Motors: Development of new technologies for biofuels utilization

Advanced School on the Present and Future of Bioenergy

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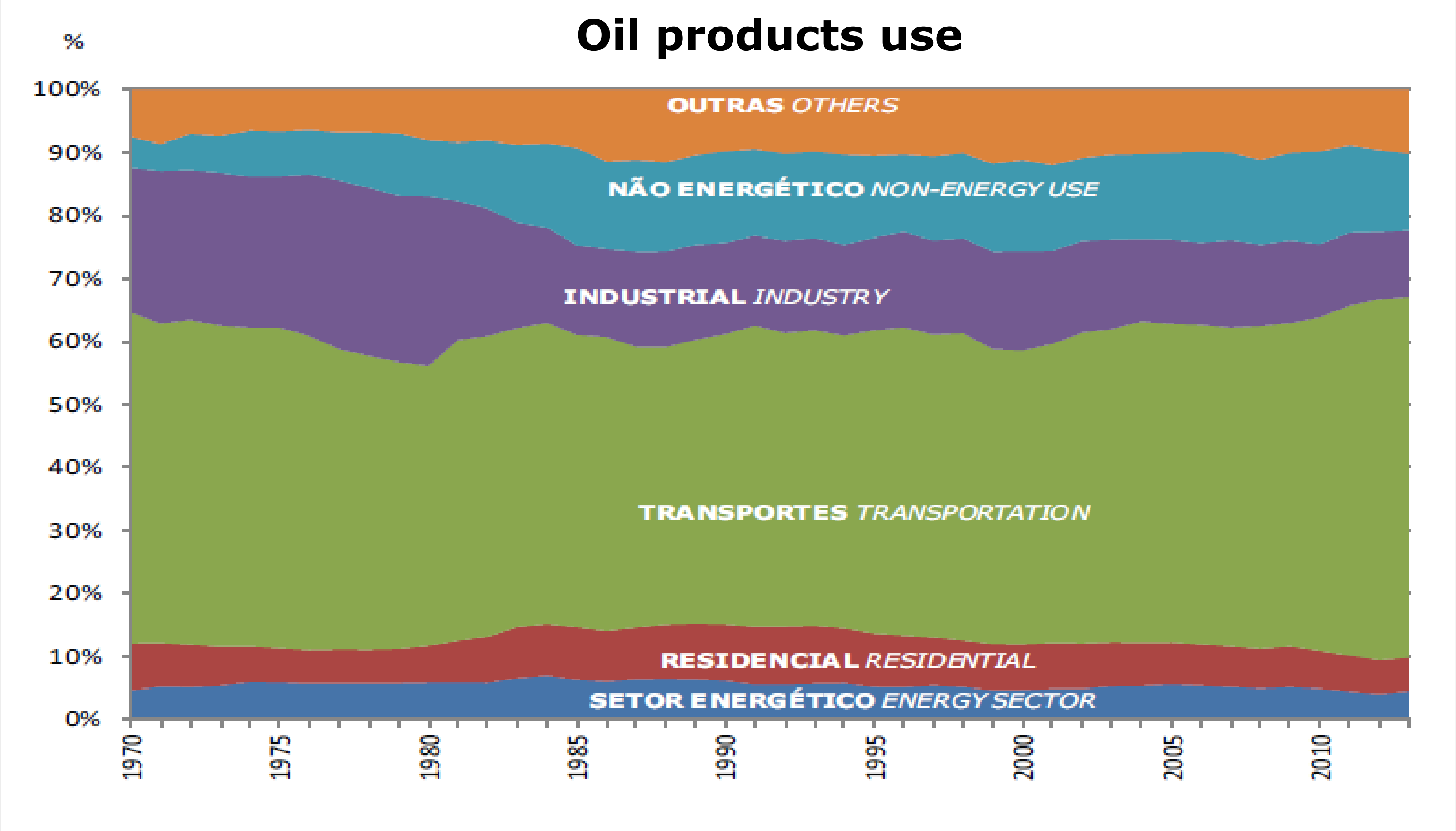
Summary

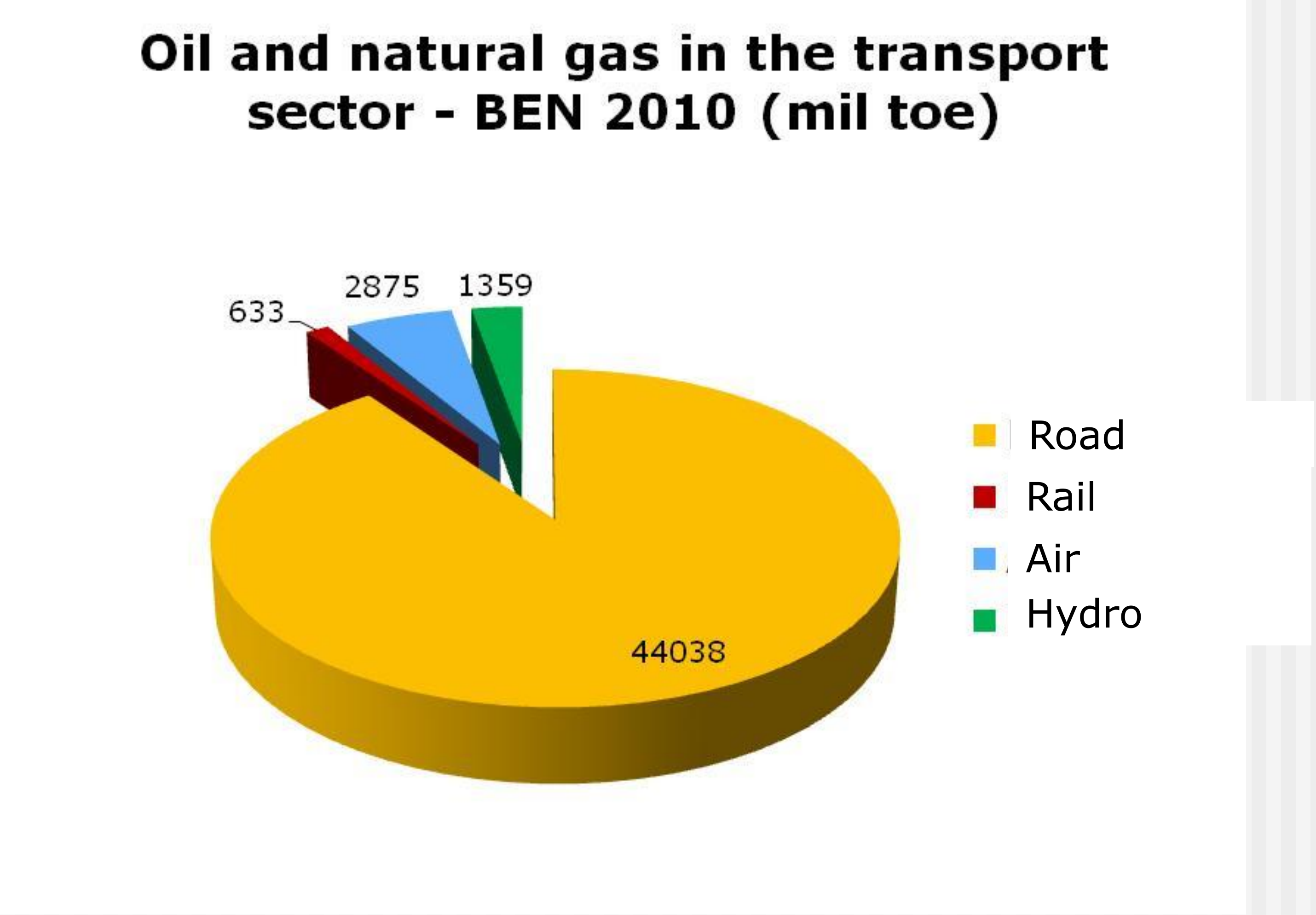
1. Biofuels in Brazil
2. Light duty Flex-fuel engines
3. Challenges for Ethanol engines
4. Challenges for Heavy-duty engines
5. Direct Ethanol Fuel Cells
6. Concluding remarks

