINES

- Cost-effective solutions for cold-start and heating of ethanol
- Electronically (flexibly) controlled valve timing
- Variable compression ratio engines
- Engine downsizing and turbo-charging
- Direct injection of fuel in the combustion chamber (homogeneous and stratified charge)
- Hybrid-electric systems with special-cycle engines

TECHNOLOGICAL OPPORTUNITIES

Dilution Tolerance (2000rpm/4bar BMEP)



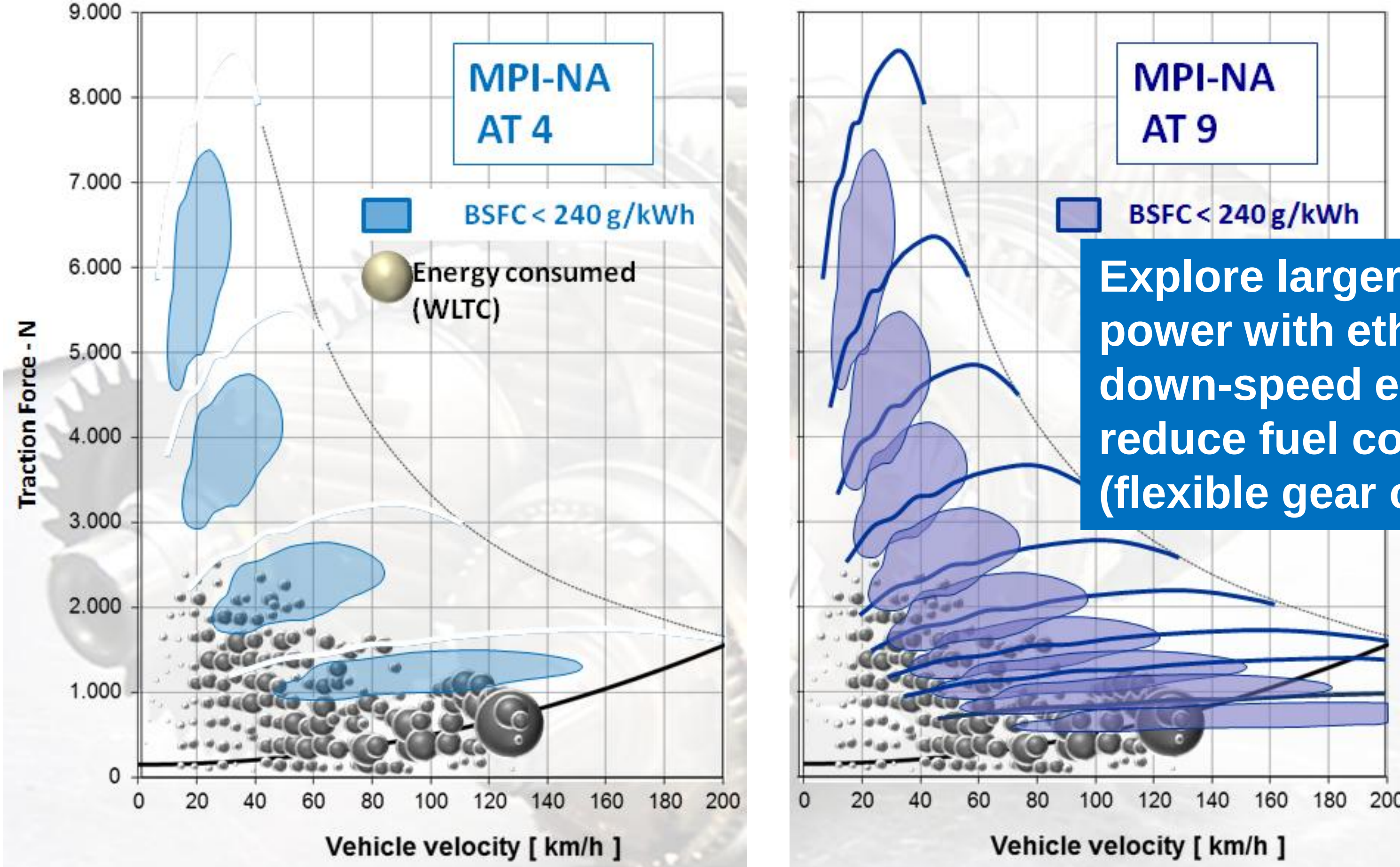
EGR could imply in 2 – 3% efficiency advantage for ethanol

