INTERNAL COMBUSTION ENGINE AND THE SUSTAINABLE ROAD MOBILITY (?)

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UNIVERSITY CENTRE OF BUCHAREST

NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY "POLITEHNICA"

ESFA 2023

Fuel Economy Safety and Reliability of Motor Vehicles
The 33rd SIAR International Automotive and Transport Engineering Congress
The 10th ESFA Congress

University of Pitești (now part of the UNSTPB)

Department Automobiles and Transport - *Tradition and academic excellence*

Brief retrospective

- 1968: First Dacia vehicle produced in Pitești
- 1969: The Institute of Sub-Engineers is established at UPIT (BAC+3)

- 1972: The Automobiles Chair is created + The first class of „Automobiles” at UPIT (BAC+3)
- 1977: „Road Vehicles” specialization at UPIT (BAC+5)
- 2005: The Bologna process begins → „Road Vehicles” (BAC+4)
- 2012: Automobiles Chair → Department Automobiles and Transport

The only academic entity in Romania that offers university studies in the field of Automotive Engineering, in all three forms accredited according to Bologna procedures (LMD)

- 2023: 43 graduation classes of „Road Vehicles” (BAC+5)

UNIVERSITATEA DIN PITEȘTI
Academia magistra vitae

“L'avenir est un présent que nous fait le passé”
André Malraux

Adrian CLENCI – short biography

- 1996: Automotive Engineering degree, University of Pitești
- 1996 - 1998: engine design engineer, CESAR – Automobile DACIA
- 1998 - present: junior assistant, assistant, lecturer, senior lecturer, habilitation, full professor, University of Pitești
- 2003: PhD in Mechanical Engineering – "VCR S.I. engine", University "Transilvania" of Brașov
- 2007 - present: trainer within Renault Romania (mathematics for engineers, mechanics, internal combustion engines, test beds)
- 2008 - 2020: associated researcher at Conservatoire National des Arts et Métiers Paris
- 2008: invited professor at Institut Supérieur de l'Automobile et des Transports, France
- 2012: invited researcher at Conservatoire National des Arts et Métiers Paris, France
- 2018: invited professor at Université de Valenciennes et du Hainaut-Cambrésis, France

Hirsch indexes :

WoS:	*7 (58 publications, cited by 260 documents)*
Scopus:	*7 (30 documents, cited by 297 documents)*
Research Gate:	*8 (113 documents, cited by 442 documents)*
Google Scholar:	*10 (99 documents, cited by 573 documents)*

https://orcid.org/0000-0003-1101-2720

University « Politehnica » of Bucharest (now part of the UNSTPB)

Department of Road Vehicles - *Tradition and academic excellence*

Brief retrospective

- 1924 – 1929: Annual lecturing by Aurel Persu at "Politehnica" on "Automotive Technology"
- 1940 – 1942: Lecturing by Constantin Ghiulai at "Politehnica" on "Automobiles" and "Automobiles and Tanks"
- 1948: The 1st higher level automobile course in Romania has been published at UPB Publishing House by prof. Constantin Ghiulai
- 1950: „Autobuzul" plant in Bucharest („Rocar" after 1990)
- 1959: Faculty of Transports at UPB
- 1960: The Automobiles Chair is created
- 1969: The Automobiles specialization is created (BAC+3)
- 1972: The Automobiles Chair became The Road Vehicles Chair + starting of „Road Vehicles" specialization at UPB (BAC+5)
- 2005: The Bologna process begins → „Road Vehicles" (BAC+4)
- 2012: Road Vehicles Chair → Department of Road Vehicles
- 2023: 48 graduation classes of „Road Vehicles" (BAC+5)

"L'avenir est un présent que nous fait le passé"

André Malraux

NATIONAL UNIVERSITY of SCIENCE AND TECHNOLOGY "POLITEHNICA"

University Centre of Bucharest

Department of Road Vehicles - *Tradition and academic excellence*

Mircea OPREAN – short biography

- 1972: Automotive Engineering degree, University Politehnica of Bucharest
- 1972 - present: junior assistant, assistant, lecturer, senior lecturer, professor, University Politehnica of Bucharest
- 1984: PhD in Mechanical Engineering, University Politehnica of Bucharest
- Author of 13 books
- Author of 77 scientific papers (WoS, Scopus, etc)
- Director of 37 research contracts

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Hirsch indexes :

WoS:	*2 (8 publications, cited by 23 documents)*
Scopus:	*2 (17 documents, cited by 40 documents)*
Research Gate:	*5 (40 documents, cited by 78 documents)*
Google Scholar:	*5 (39 documents, cited by 120 documents)*

http://autovehiculerutiere.pub.ro/ https://www.researchgate.net/profile/Mircea-Oprean

STRUCTURE OF THE PRESENTATION

- INTRODUCTION
- LEGISLATIVE CONTEXT
- INTERNAL COMBUSTION ENGINE
- CONCLUSIONS

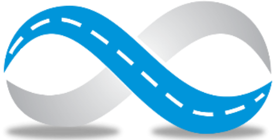
Individual Road Mobility

SUSTAINABLE

?

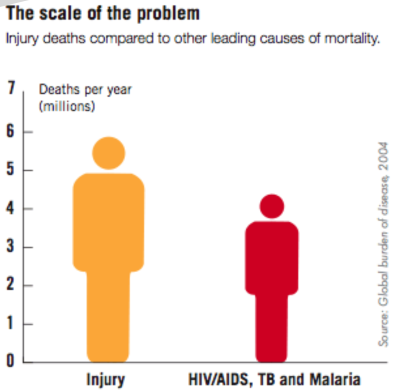
INTRODUCTION – Individual road mobility: stakes and challenges