1. Biofuels in Brasil



Source: BEN 2014 - EPE

1. Biofuels in Brasil



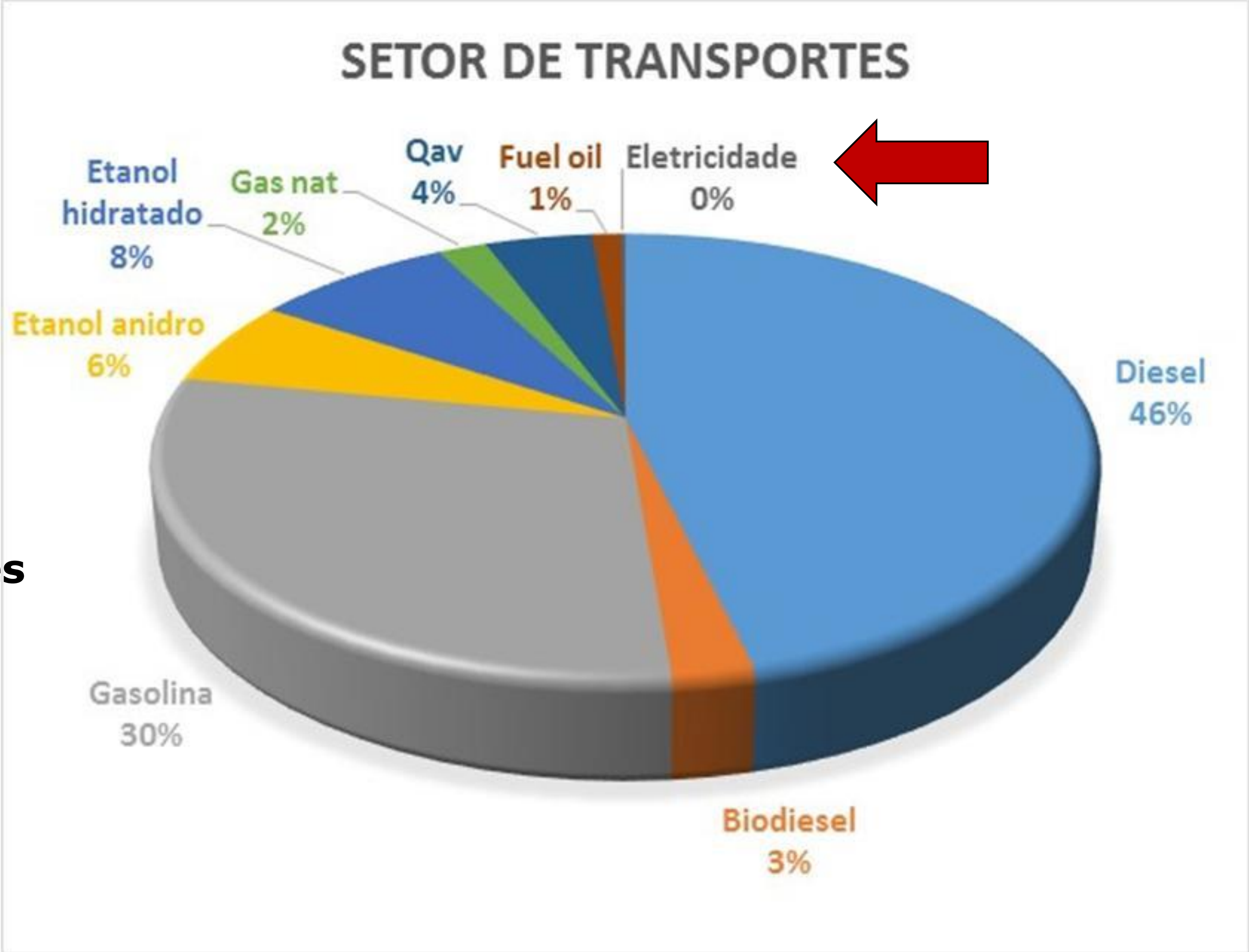
1. Biofuels in Brasil

However…

Ethanol
+
Biodiesel

17%

Far beyond other countries



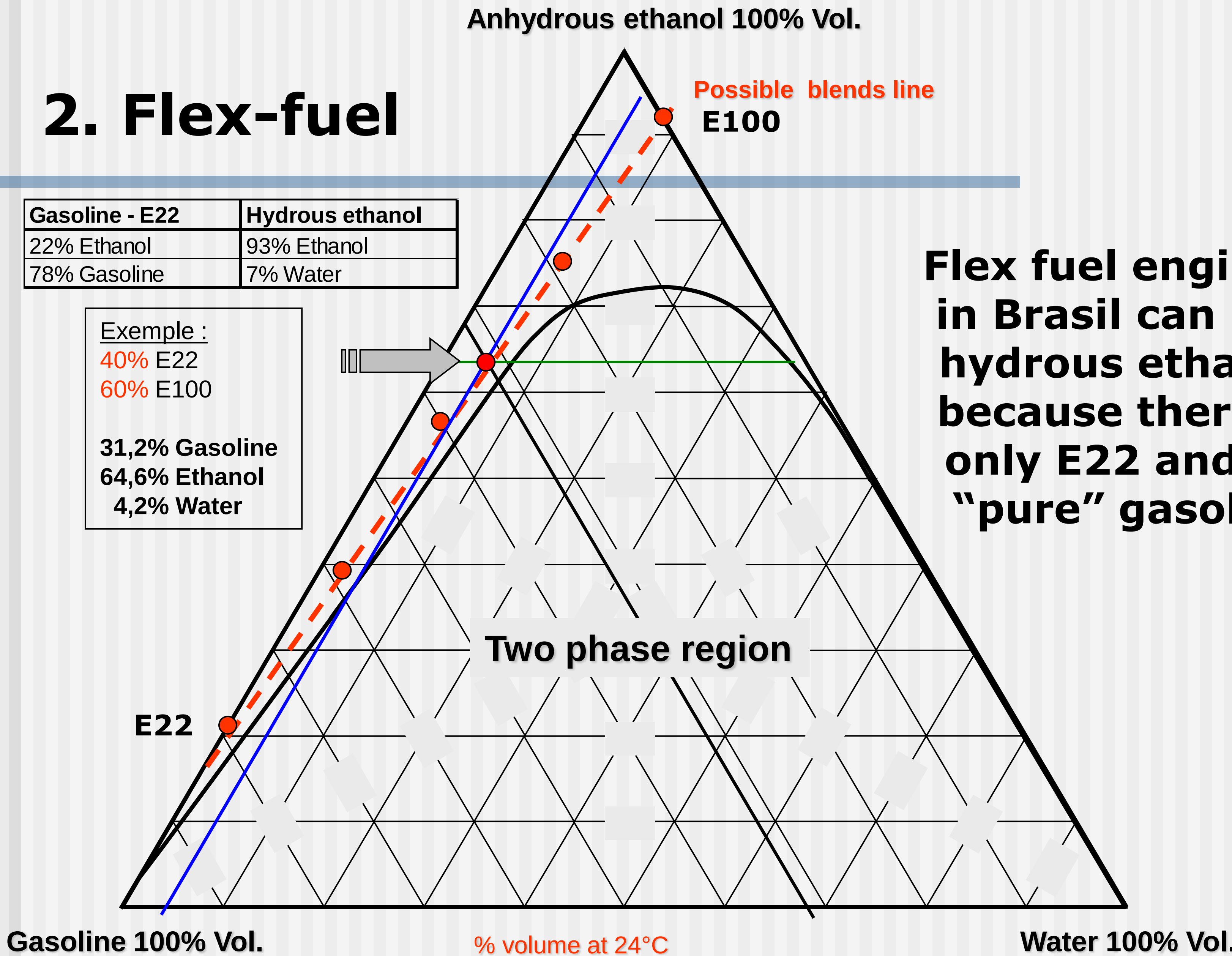
Source:
BEN 2014 - EPE

2. Flex-fuel

Gasoline - E22	Hydrous ethanol
22% Ethanol	93% Ethanol
78% Gasoline	7% Water

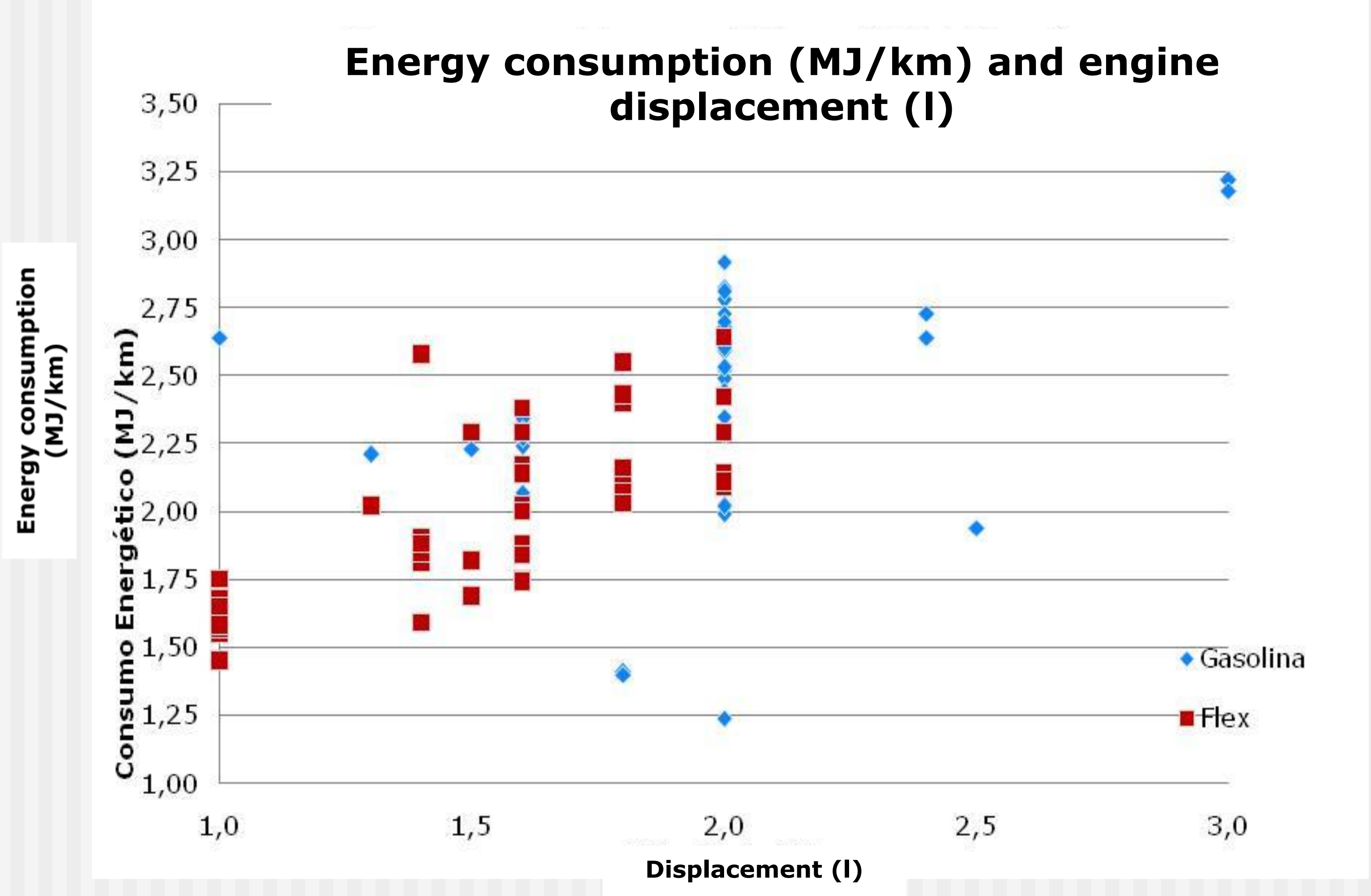
Exemple :
40% E22
60% E100

31,2% Gasoline
64,6% Ethanol
4,2% Water

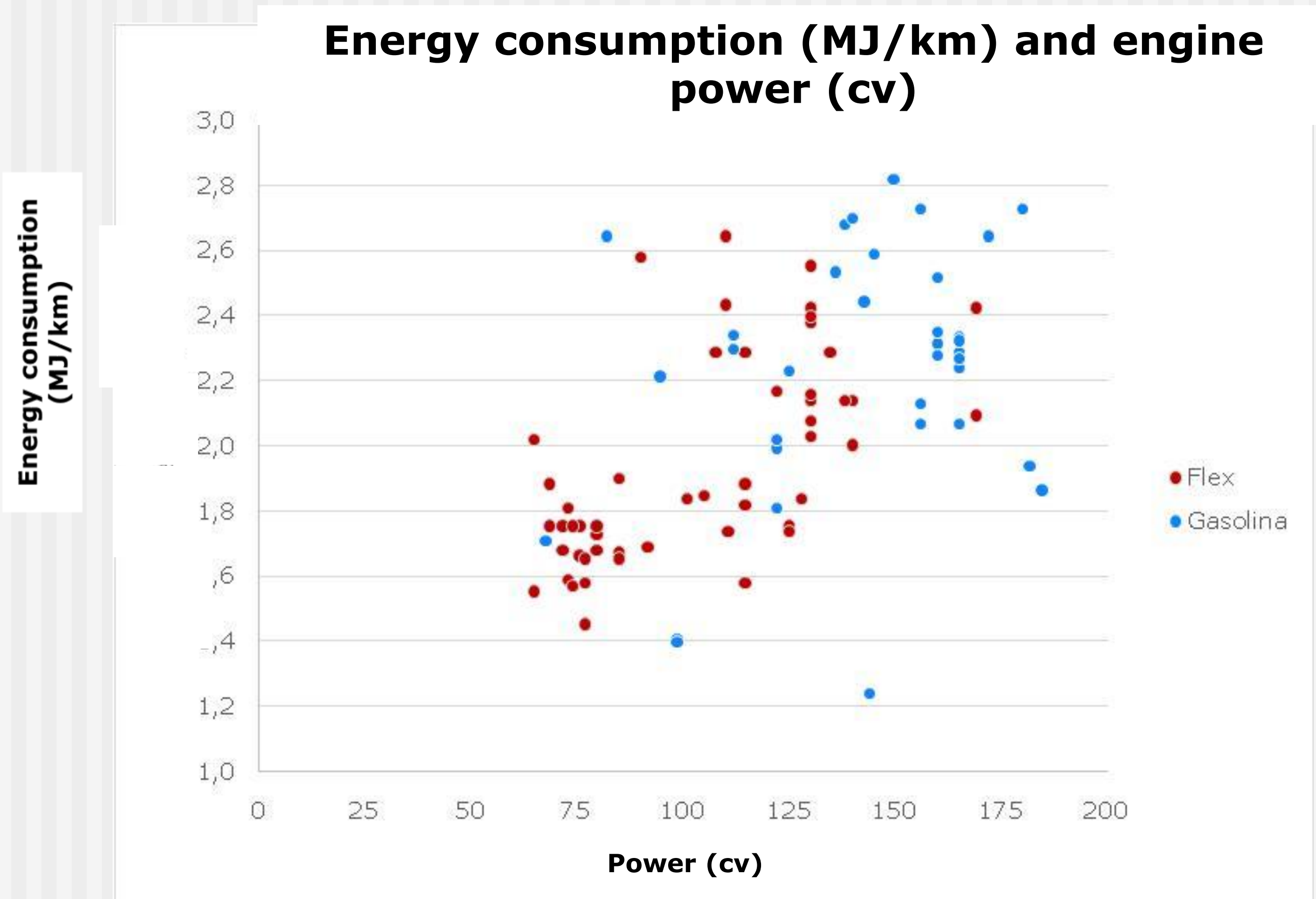


Flex fuel engines in Brasil can use hydrous ethanol because there is only E22 and no "pure" gasoline