- MBT spark timing at every data point
- Fuel injection settings optimised for each fuel

Tomanik, E "Ethanol as future fuel for optimized combustion engines" – BBEST, August 2011

TECHNOLOGICAL OPPORTUNITIES

Increased Number of Gears

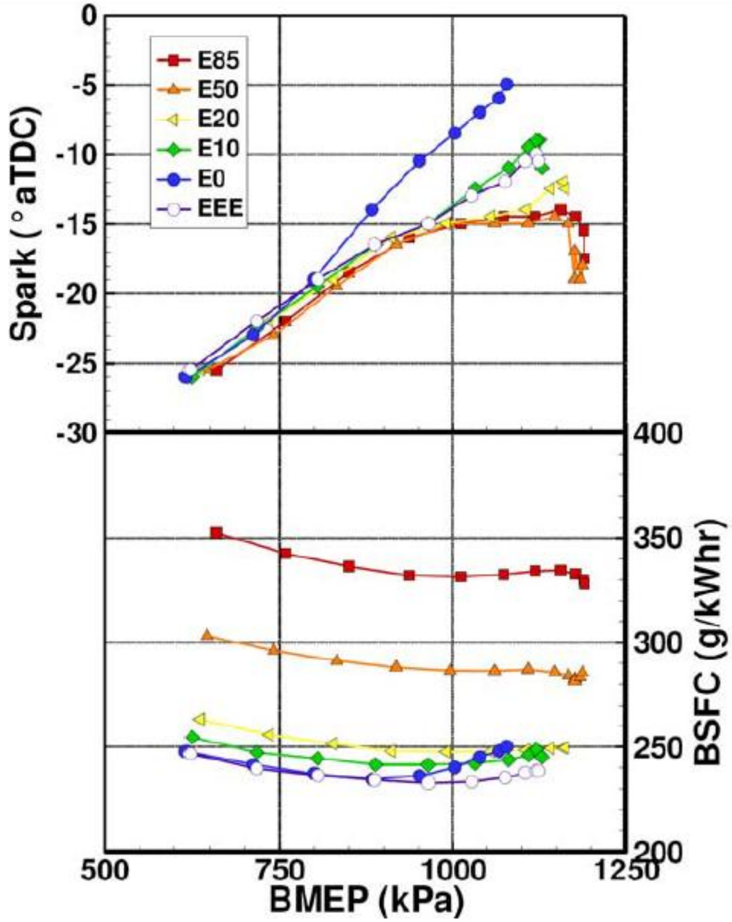


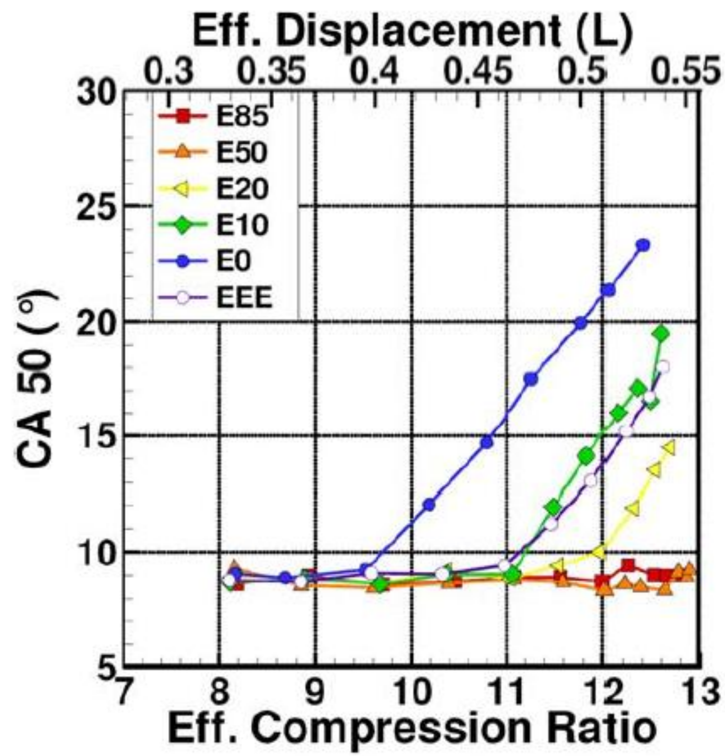
Explore larger torque and power with ethanol to down-speed engine and reduce fuel consumption (flexible gear change)