Sustainable road mobility



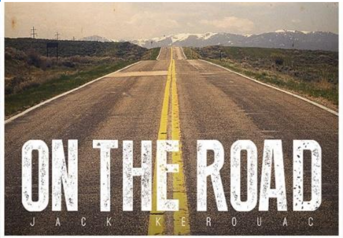
Impact upon the environment

Road security



Agglomeration

Freedom of movement



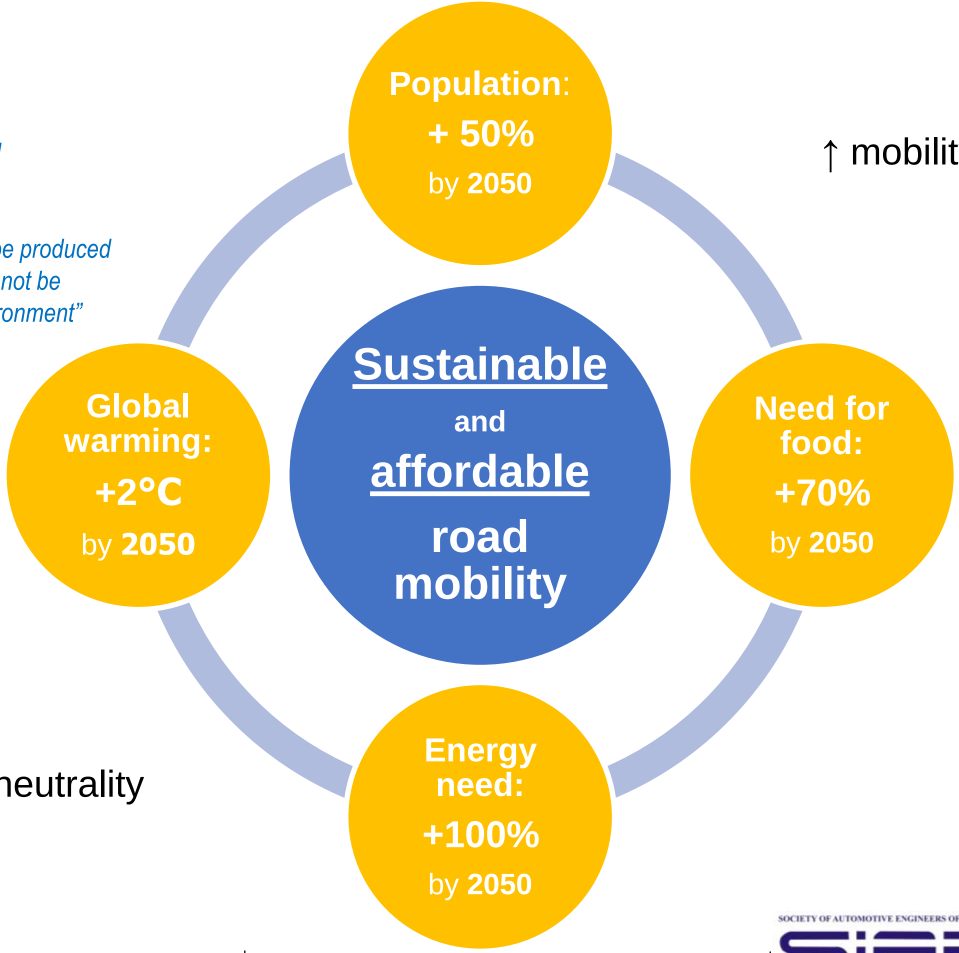
Individual road mobility

INTRODUCTION – Individual road mobility: stakes and challenges

According to Cambridge Dictionary:

*“**Sustainability** = the quality of causing little or no damage to the environment and therefore, able to continue for a long time”*

“the idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment”



↑ mobility need ?

! ↓ CO_2 → Carbon neutrality

INTRODUCTION – Technological development vs. Constraints

Client

Fun to drive

TCO

Bio
E-fuel

ICEV
HEV
BEV

hydrogen EV
FCEV

to ensure an affordable & sustainable road mobility ?

§ Regulation

Fit for 55 by 2030
CO2 neutral in 2050

2009 & 2019
2023
CO_2

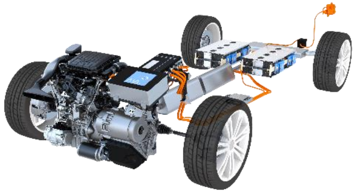
2017
WLTP

2017
RDE

ICE

Transmission

Electrification



Vehicle

Automotive engineering = management of compromise

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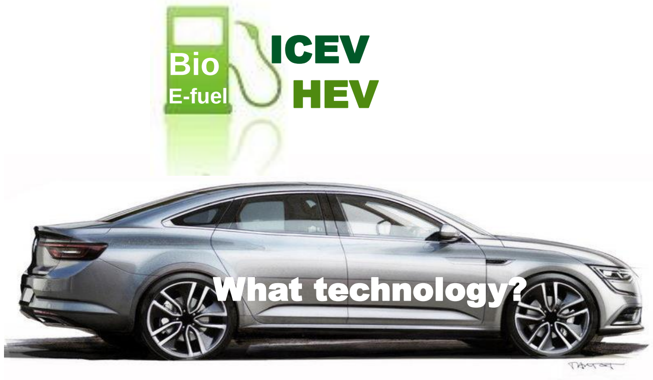
INTRODUCTION – Technological developments vs. Constraints

Client

- Fun to drive
- TCO



§ Legislation

- Fit for 55 by 2030
- CO2 neutral in 2050
- 2009 & 2019, 2023: CO_2
- 2017: WLTP
- 2017: RDE


TRANSPORT & ENVIRONMENT

The beginning of the end for the infernal combustion engine

By Greg Archer, clean vehicles director

+

PUBLIC PRESSURE WITHOUT PRECEDENT

↓

BIG CITY ACCESS BAN

RISK


Newsweek WORLD U.S. PODCASTS OPINION CULTURE SPORTS TECH & SCIENCE

PARIS IS CHOKING. TRAFFIC CONGESTION AND GRIDLOCK BLAMED.

Paris joins Athens, Madrid and Mexico City in banning diesel by 2025.