2. Light-duty Flex-fuel vehicles



2. Light-duty Flex-fuel vehicles



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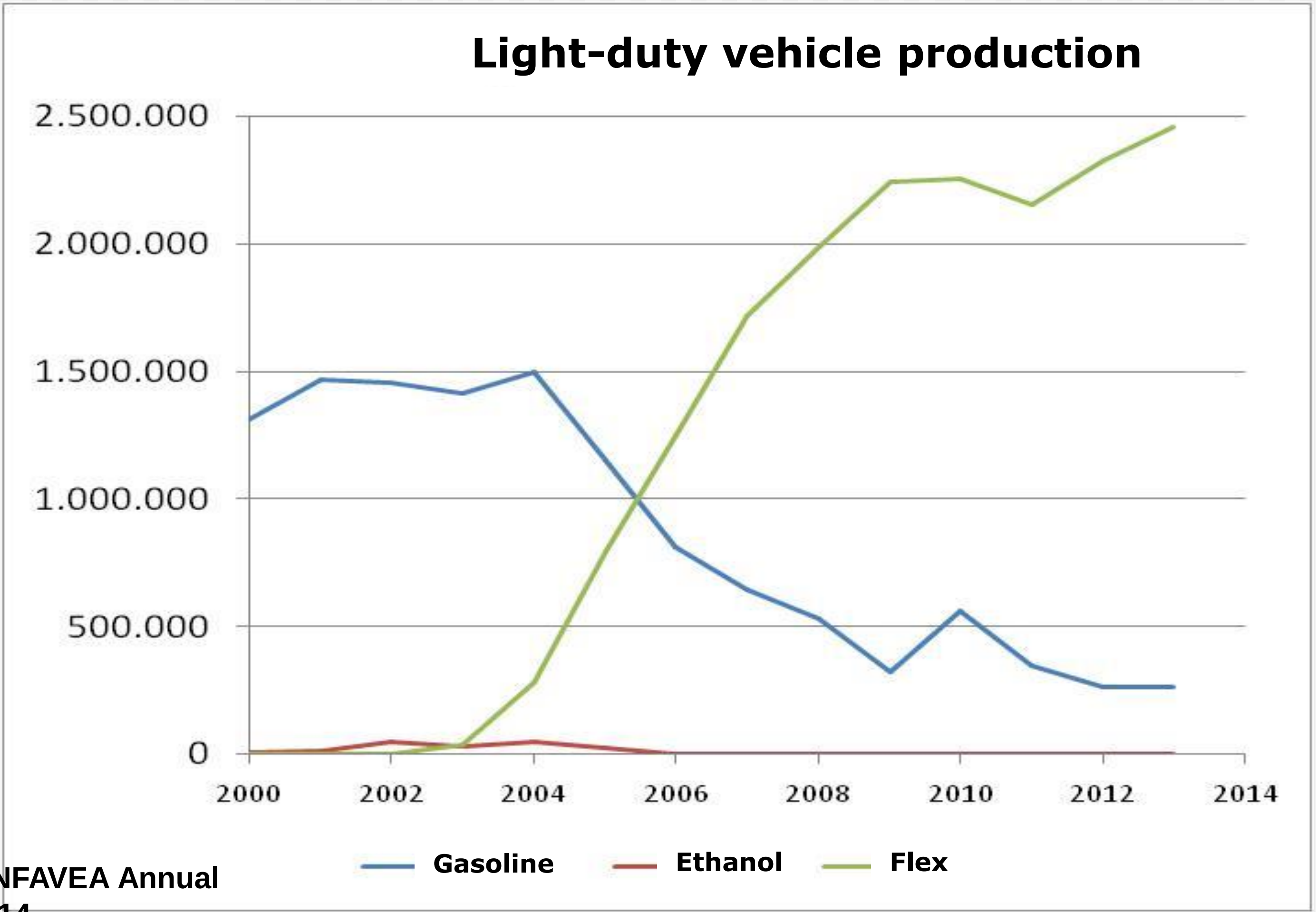
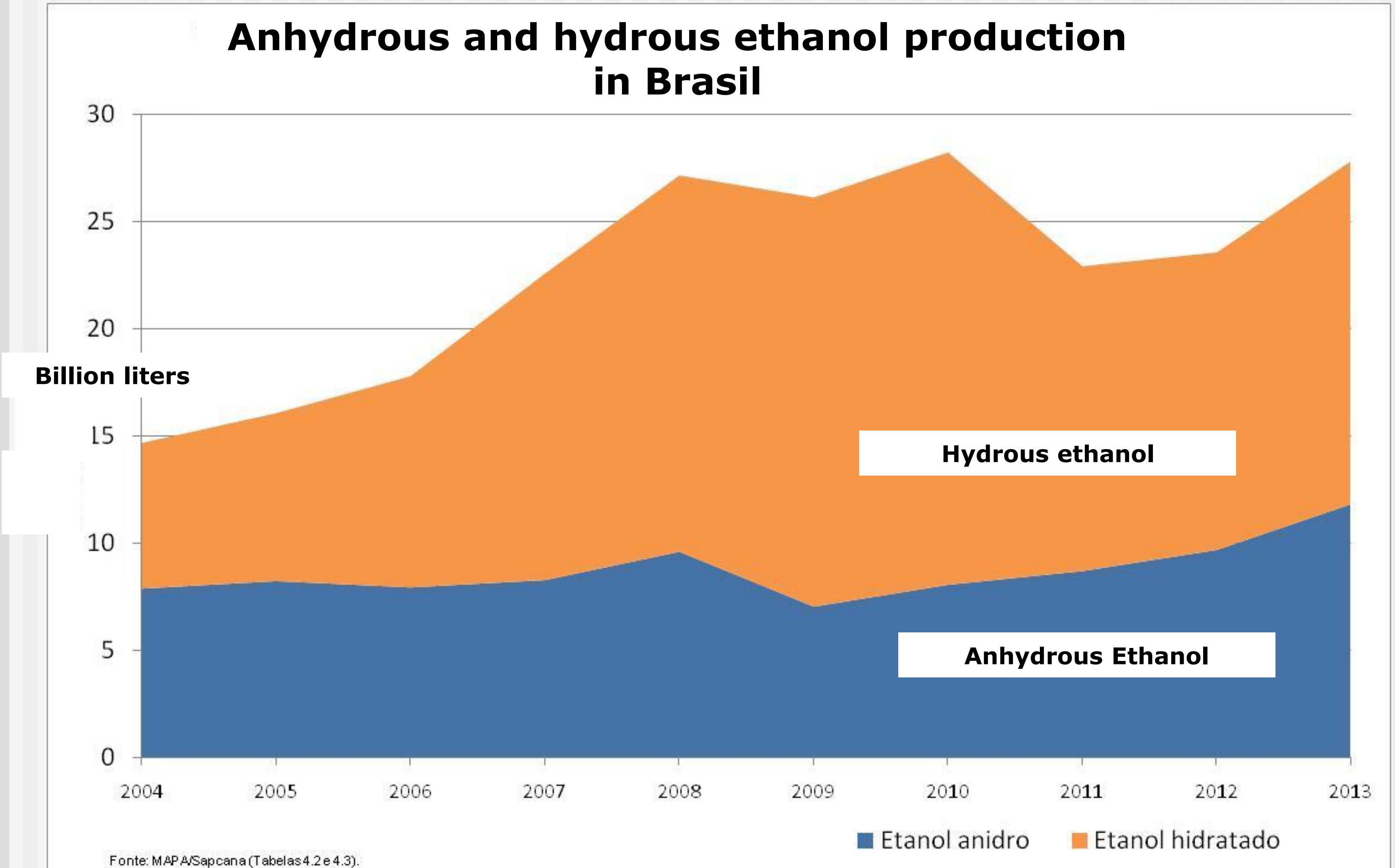