Fraidl, G. "Market & Technology Trends – Passenger Car Powertrain " – AVL Fuel efficiency Seminar, July 2013

OPPORTUNITIES FOR ETHANOL USE ON FFVs

Variable Intake Valve Actuation



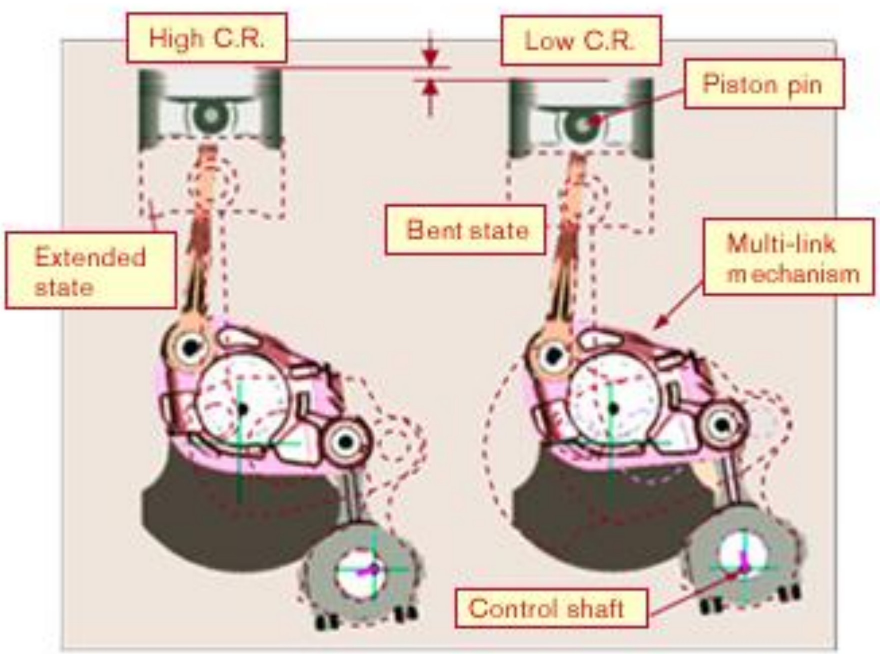


Fuel efficiency benefits of 5 to 20% on E85 operation

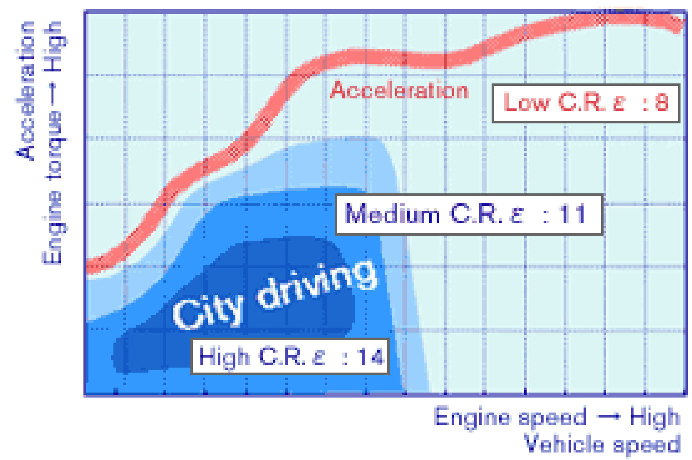
Moore, W. et al "Engine Efficiency Improvements Enabled by Ethanol Fuel Blends in a GDi VVA Flex Fuel Engine"- SAE 2011-01-0900, December 2011