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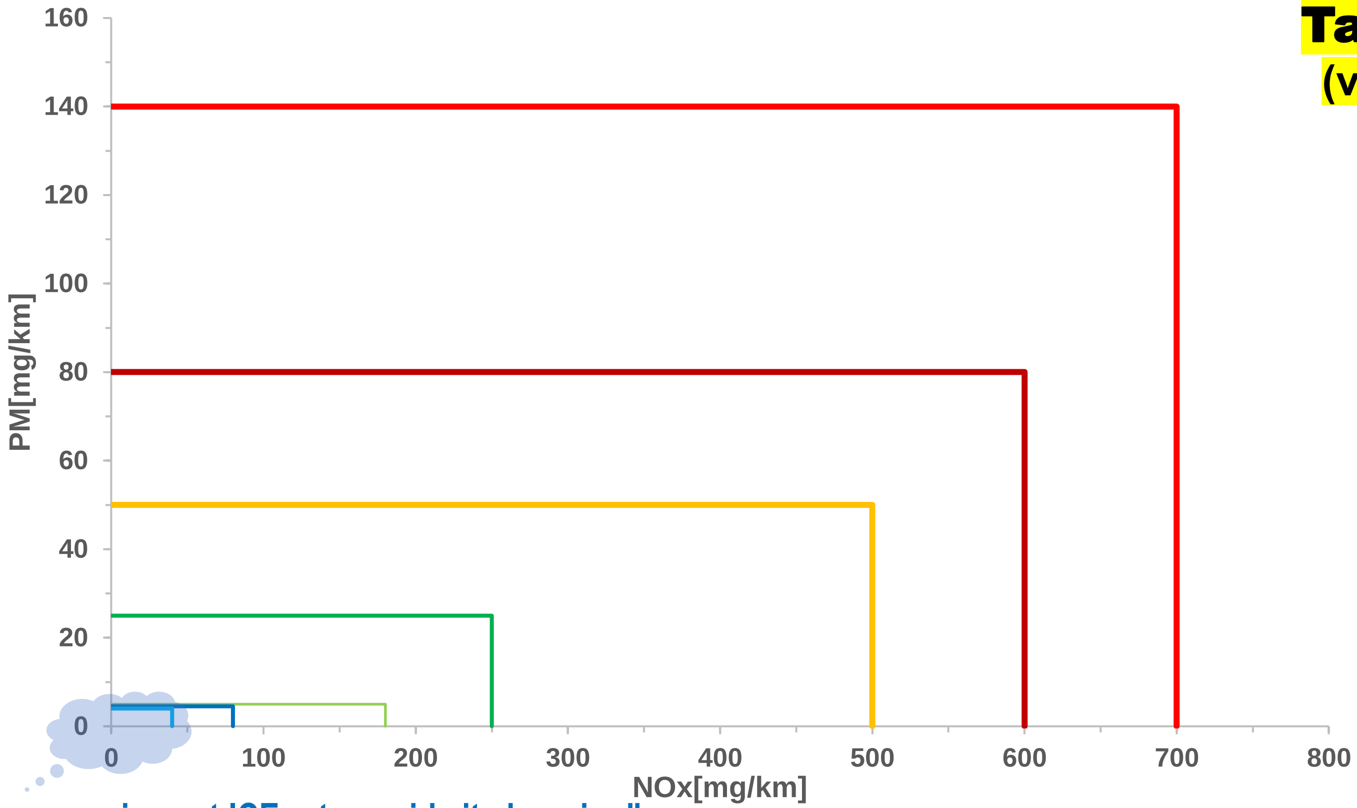
Individual road mobility

sustainable

?

LEGISLATIVE CONTEXT – Pollutants. Evolution



Tank-to-Wheel
(vehicle "cycle")

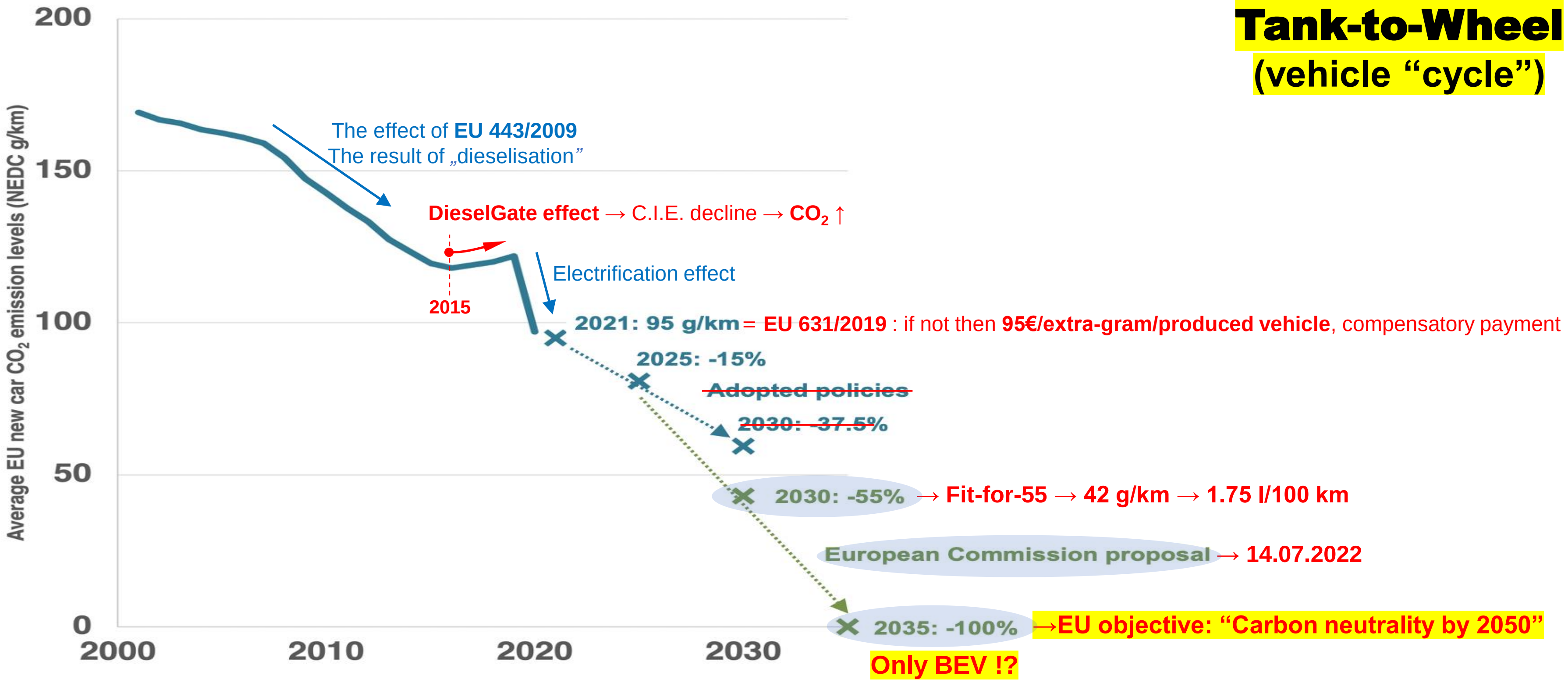
- EURO1 (1992)
- EURO2 (1996)
- EURO3 (2000)
- EURO4 (2005)
- EURO5 (2009)
- EURO6 (2014)
- EURO7 (2026)