Source: ANFAVEA Annual Report, 2014

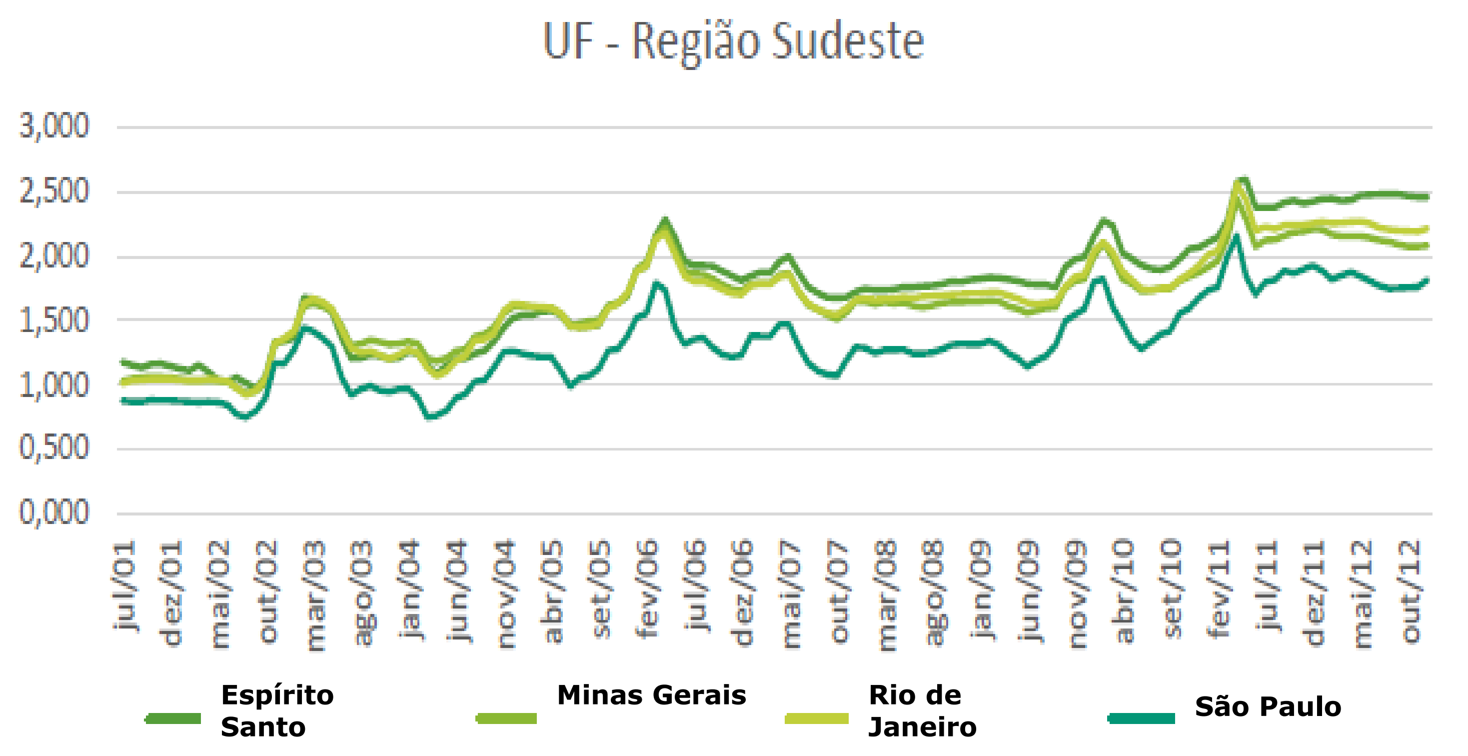
2. Light-duty Flex-fuel vehicles



Source: BEN 2014 - EPE

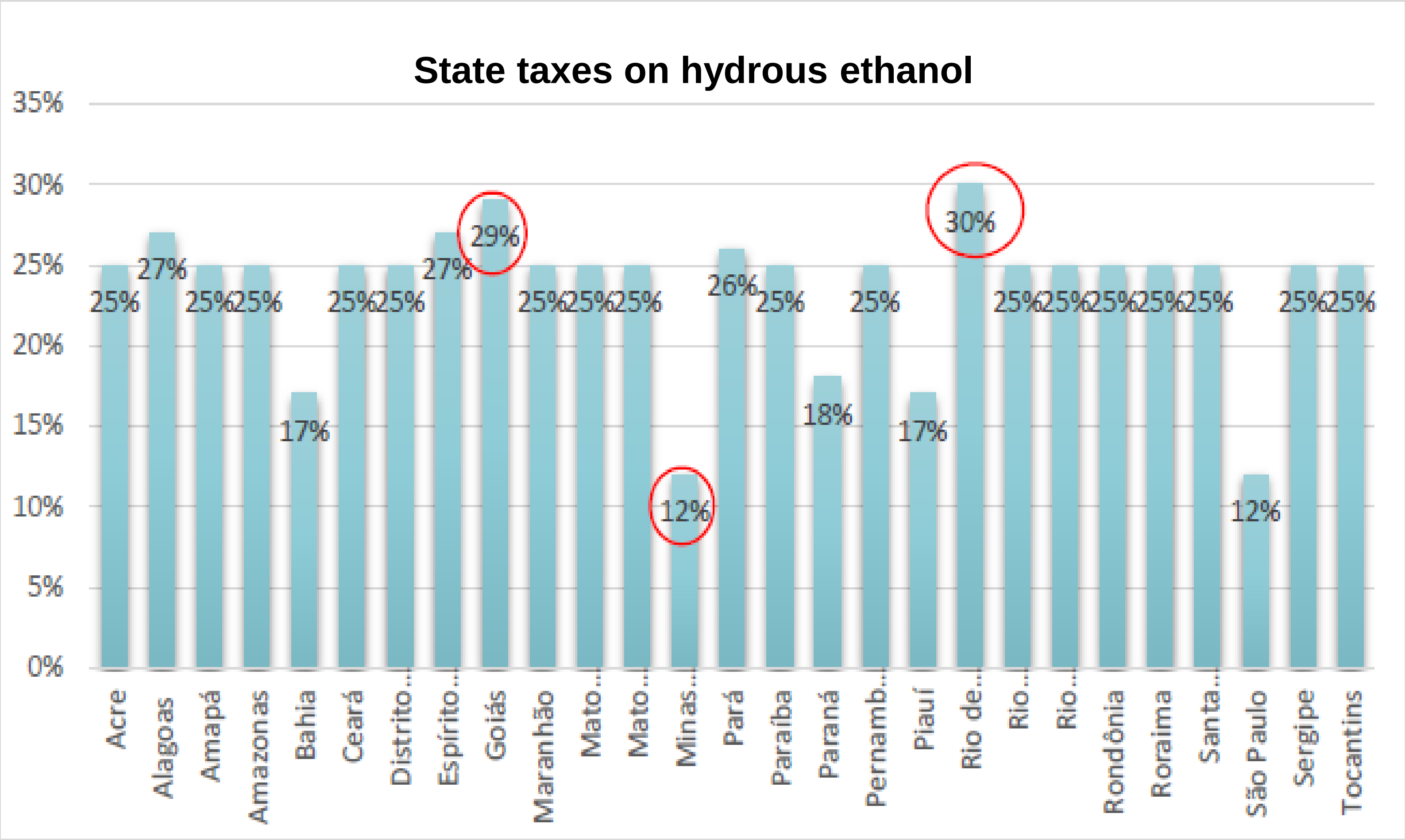
2. Light-duty Flex-fuel vehicles

Average prices – hydrous ethanol (R$/l) in some States



Source: Barbieri, PIBIC Final Report, 2014

2. Light-duty Flex-fuel vehicles



Source: Barbieri, PIBIC Final Report, 2014

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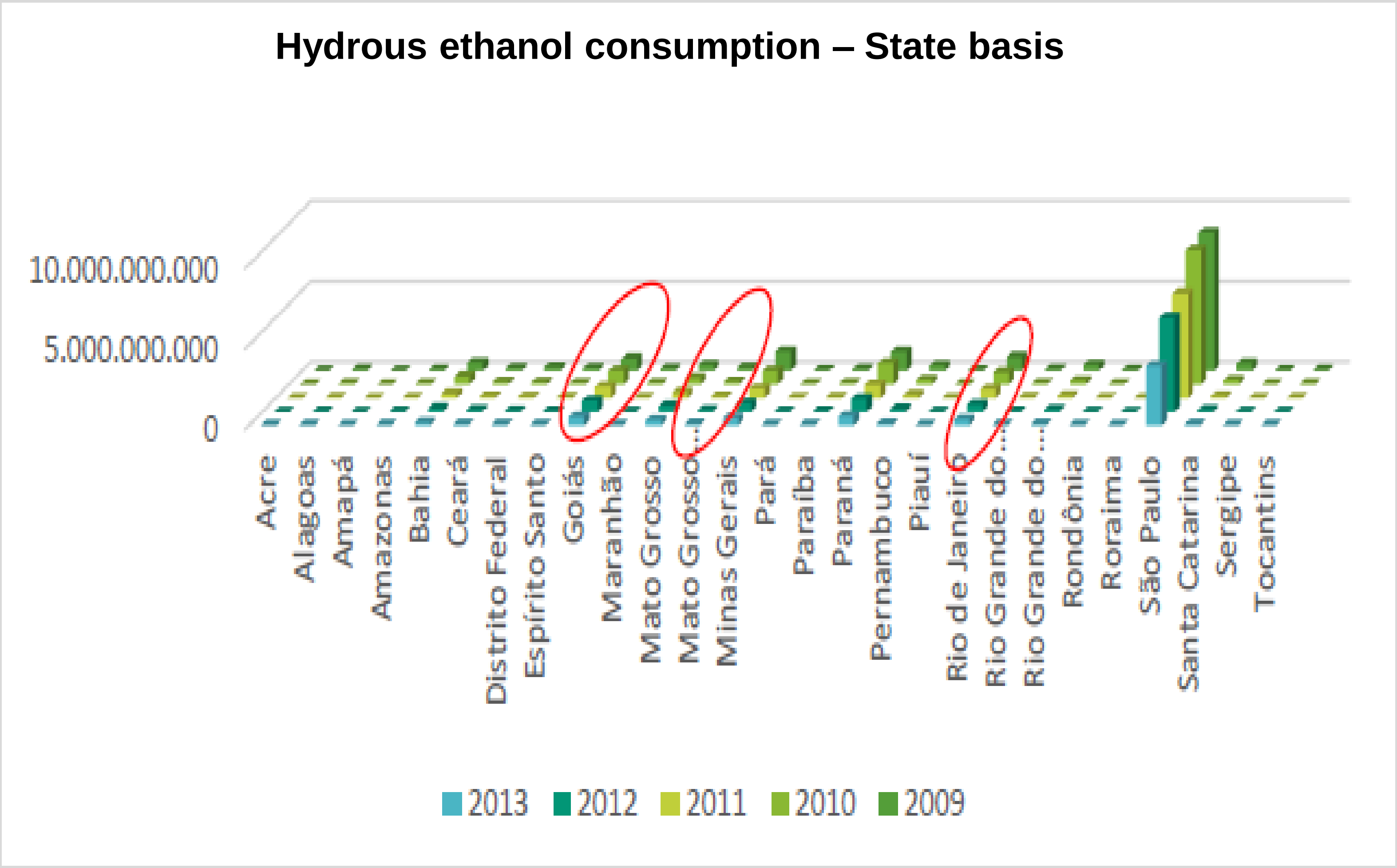


Source: Barbieri, PIBIC Final Report, 2014

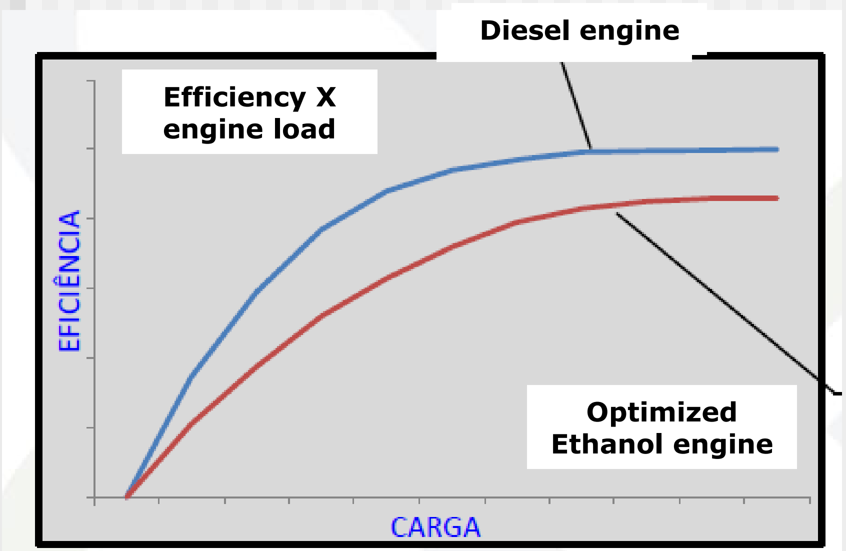
3. Challenges for ethanol engines

Flex-fuel engines does not explore the ethanol advantages:

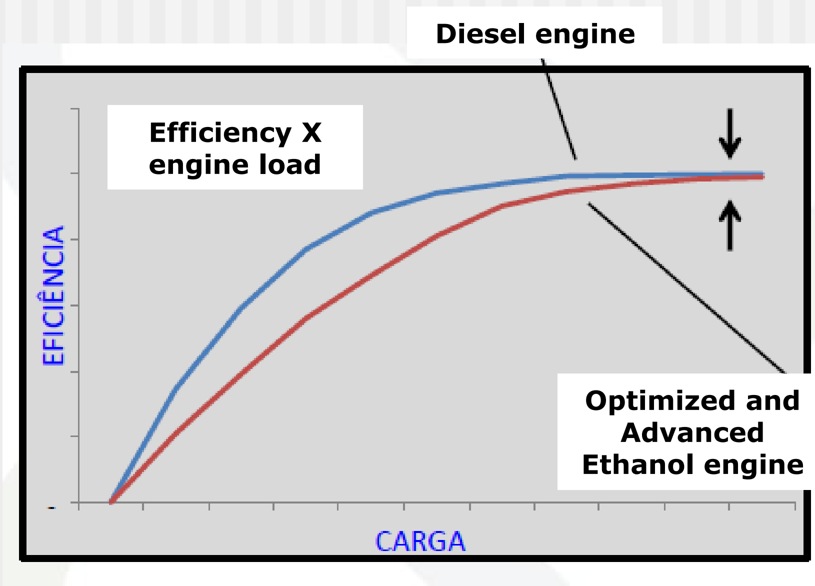
- **A compromise solution → flexibility X optimization**
- **Ethanol engines can operate on higher compression ratio**
- **Ethanol has a higher burning speed**
- **Ethanol has a higher latent heat of vaporization**
- **Water content on hydrous ethanol can have a cooling effect on engine and can allow greater compression ratio**
- **Modern technologies can be adopted to increase its efficiency to values close do that of diesel engines**
- **However, since the end of production of the ethanol engine, automakers stopped research.**

3. Challenges for ethanol engines

A recent study (Langeani, 2011) proposing an extensively modified ethanol S-I engine, showed the potential of ethanol engines. Direct injection, ERG, turbo-charging, stratified charges and huge use of electronics to control engine can now be adopted. Its efficiency can approach that of diesel engine.



marcos.langeani



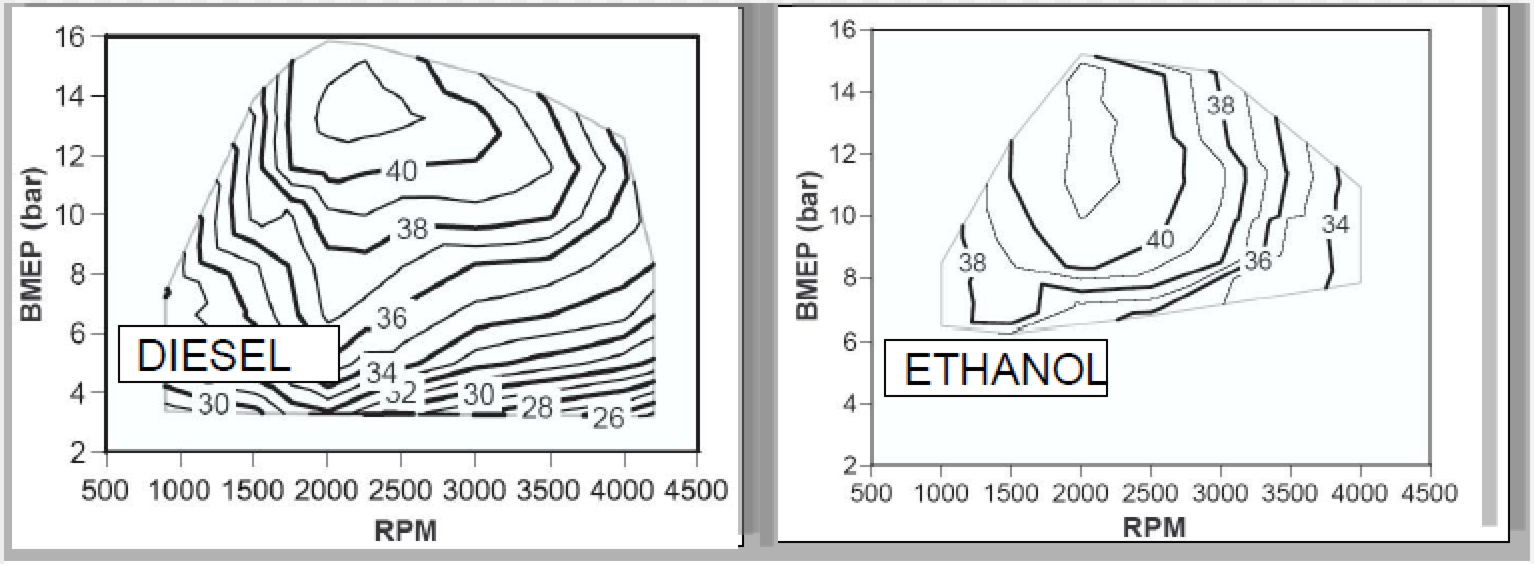
3. Challenges for ethanol engines

New technologies which were not fully tested yet for ethanol engines:

- Direct injection → vaporization of the water in the hydrous ethanol in the late compression process can reduce knock tendencies;
- Late DI also permits stratified charge operation, with benefits to engine efficiency
- Turbocharger with cooled EGR can lead to very high bmep – which means high performance from small displacement engines
- Load control through variable valve strategies – can increase the part-load efficiency
- Massive use of sensors and electronics to better control

3. Challenges for ethanol engines

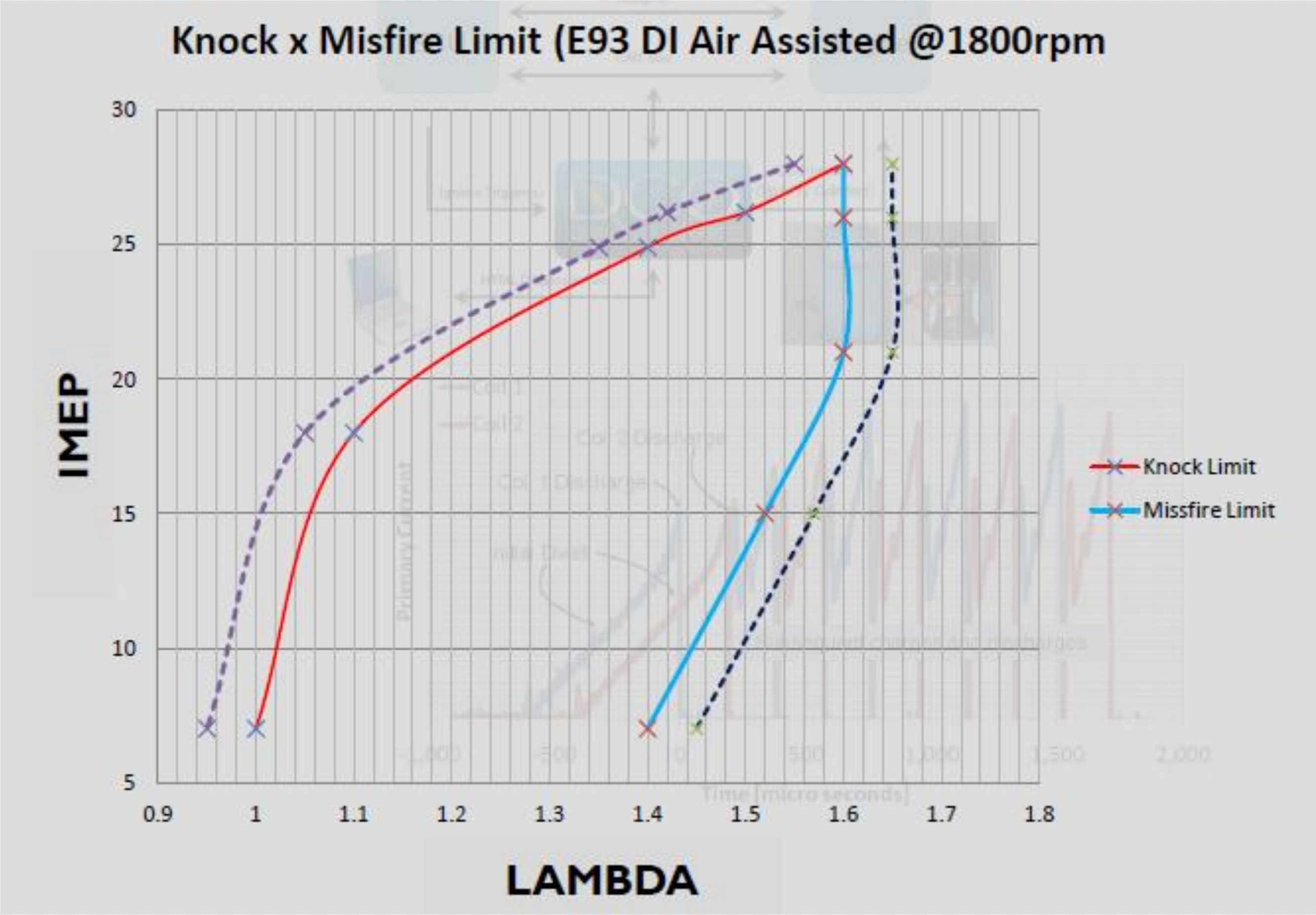
Examples of results obtained with anhydrous ethanol. Hydrous ethanol can have even better results.