OPPORTUNITIES FOR ETHANOL USE ON FFVs

Variable Compression Ratio



Principle of Variable Compression Ratio



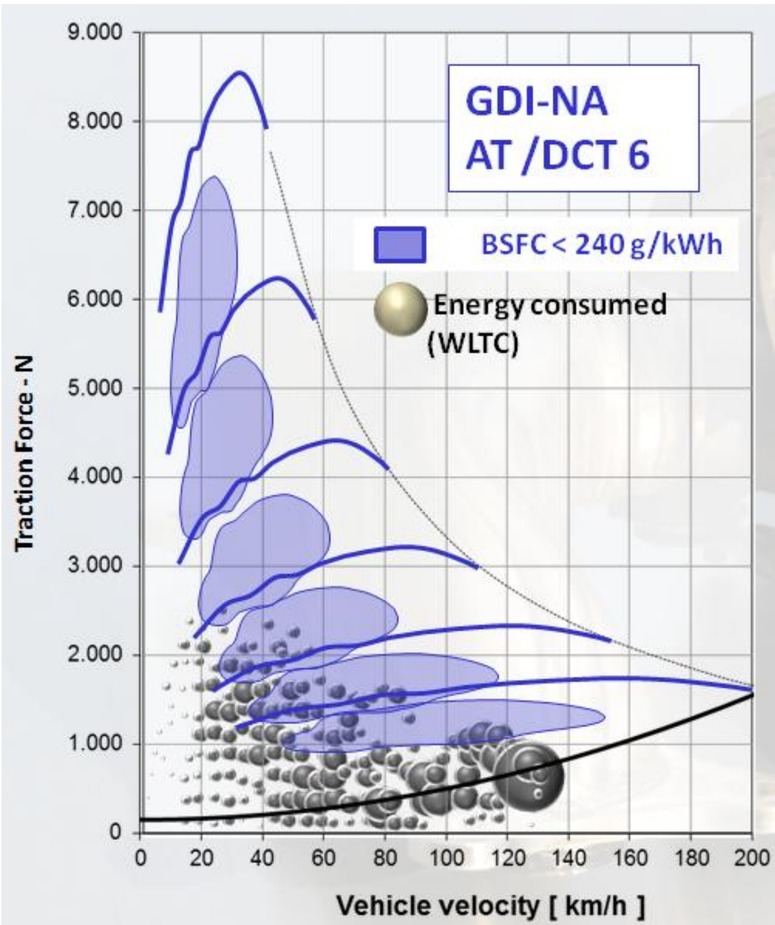
C.R. control map
(engine operating conditions)

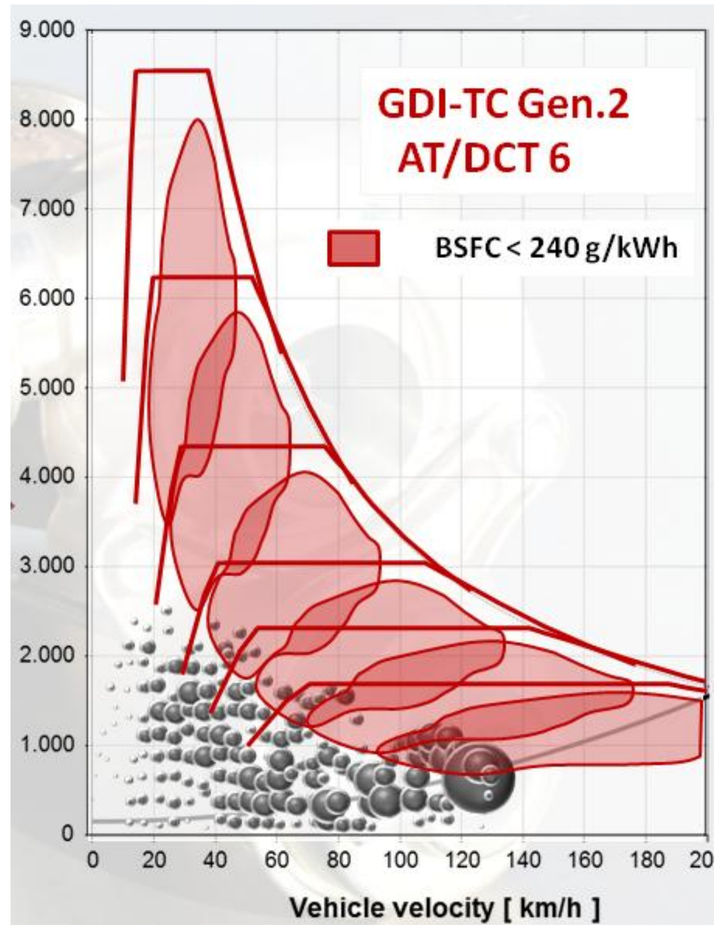
Fuel efficiency benefits of 4 – 5% on E100 over E22