Technology & Fuel neutral
NO_x → 35 mg/km !
PM → 3 mg/km !
+ CH_4, N_2O, NH_3,
formaldehyde (CH_2O),
NMOG
d_{minPM}: 23 → 10 nm !
RDE: $FC_{RDE / EU7}$ = 1 !
(-7 .. 35)°C
RDE w/o restriction
related to driving style

Euro7: **"Near-zero impact ICE… to avoid city banning"**
(i.e., impact so small that can be negligeable)"

LEGISLATIVE CONTEXT – CO2 emission. Evolution

Tank-to-Wheel
(vehicle "cycle")



Source: https://theicct.org/the-european-commissions-fitness-program-for-climate-protection-sluggards/

LEGISLATIVE CONTEXT – EURO7, regulating chemical species with GWP via CO_2 eq ?

Tank-to-Wheel
(vehicle "cycle")

GWP = Global Warming Potential

Source: Ricardo

Species	CO_2 Equivalence Ratio (100-yr GWP)	Typical Emissions (Euro 6d-FINAL, GDI, GPF)	Potential Limit	CO_2e
CO_2	1g CO_2 = 1g CO_2	150 g/km*	81g/km (NEDC) Fleet @ 2025	150 g/km
CH_4	1g CH_4 ~ 30g CO_2	~3.5 mg/km	15 mg/km	~0.1 g/km
N_2O	1g N_2O ~ 300g CO_2	~4 mg/km	10 mg/km	~1.2 g/km

Euro7: Adding **N_2O** in particular could lead to a significant **increase in CO_2**eq. emissions

OEMs: considering the investments for electrification, is it really worth the effort ?...

European Council: we need to relax EU7 to support investments in electrification

LEGISLATIVE CONTEXT – CO2 regulation → Consequences

THE CONSEQUENCE OF THE EUROPEAN PARLIAMENT DECISION FROM 14.07.2022 (-100% CO_2 by 2035):
(339 votes in FAVOUR, 249 AGAINST, 24 ABSTENTIONS)

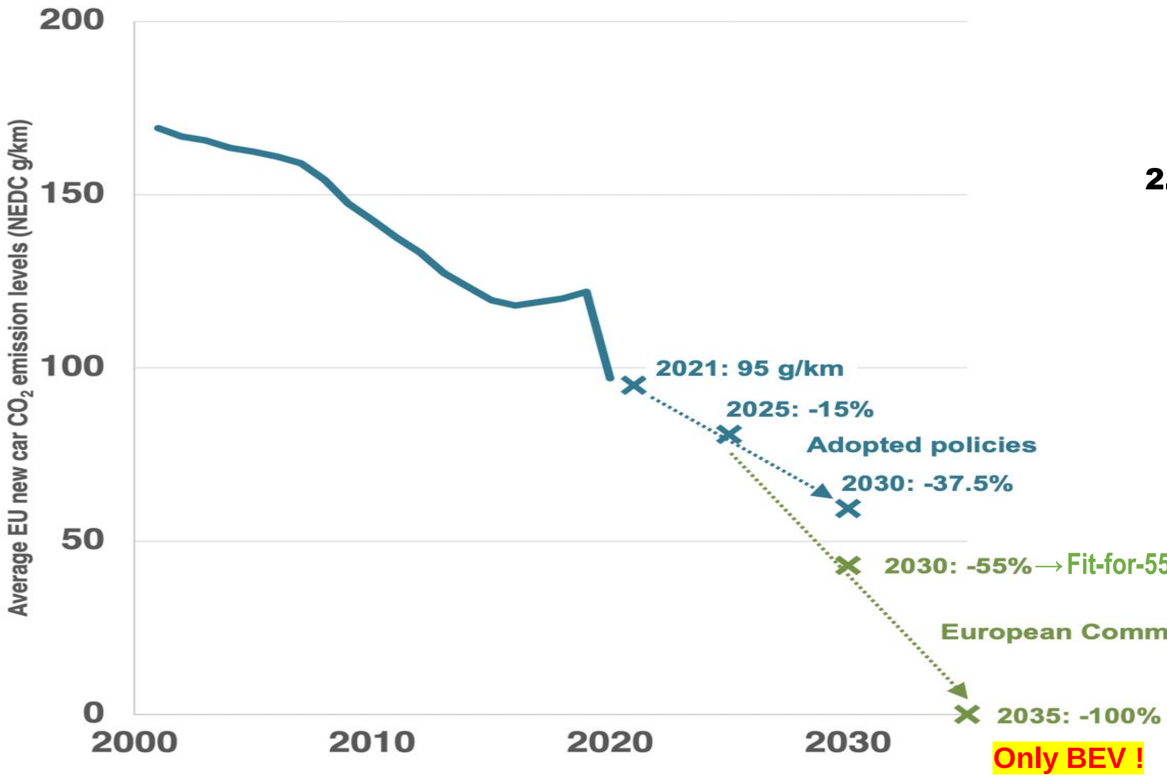
PUBLIC ANNOUNCEMENTS TO MIGRATE TOWARDS 100% BEV (i.e., TOTAL ELECTRIFICATION)…

2030
Renault, Fiat, Volvo
Ford, Mercedes

2033
Audi

2035
General Motors

LEGISLATIVE CONTEXT – CO2 emission. Evolution



→ Fit-for-55 → 42g/km → 1.75 l/100 km

proposal / 14.07.2022

Only BEV !