1.9 l, 4 CYLINDERS, 19.5:1 COMPRESSION RATIO, HIGH-SWIRL

SAE 2002-01-2743

3. Challenges for ethanol engines



3. Challenges for ethanol engines

However:

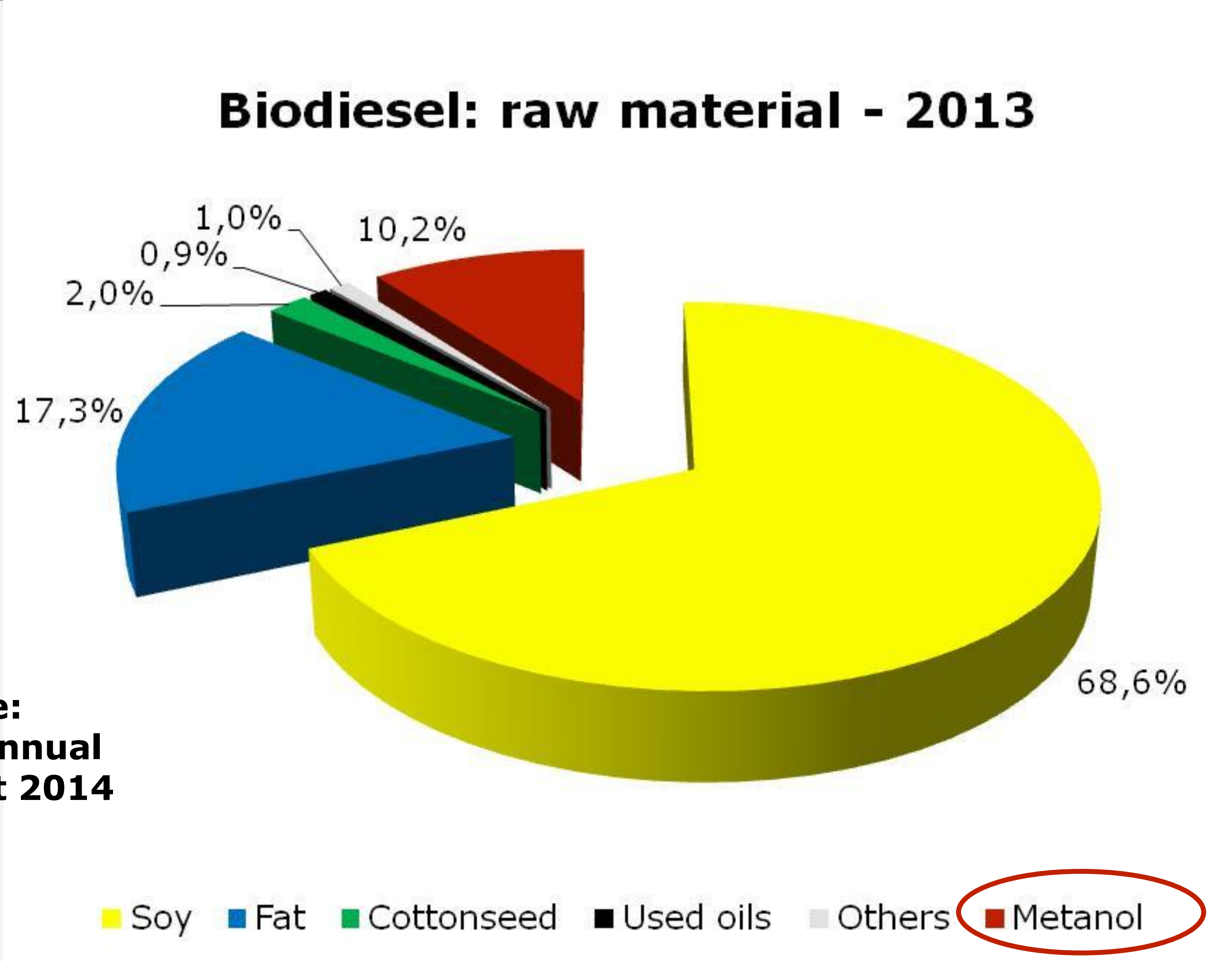
- For passenger cars the consumer want to have the choice and convenience → flex-fuel vehicles are better
- Automakers are globalized → local solutions are not wellcome
- Three options (flex-fuel, gasoline or hydrous ethanol) of the same car are more expensive
- To be adopted in heavy-duty vehicles, the ethanol engine must prove efficiencies close to the ones obtained in diesel engines
- AND: the ethanol production must increase to feed the fleet!

4. Challenges for heavy-duty vehicles

Biodiesel option: cost, seeds and taxes

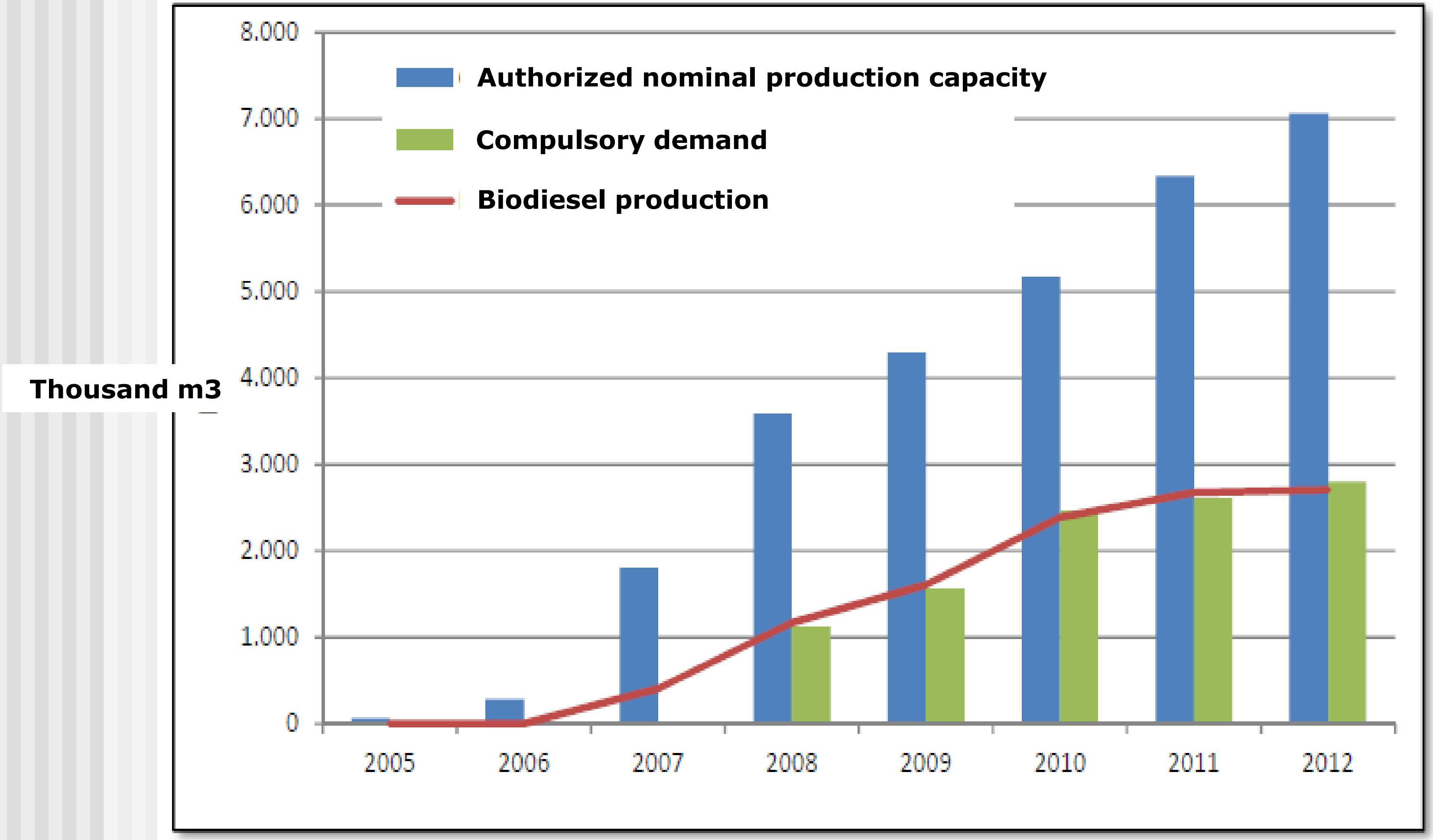
- Reduction of production costs (today higher than the final price of diesel from petroleum – including taxes on diesel)
- Development of non – food raw material for biodiesel → there are lots of non–edible types of seeds, but insufficient knowledge; technology and productivity to be developed
- To evolve to a market-driven condition; it must be competitive with production cost of diesel oil
- Today → Biodiesel program is still under Federal umbrella
- Minor engine modifications needed;
- Engine warranties: limited (poisoning of after-treatment)

4. Challenges for heavy-duty vehicles



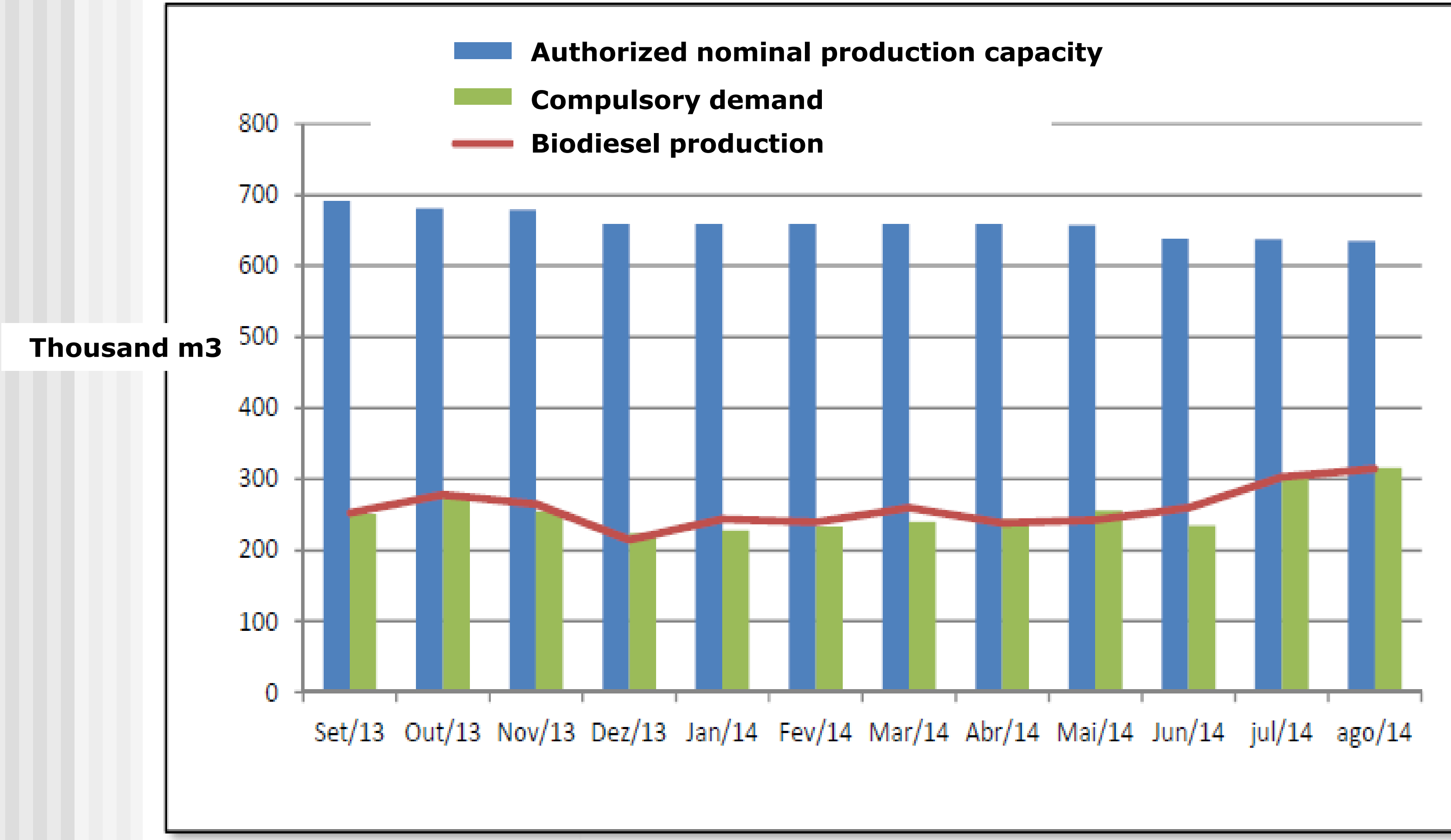
**Source:
ANP Annual
Report 2014**

4. Challenges for heavy-duty vehicles



Source: ANP Annual Report 2013

4. Challenges for heavy-duty vehicles



Source: ANP – Biodiesel monthly Bulletin, sep. 2014

4. Challenges for heavy-duty vehicles

Challenges to employ ethanol fuel in C-I engines:

- **Since ethanol has high ON, it is a poor C-I fuel; its lubricity is also smaller than required by the injection system;**
- **How to use ethanol in C-I engines?**
  - **To transform the C-I engine in a S-I engine**
  - **To blend ethanol with diesel (also some co-solvent)**
  - **To use the dual concept: create an homogeneous mixture of ethanol and air (fumigation or injection) to substitute the diesel partially (diesel auto-ignition acts as a spark)**
  - **To use surface ignition with glow plug**
  - **To use additives to improve ethanol CN and lubricity**

4. Challenges for heavy-duty vehicles

Transformation of C-I engine in a S-I engine:

- **This option was analyzed in the 80's but was abandoned;**
- **The option implies in modify the engine to adapt it to the available fuel; load control by air restriction; spark plug is added to begin the combustion; near stoichiometric mixtures; all advantages of the C-I engines are lost;**
- **There is loss of efficiency for high loads; at partial load, the reduction is even more dramatic;**
- **The increase of fuel consumption is high, due to smaller efficiency of the S-I engine and smaller heat content in the ethanol.**
- **The final balance proved uneconomical in the 80's**

4. Challenges for heavy-duty vehicles

Dual fuel system: partial substitution of diesel by ethanol:

- **Previous experience, also in the 80's: ethanol was carbureted; diesel injection acts as ignition source for air–ethanol mixture; some degree of substitution is possible, but with a huge increase in CO and HC emissions (engines without post-treatment); poor load control.**
- **In recent works, ethanol is injected in the inlet port and electronic load control is employed; in some cases, ethanol is evaporated to obtain a more homogeneous mixture with air.**
- **In this option, the engine can run only on diesel, or in dual fuel mode; PM can be reduced; a small NOx reduction can also be obtained. CO and HC emissions, however, increase.**

4. Challenges for heavy-duty vehicles

Dual fuel: Bosch system and Iveco truck

Dataset	Speed Km/h	GCW (ton)	Diesel substitution
Diesel/Ethanol	30.57	80 (Full Load)	37.63%
Diesel/Ethanol	49.23	25 (Empty)	37.60%

Table 2 – Diesel substitution rate

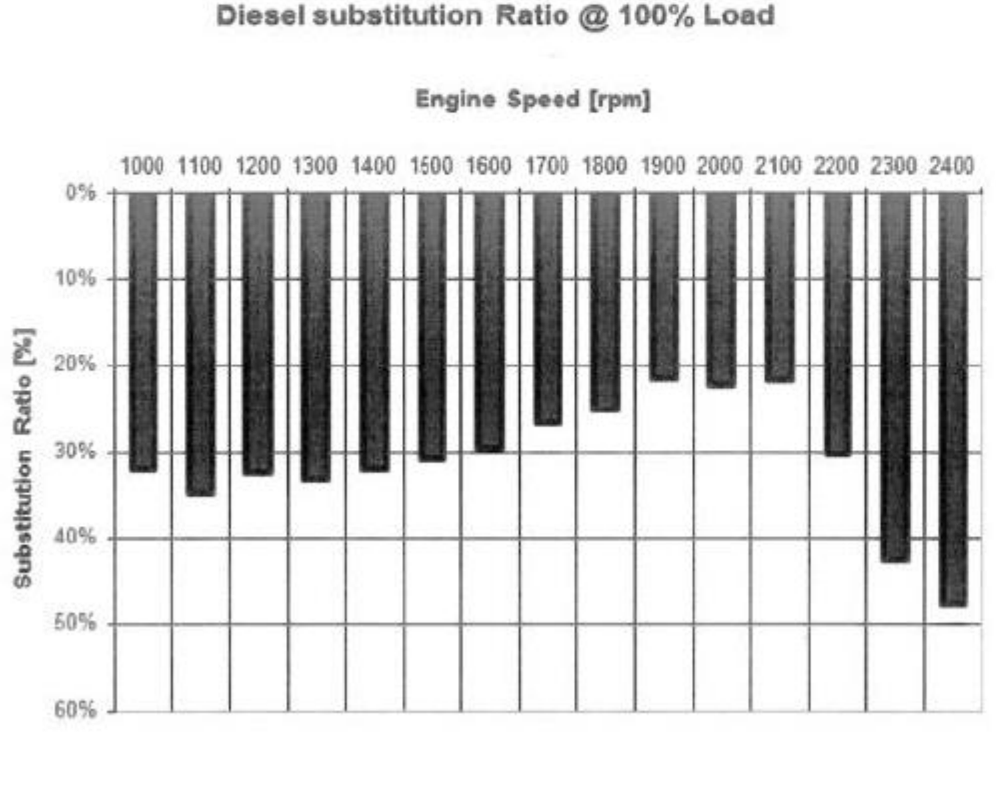


Figure 4 – Diesel substitution ratio (100% load)

Source: Resende et al. SAE Technical Paper Series 2011-36-0319

4. Challenges for heavy-duty vehicles

To use additives to improve CN and lubricity

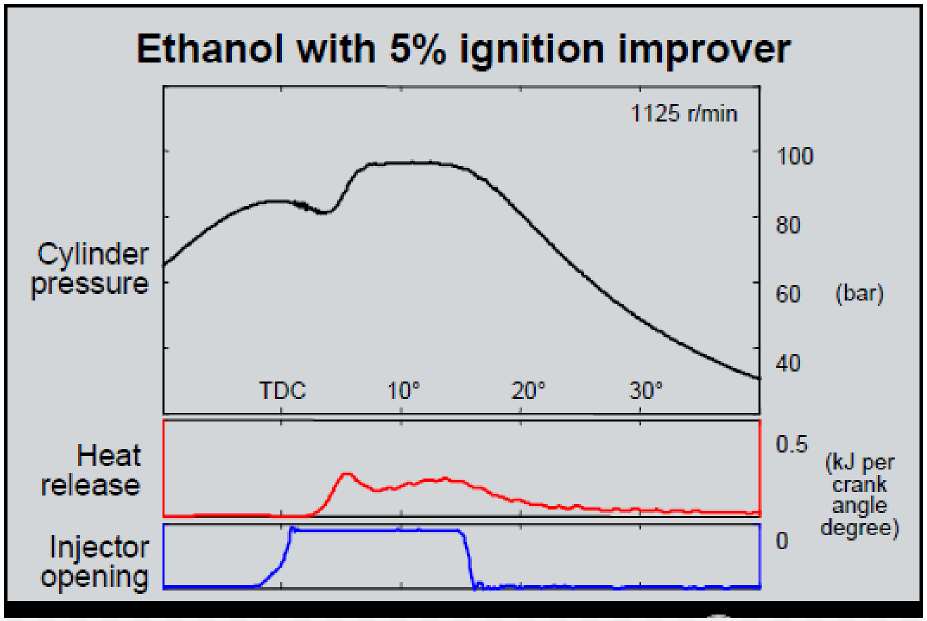
- This option also was studied in the oil crisis in the 80's;
- The cetane number improver usually is a light explosive; most of time, some kind of nitrite.
- The idea is to use as much additive as necessary to obtain, with ethanol, auto-ignition like that of diesel fuel;
- Usually, a co-solvent is adopted; biodiesel can be used to this role and increase the lubricity of ethanol;
- Stockholm buses adopt ethanol with additives to reduce urban emissions since the early 90's (NOx and PM);
- This solution can be adopted only by environmental motivation (GHG emissions), since costs are high;

4. Challenges for heavy-duty vehicles

Ethanol with additives: Scania solution

- The engine was modified to a very high compression ratio (28:1) and uses a ethanol resistant fuel system
- The fuel (by mass): 92,2% wet ethanol (6,4% water) + 5% ignition improver + 2,8 MTBE and isobutyl alcohol
- Lubricating system adopts an oil compatible with ethanol
- Increased flow injectors
- Reduced service interval
- Heat of combustion:

  25,7 MJ/kg X 44,5 MJ/kg
- Thermal efficiency: up to 43%
- Oxidizing catalyst (CO, HC)
- EGR (NOx)



Source: Westman, B. – Eng. Director Saab- Scania

4. Challenges for heavy-duty vehicles

Diesel from sugarcane

There are some research to obtain diesel–like renewable fuels using modern bioengineering and knowledge on metabolism of specific micro-organisms.

- This route is called 3th generation bio–fuels, or bio–refineries.
- The objective is to obtain renewable diesel, or gasoline or aeronautical kerosene.
- These fuels does not require modifications in the engines or engine systems → optimal solution, from engine manufacturer viewpoint
- The final goal is to reduce GHG emissions

5. Direct Ethanol Fuel Cells

Fuel cells → chemical energy is converted directly into electrical energy.

- **Difference with batteries: fuel flow to produce electricity.**

- **Heat is produced from electrochemical reaction and not from combustion.**

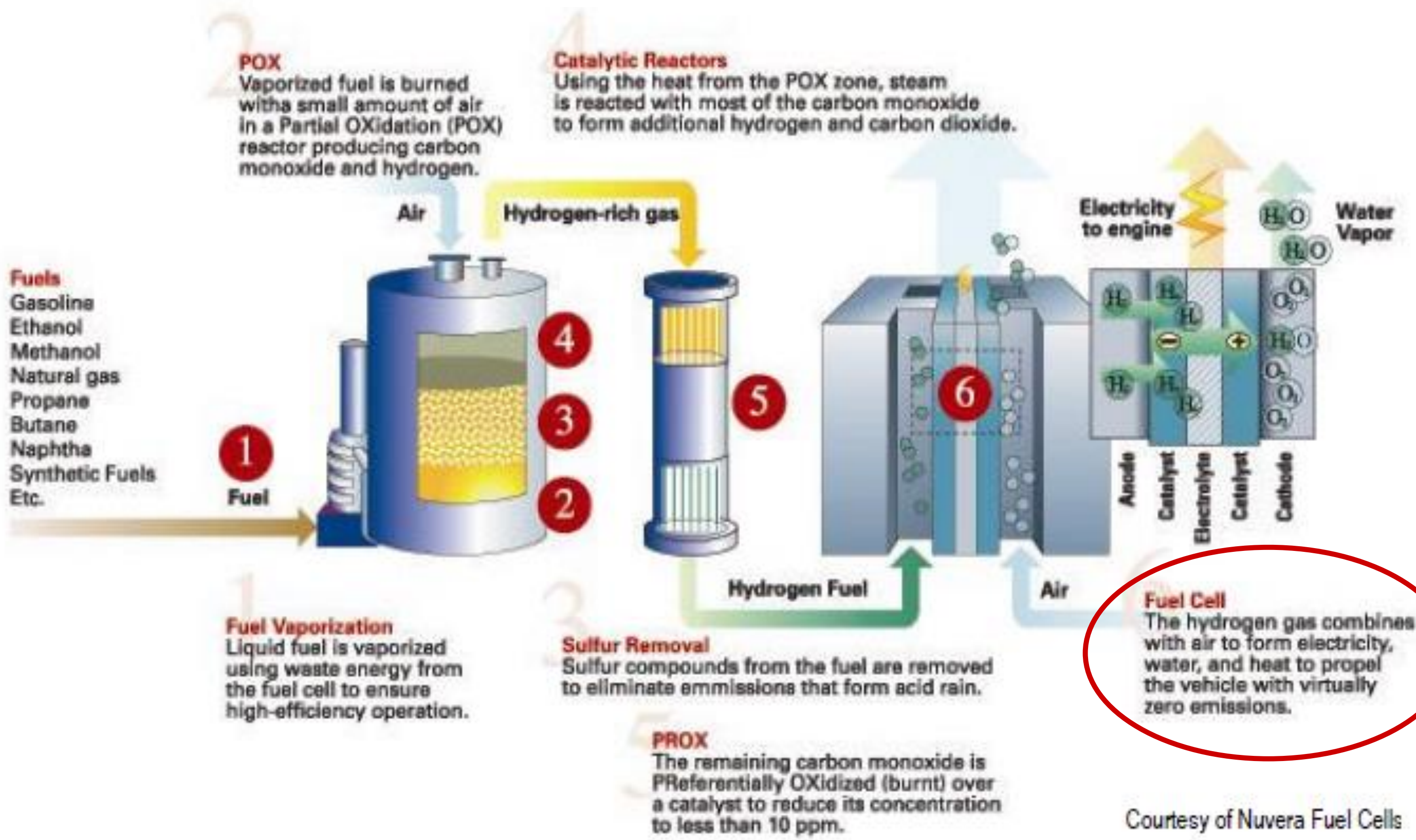
- **Types of fuel cells:**
  - **Alkaline fuel cell (AFC) → pure O2 and H2**
  - **Solid-oxide fuel cell (SOFC) → Fuel reform, H2**
  - **Phosphoric acid fuel cell (PAFC) → Fuel reform, H2**
  - **Molten-carbonate fuel cell (MCFC) → Fuel reform, H2**
  - **Proton exchange membrane (PEMFC) → Fuel reform, H2**
  - **Direct Methanol fuel cell (DMFC) → methanol**
  - **Direct Ethanol fuel cell (DEFC) → ethanol**