http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vcr.html

TECHNOLOGICAL OPPORTUNITIES

Downsizing and Turbo-charging (>25% of SI in 2020)





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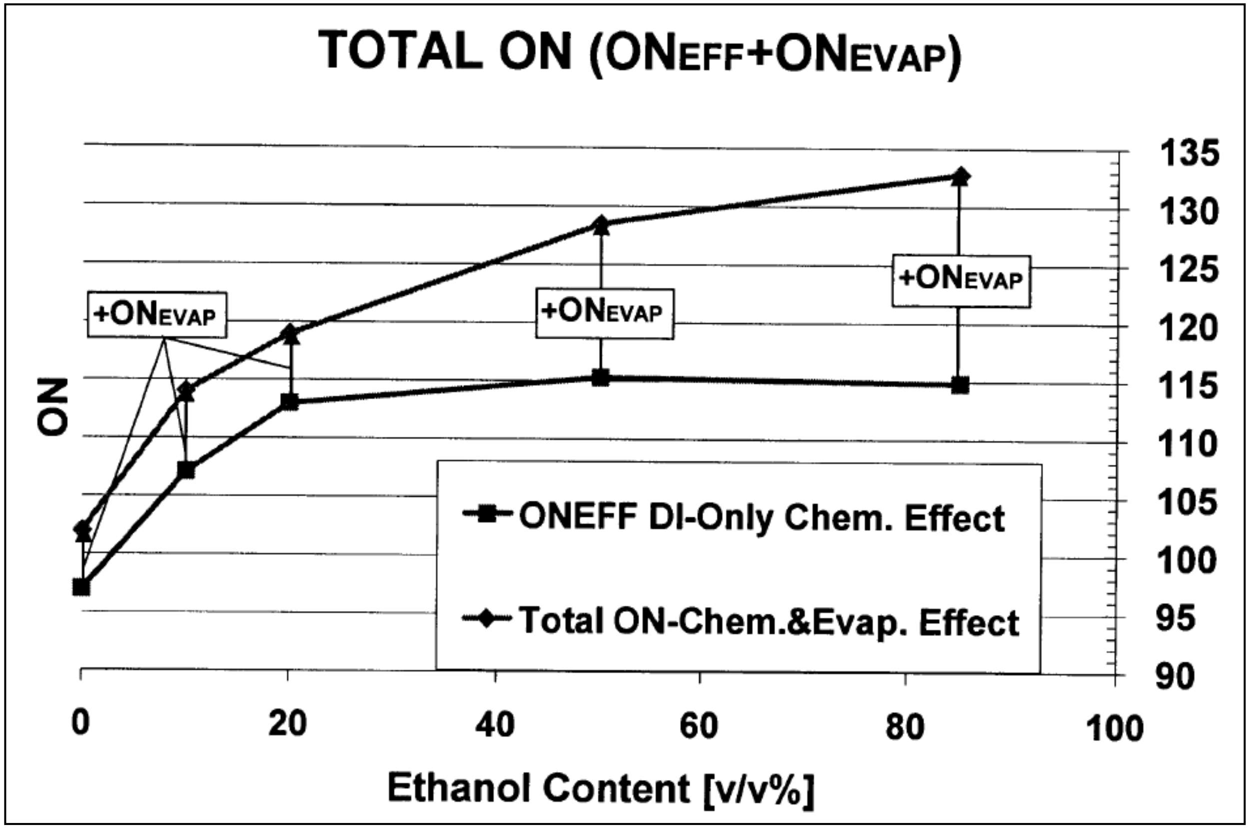
OPPORTUNITIES FOR ETHANOL USE ON FFVs