Tank-to-Wheel
(vehicle "cycle")

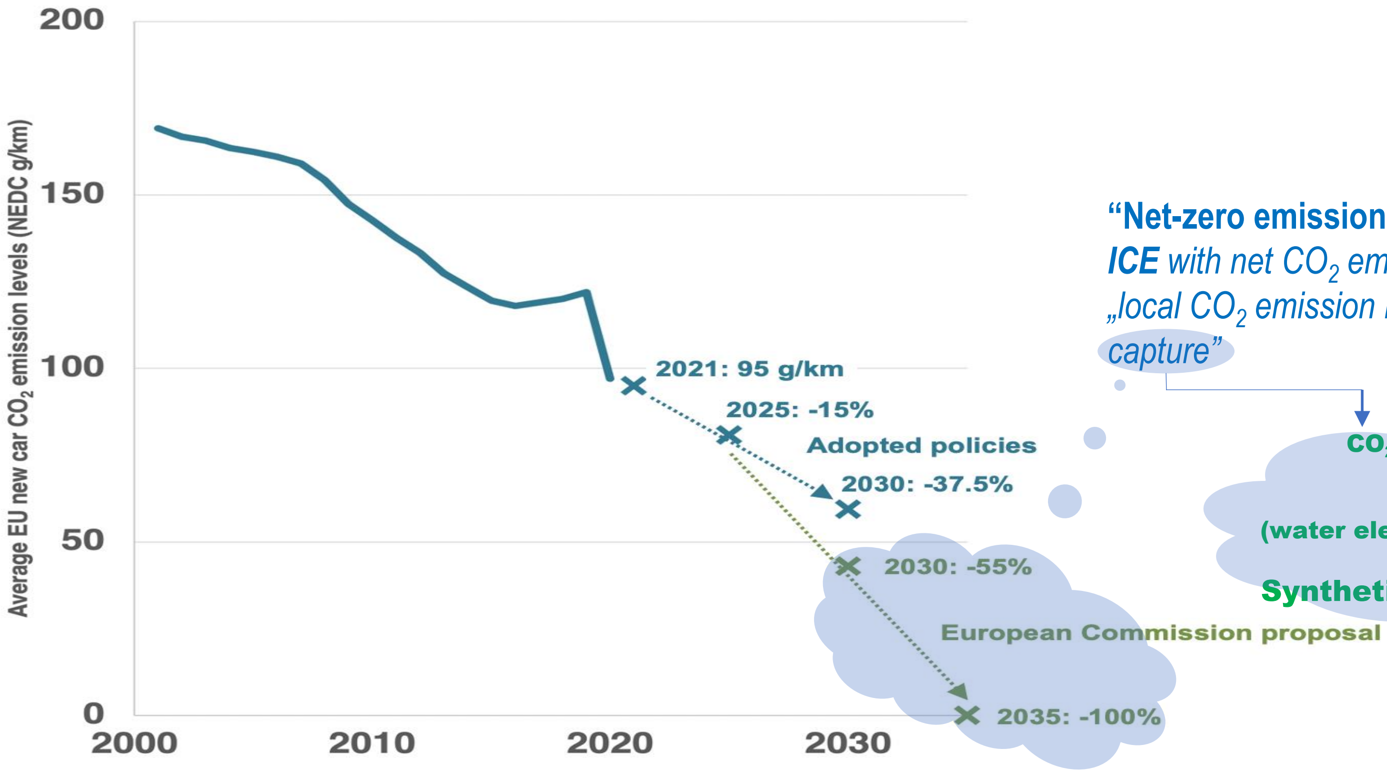
2. End of March 2023, further to negotiations,
only synthetic fuels-based ICE
will be allowed to be sold after 2035

1. FINAL VOTE
regarding "only BEV" from 2035
was postponed:
on 03.03.2023, 23h55,
Germany, Italy, Poland and Bulgaria
abstained.

Source: https://theicct.org/the-european-commissions-fitness-program-for-climate-protection-sluggards/

LEGISLATIVE CONTEXT – CO2 emission. Evolution

Tank-to-Wheel
(vehicle “cycle”)