5. Direct Ethanol Fuel Cells

	PEMFC	DMFC	AFC	PAFC	MCFC	SOFC
Fuel	H_2	CH_3OH	H_2	H_2	H_2, CO, CH_4, HCs	H_2, CO, CH_4, HCs
Electrolyte	Solid polymer (usually *Nafion*)	Solid polymer (usually Nafion)	Potasium hydroxide (KOH)	Phosporic acid (H_3PO_4 solution)	Lithium and potassium carbonate	Solid oxide (ytria, zirconia)
Charge carried in electrolyte	H^+	H+	OH^-	H^+		O^{2-}
Operational temperature (°C)	50 – 100	50 - 90	60 - 120	175 – 200	650	1000
Efficiency (%)	35 – 60	< 50	35 – 55	35 – 45	45 – 55	50 – 60
Unit Size (KW)	0.1 – 500	<< 1	< 5	5 – 2000	800 – 2000	> 2.5
Installed Cost ($/kW)	4000	> 5000	< 1000*	3000 – 3500	800 – 2000	1300 - 2000

5. Direct Ethanol Fuel Cells

Fuel reform for fuel cells



5. Direct Ethanol Fuel Cells

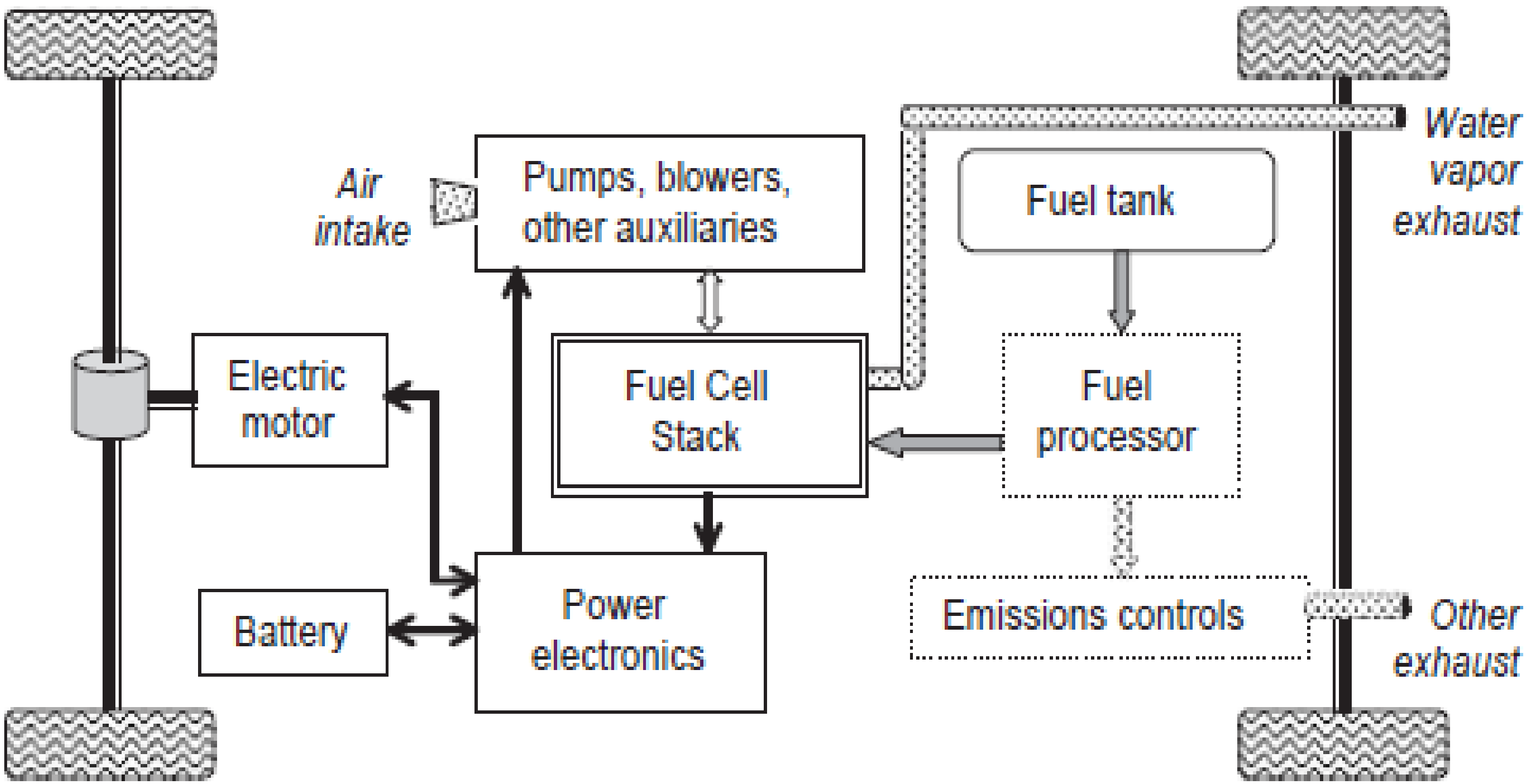
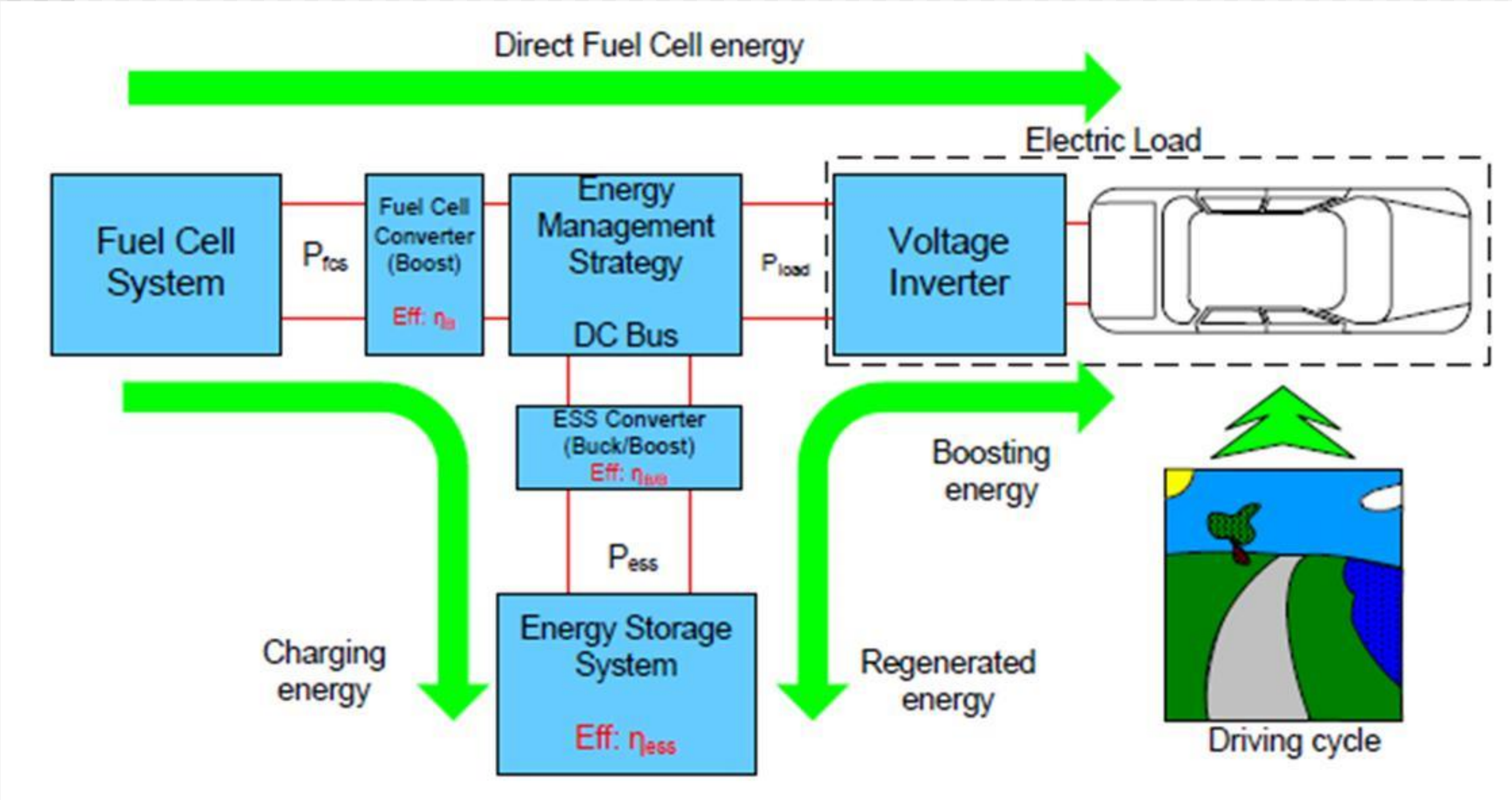


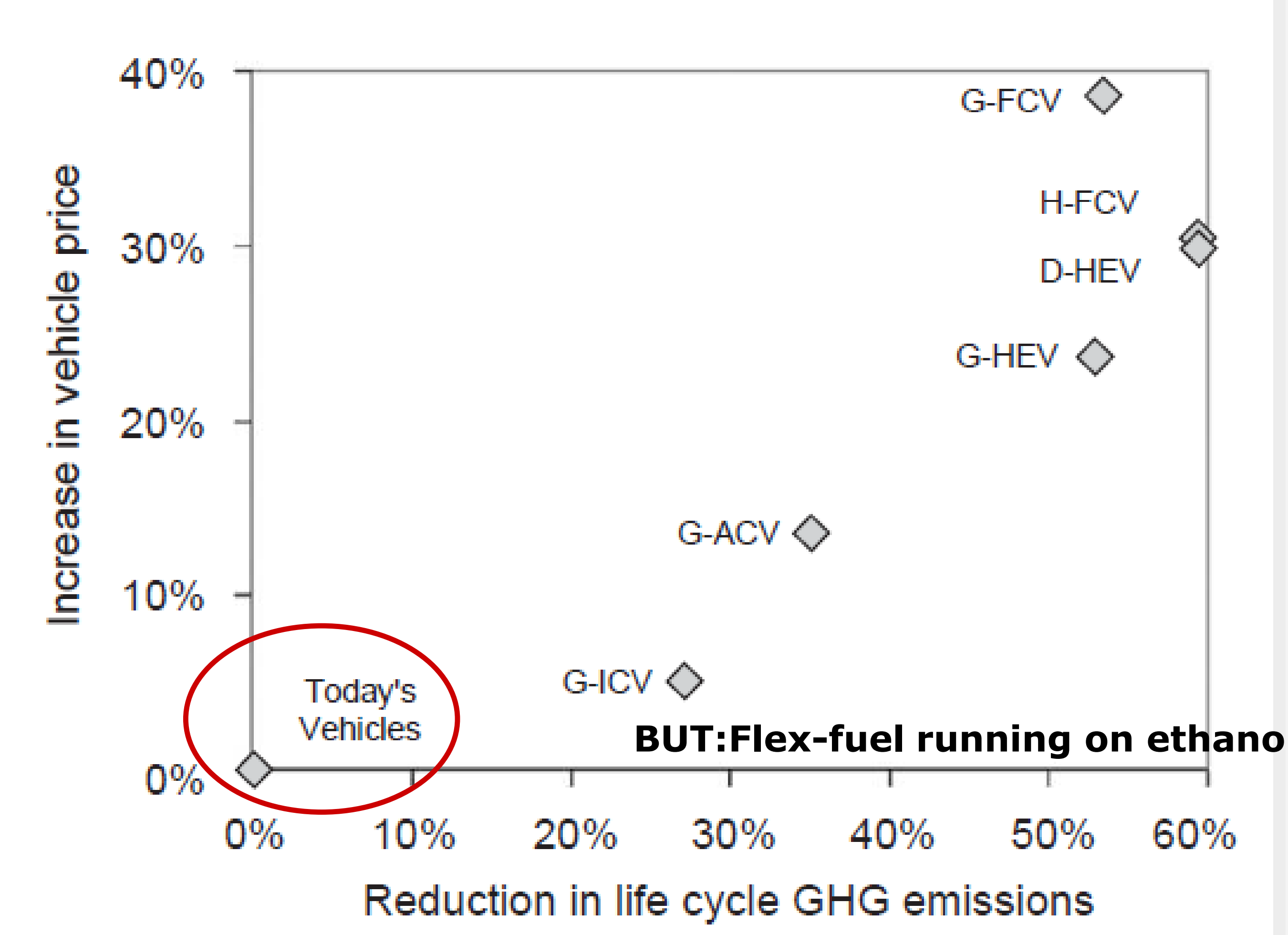
FIGURE 1 Major components of a fuel cell vehicle.