- Downsizing and Turbo-charging [>25% of SI engines in 2020 (IHS)]
- Advantage of Ethanol: Increasing Performance and Fuel Efficiency



Kasseris E. “Knock limits in spark ignited direct injected engines using gasoline/ ethanol blends” Ph.D Thesis – MIT, 2011

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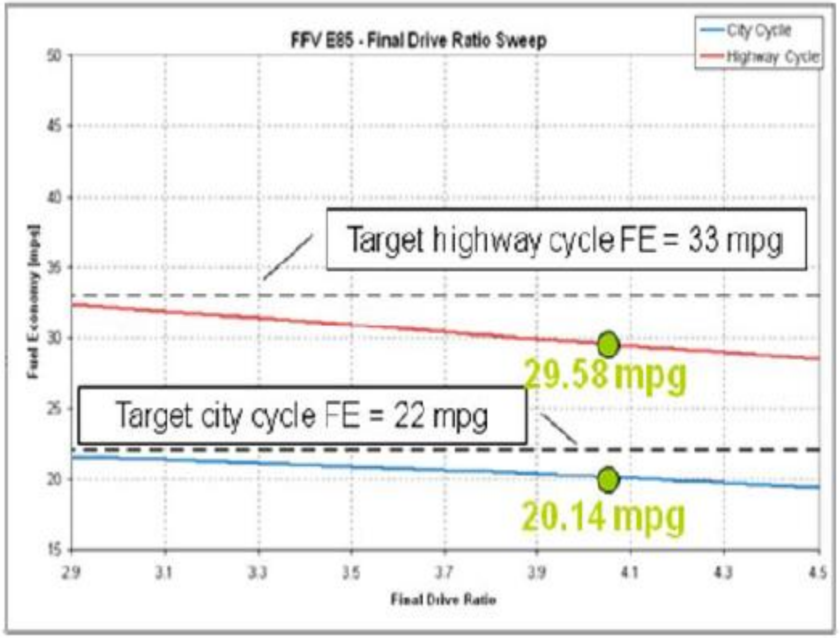
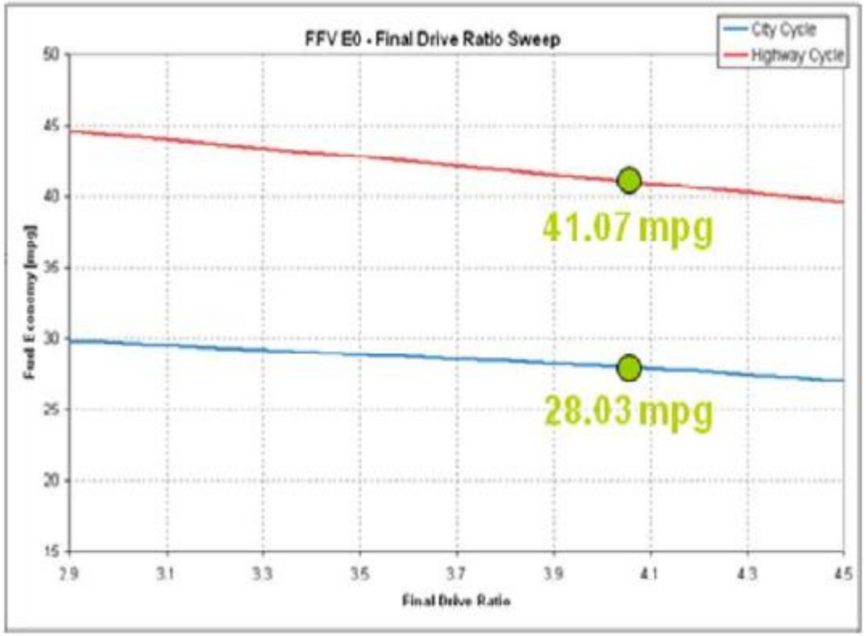
OPPORTUNITIES FOR ETHANOL USE ON FFVs