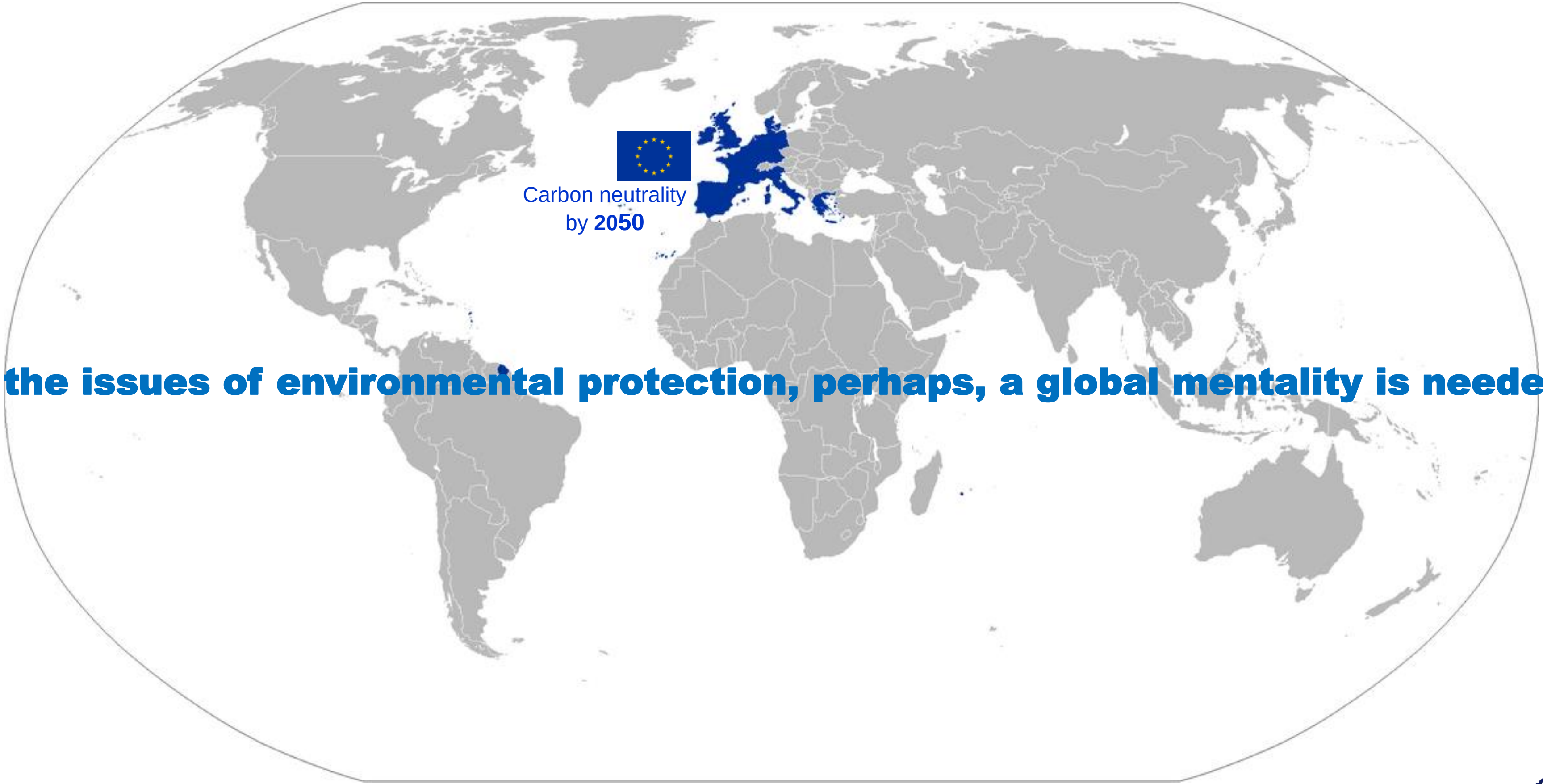


“Net-zero emissions”
ICE *with net CO_2 emission zero, i.e.,*
„local CO_2 emission is compensated elsewhere through capture”

CO_2 Capture and Usage (CCU)
+
Green H_2
(water electrolysis with renewable energy)
=
Synthetic fuel / electro-fuel / e-fuel

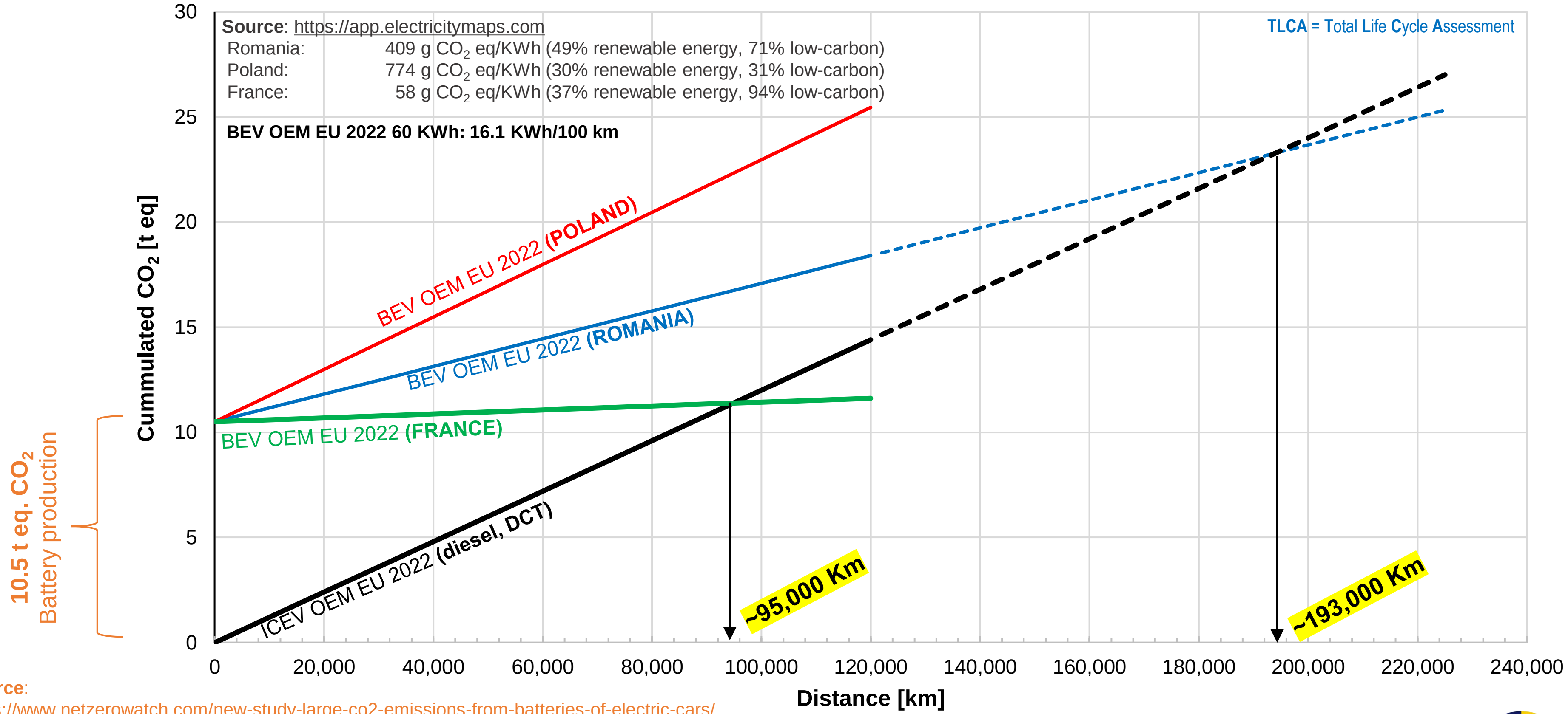
Source: https://theicct.org/the-european-commissions-fitness-program-for-climate-protection-sluggards/

LEGISLATIVE CONTEXT – CO2 regulation. Europe vs. RoW



On the issues of environmental protection, perhaps, a global mentality is needed…

LEGISLATIVE CONTEXT – Why only Tank-to-Wheel ? Why not TLCA ?