Source: DeCicco, J.M. Encyclopedia of Energy, V.2, 2004

5. Direct Ethanol Fuel Cells



5. Direct Ethanol Fuel Cells



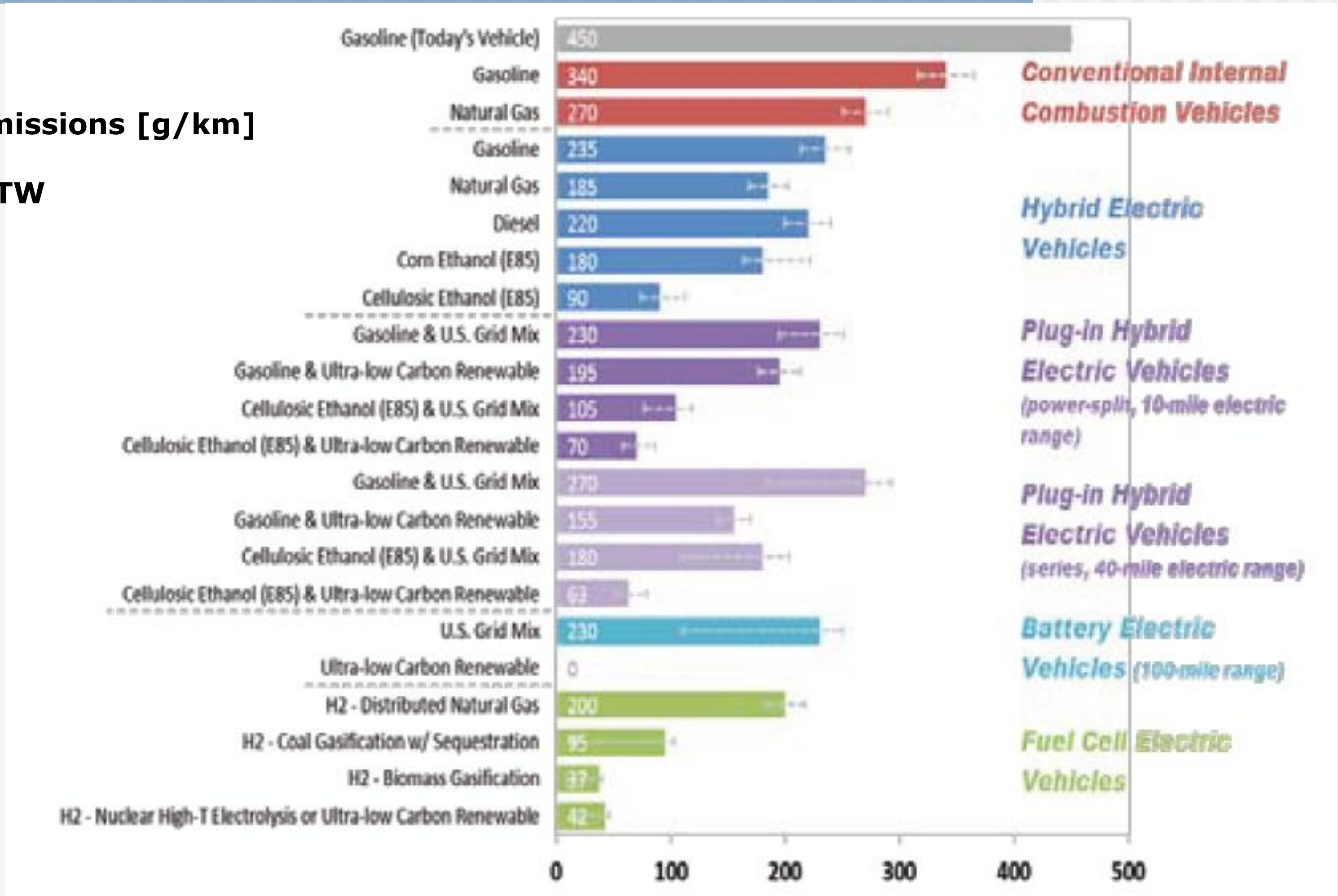
BUT:Flex-fuel running on ethanol →

Source: DeCicco, J.M. Encyclopedia of Energy, V.2, 2004

5. Direct Ethanol Fuel Cells

CO2 emissions [g/km]

LCA WTW



Source: IEA – Advanced fuel cells Annual Report 2011

5. Direct Ethanol Fuel Cells

Direct ethanol fuel cell → follow the path of DMFC

- **Direct Oxidation of the carbon in the cell stack to produce CO2 and proton flow through a permeable membrane**

	Equation
Anode	$C_2H_5OH + 3\ H_2O \rightarrow 12\ H^+ + 12\ e^- + 2\ CO_2$ oxidation
Cathode	$3\ O_2 + 12\ H^+ + 12\ e^- \rightarrow 6\ H_2O$ reduction
Overall reaction	$C_2H_5OH + 3\ O_2 \rightarrow 3\ H_2O + 2\ CO_2$ redox reaction

5. Direct Ethanol Fuel Cells

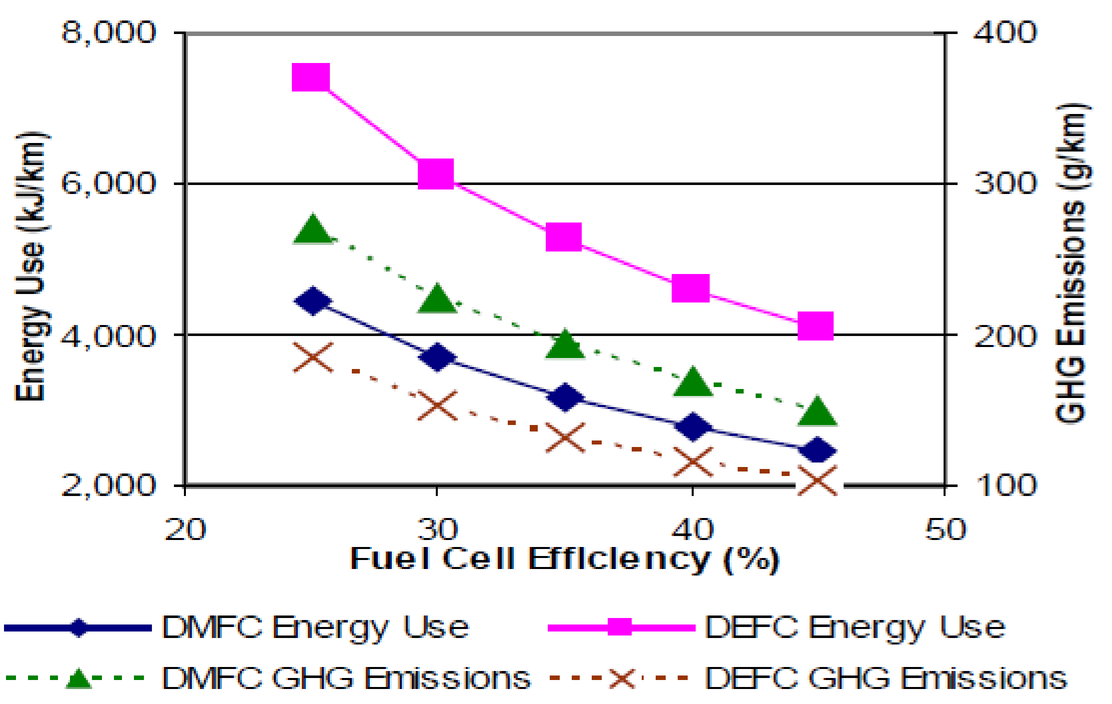
- **Technical issues to be solved:**
  - **Catalysts for the low T reaction**
  - **Break the carbon–carbon chemical bound**
  - **Water management**
  - **Fuel crossover (through the membrane)**
  - **Formation of undesirables sub-products (aldehydes, acids, etc.)**
  - **Poisoning of the catalysts with CO**
  - **Start and stop procedures**
  - **Load control (transient behavior)**
  - **Durability**
  - **Production costs**

5. Direct Ethanol Fuel Cells

Some results (from simulations) for DEFC

TABLE II TOTAL GHG EMISSIONS IN THE ENTIRE FUEL CYCLE

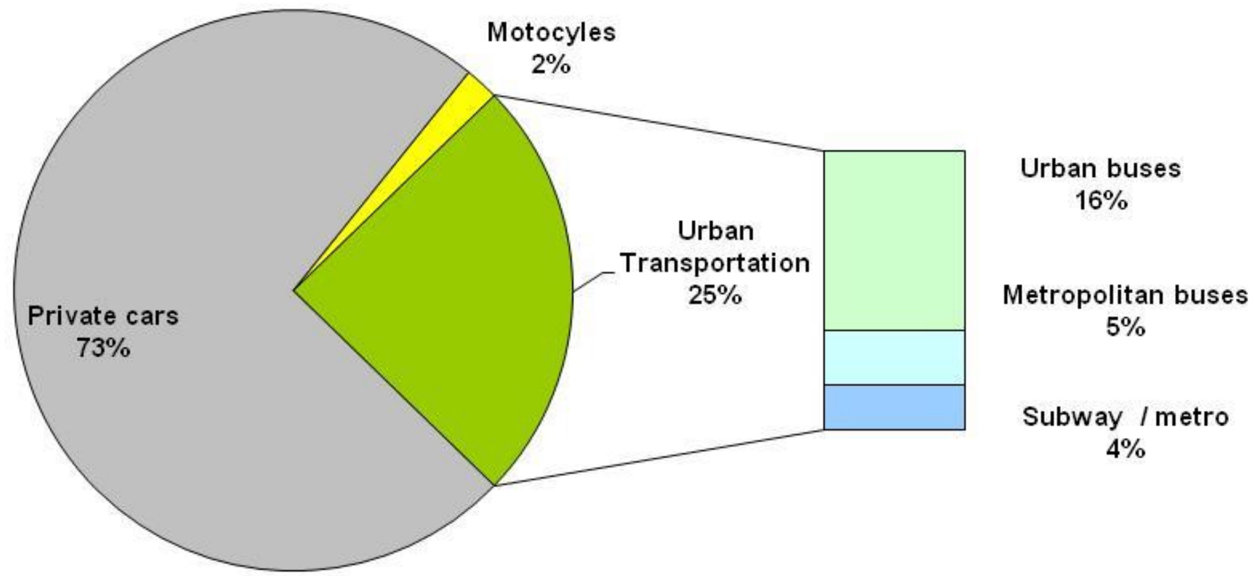
Vehicle types	GHG emissions (g/km)
CONV SI	274
ICEV M90	259
H2FCV LM	170
DMFC	184
ICEV E85	188
H2FCV LE	103
DEFC	108
H2FCV	134



Source: Gao et al. Int.J. Energy Science, V2, n5, 2012, pp 211-216

6. Concluding remarks

Transportation of people in cities employs 10,7 million tep Private cars are responsible for 73% of this energy consumption.



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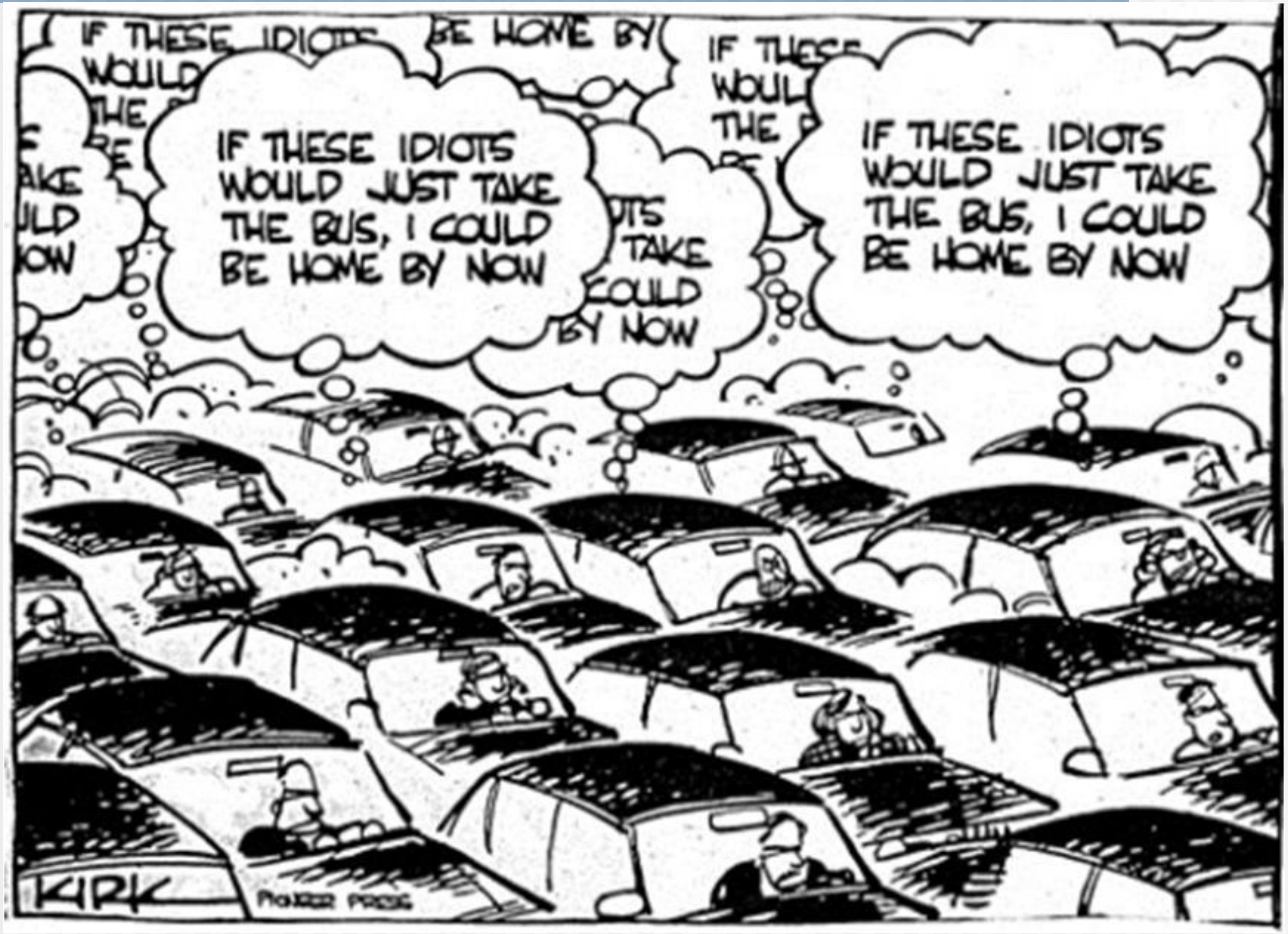

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