- **Ethanol Direct Injection with downsizing and turbo-charging (combustion pressure - 140 bar; injection pressure 250 bar)**
- **Increase of 17% and 22% in torque and power respectively**
- **CVT and same performance, 10 – 12% of energy economy on E85**





Yilmaz, H. et al "Optimally Controlled Flexible Fuel Powertrain System"- Completion Report – Bosch, November 2010

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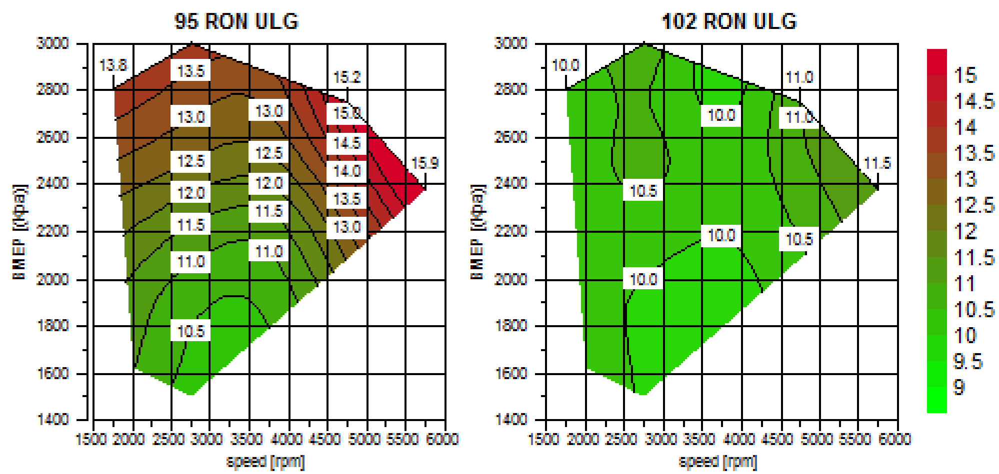
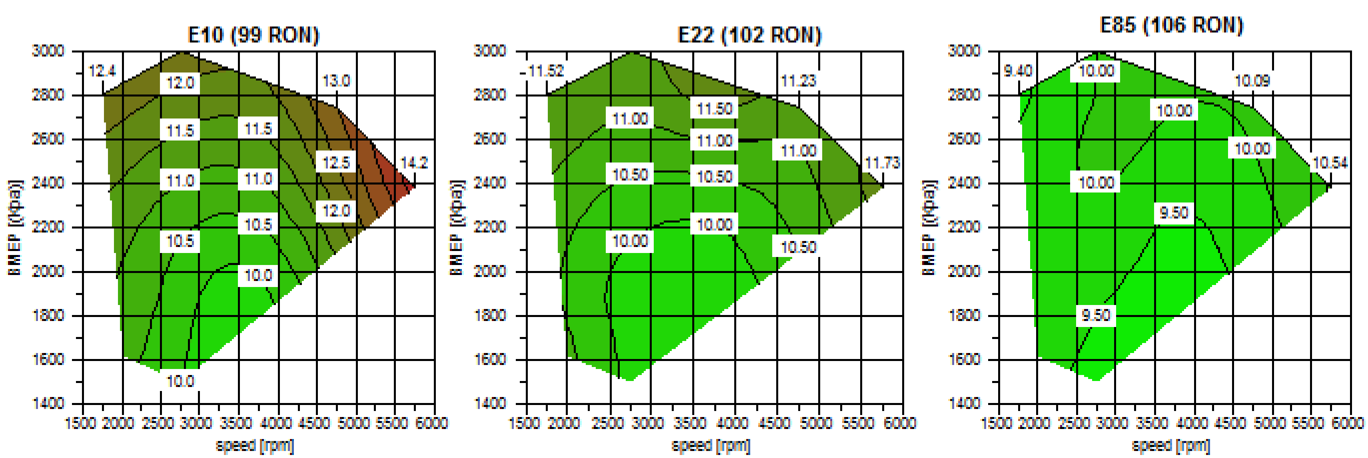
TECHNOLOGICAL OPPORTUNITIES