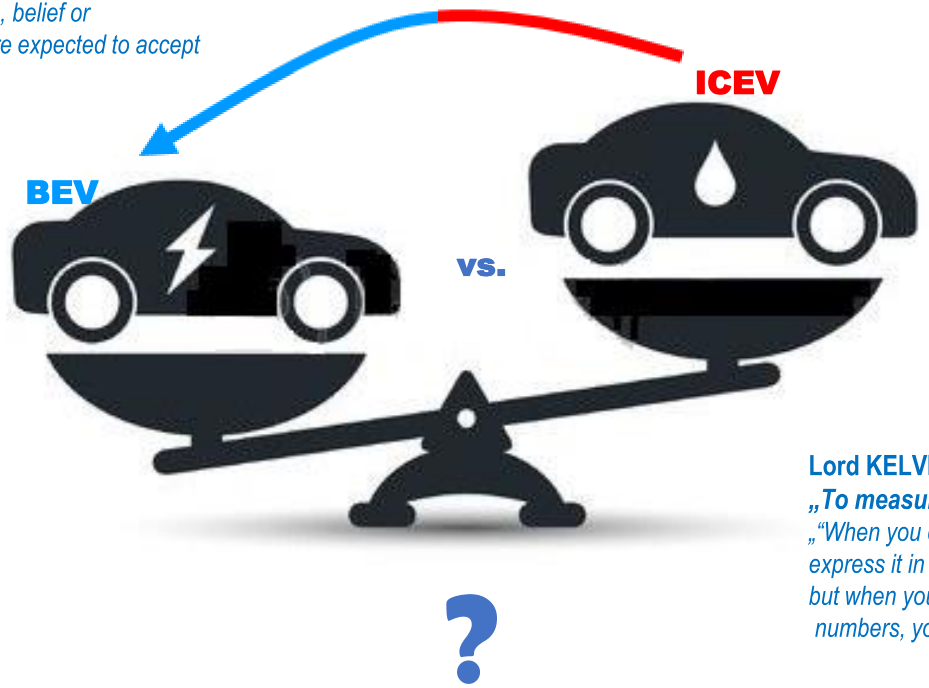
Source:
https://www.netzerowatch.com/new-study-large-co2-emissions-from-batteries-of-electric-cars/

*« 150-200 Kg eq. CO_2/KWh » → **175 Kg eq. CO_2/KWh** x 60 KWh = 10.5 t eq. CO_2*

*Hypothesis: iso-emissions of CO_2 in production (**with the exception** of battery manufacturing)*

LEGISLATIVE CONTEXT – All in favor of BEV (?)

According to Cambridge Dictionary,
*„**Dogma** = a fixed, especially religious, belief or set of beliefs that people are expected to accept without any doubts"*



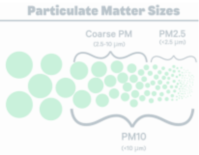
Lord KELVIN:
„To measure is to know"
„"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

LEGISLATIVE CONTEXT – All in favour of BEV (?)

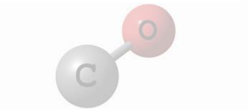
BUT, yet, WHY? Why ONLY about Tank-to-Wheel and ONLY about CO_2?

- Quantification of **pollutant emissions** associated to electric energy production for **BEV** ?
- Quantification of **pollutant emissions** associated to **BEV** manufacturing ?
- Quantification of **pollutant emissions** associated to **BEV** decommissioning/recyling ?

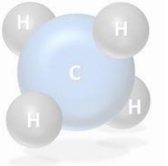
From
Tank-to-Wheel
through
Well-to-Wheel
to
Total Life Cycle Assessment / From Cradle-to-Grave



PM, PN



CO



CH_4, NMHC, H_xC_y

Sustainable Mobility

STRUCTURE OF THE PRESENTATION

- INTRODUCTION
- LEGISLATIVE CONTEXT
- INTERNAL COMBUSTION ENGINE
- CONCLUSIONS

Individual road mobility

sustainable

?

INTERNAL COMBUSTION ENGINE – Chronology

1860: The 1st ICE (2 strokes without compression) – Etienne Lenoir (BELGIA)
1876 : The 1st 4 stroke SIE – Nikolaus Otto (GER) si Beau de Rochas (FRA)
1893: The 1st 4 CIE – Rudolph Diesel (GER)
1902: The 1st patent on VVA – Louis Renault (FRA)
1902: The 1st patent in mechanical charging – Louis Renault (FRA)
1905: The 1st patent on turbocharging – Buchi (Elvetia)
1943: The CR system is patented – Cummins (USA)
1957: The 1st operational prototype of rotative ICE – Felix Wankel (GER)
1967: The 1st serial application of the Wankel rotary engine – Mazda Cosmo (JAP)
1968: The 1st CIE introduced on a passenger car – Peugeot 204 (FRA)
1977: The 1st turbocharged CIE introduced on a passenger car – Mercedes 300 SD (GER)
1983: The 1st anti-pollution regulation (USA)
1986: Emergence of electronic control in the diesel engine – Bosch cu BMW524tD (GER)
1988: The 1st turbocharged CIE with direct injection on a passenger car– Fiat Croma (ITA)
1993: The introduction of **Euro I** anti-pollution regulation
1996: The 1st serial application of the GDI – Mitsubishi Carisma (JAP)
1996: The introduction of **Euro II** anti-pollution regulation
1997: The 1st serial application of the high-pressure direct injection CR system– Alfa Romeo 156 (ITA)
1999: The 1st GDI engine of an European OEM – Renault idE (FRA)
2000: The introduction of **Euro III** anti-pollution regulation
2001: The 1st throttle-less SIE – BMW Valvetronic-Vanos (GER)
2005: The introduction of **Euro IV** anti-pollution regulation