High Load Fuel Consumption Benefit (MJ/kWh)



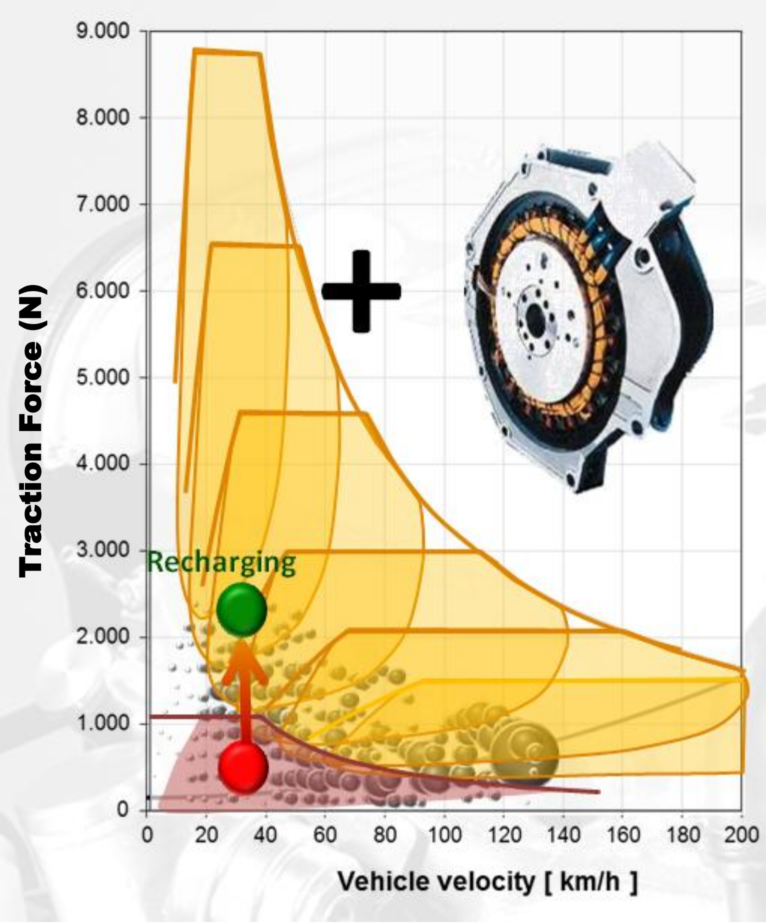
With Downsizing & Turbo-charging, full load enrichment is necessary to control exhaust temperature.
Fuel energy economy with E85 can reach 15-20% over regular gasoline



Freeland, P. et al “Technologies for the Next Generation of Downsized SI Engines ” – Mahle Powertrain - Simpósio SAE Brasil de Powertrain, Agosto 2013

TECHNOLOGICAL OPPORTUNITIES

Hybrid–Electric FFV – Good Solution for GHG Mitigation



When vehicle demands is out of engine efficiency island, load is increased for recharging or engine is turned-off. Atkinson or Miller cycles could be applied to complement ethanol fuel efficiency.

Fraidl, G. “Market & Technology Trends – Passenger Car Powertrain ” – AVL Fuel efficiency Seminar, July 2013

CONCLUSIONS

- It is necessary to use ethanol Total Octane Number and "pure substance" properties to get practical fuel efficiency advantage in FFVs or neat ethanol vehicles
- Once fuel economy is becoming mandatory in global markets and DI engines are forecasted to represent more than 50% of SI powertrains in 2020, half of them turbocharged, ethanol has an excellent opportunity to regain its fuel energy efficiency (10 - 15%) over gasoline, exploring transmission ratios.
- Due to extreme peak combustion pressures possible to be used with ethanol without knocking (140 bar versus 90 for gasoline in DI engines) the demand for materials strength on future engines will drop on ethanol.
- If Brazil intends to make future good use of ethanol and to play some significant role in the automotive sector, the time is now.

THANK YOU FOR YOUR ATTENTION

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