INTERNAL COMBUSTION ENGINE – Chronology

2006: The 1st serial SIE fuelled either with $\mathbf{H_2}$ or with gasoline (bivalent engine) – BMW **Hydrogen** 7 (V12, 6000 cm^3, 13.9 l gasoline/100 km; 50.0 l H_2/100 km; 100 models produced)

2007: The 1st serial application of CIE featuring a specific power greater than 100 CP/l: BMW N47, 1995 cm^3, **102 hp/l**, double turbocharging, sfc_{min} = 204 g/KWh

2009: The introduction of **Euro V** anti-pollution regulation

2012: Mazda SKYACTIV: a new generation of SIE and CIE, Euro VI, both characterized by an identical value of compression ratio (**ε = 14**)

2012: The 1st CIE featuring triple turbocharging : BMW N57S, 2993 cm^3, **127 hp/l**

2015: The introduction of **Euro VI** anti-pollution regulation

2015: VW « **Dieselgate** » in S.U.A. + UE : **the beginning of ICE's decline** ☹

2016: The 1st CIE featuring 4 turbochargers : BMW N57S, 2993cm^3, **135 hp/l,** 760 Nm@(2000-3000) rpm

2017: The 1st large series SIE equipped with a VNT (VW 1.5 TSI **Miller cycle**)

2017: Introduction of the **RDE** in the type-approval tests (In-Service Conformity with **PEMS**)

2018: Homologation via **WLTP (+ RDE)** – i.e., giving up to NEDC

2019: The 1st serial application of a **VCR SIE**, **ε = 8 – 14**, (VC-Turbo) – Nissan (JAP)

2020: The 1st commercial gasoline engine to use compression ignition – SPark Controlled Compression Ignition (SPCCI), (Mazda Skyactive-X, **ε = 16.3**, **λ = 1.0 –1.9**)

2027(?): The introduction of **Euro VII** anti-pollution regulation (not earlier than 2027…maybe 2029?)

2035: **EUROPE: abandoning the ICEV (?) …with the except of e-fuels powered ICEV**

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

Stakes ?

1. **CO_2** emission (GHG) → **the most challenging !**
2. Quality of the atmosphere (**pollution**)

} → **health issues/risks**

Sustainable mobility: Efficient and ecologic ICE + Ecologic fuels

- Improvement of ICE energetic and ecologic performance → “how-to-burn” a fuel
- Use of fuels with ecologic potential → “what-to-burn”
- Exhaust aftertreatment system → “EATS”
- Electrification of propulsion/hybridization → “HEV”

How ?

- Improvement of ICE energetic and ecologic performance → "how-to-burn" a fuel

Global warming theory (1896) by Svante Arhenius (Nobel prize for chemistry in 1903):

if ↑ CO_2 then ↑ Greenhouse effect => ↑ Earth temperature => **Global warming**

The theory of maximization of energetic efficiency (1824) by Sadi Carnot:

if ↑ T_{HS} then ↑η_{td} & ↓ CO_2

$$\nearrow \eta_{td_{Carnot}} = 1 - \frac{T_{HS}}{\nearrow T_{CS}}$$

NO_x production theory by Svante Arhenius:

if ↑ T_{HS} then ↑NO_x (exponentially) => **↑ Pollution**

$$\nearrow W_{NO_x} = A \cdot e^{-\frac{B}{T\nearrow}}$$

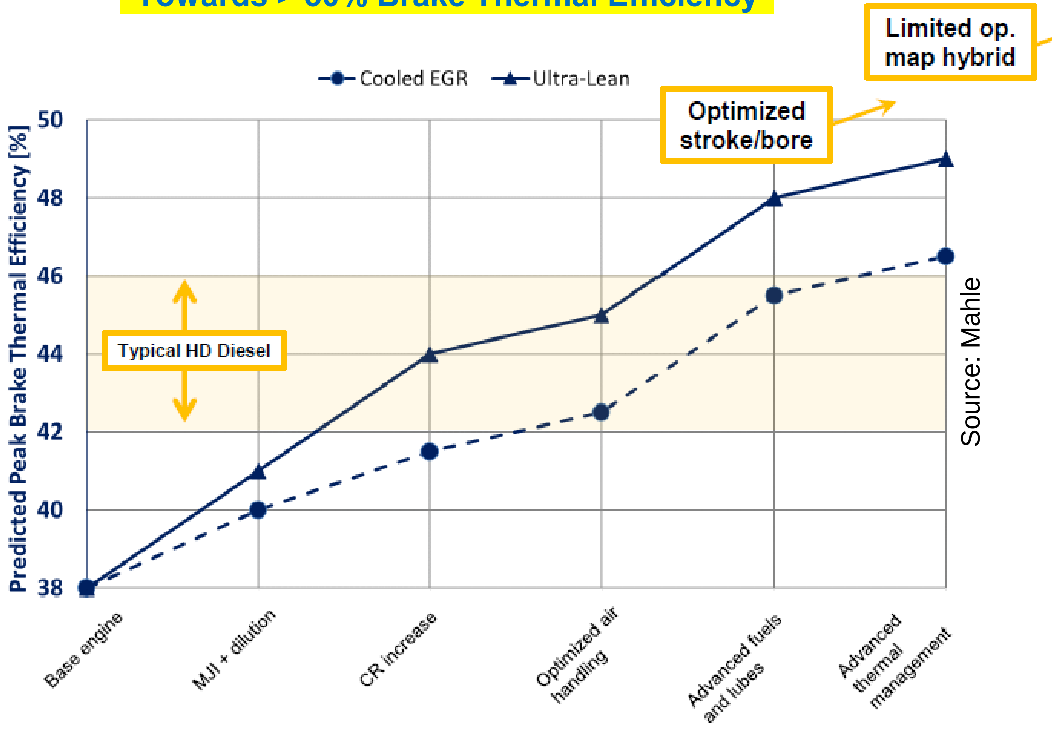
HARDSHIP → TRADE-OFF / COMPROMISE

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Improvement of ICE energetic and ecologic performance → "how-to-burn" a fuel

"Towards > 50% Brake Thermal Efficiency"



DHE / Serial Hybrid
Sinergy with electrification of propulsion

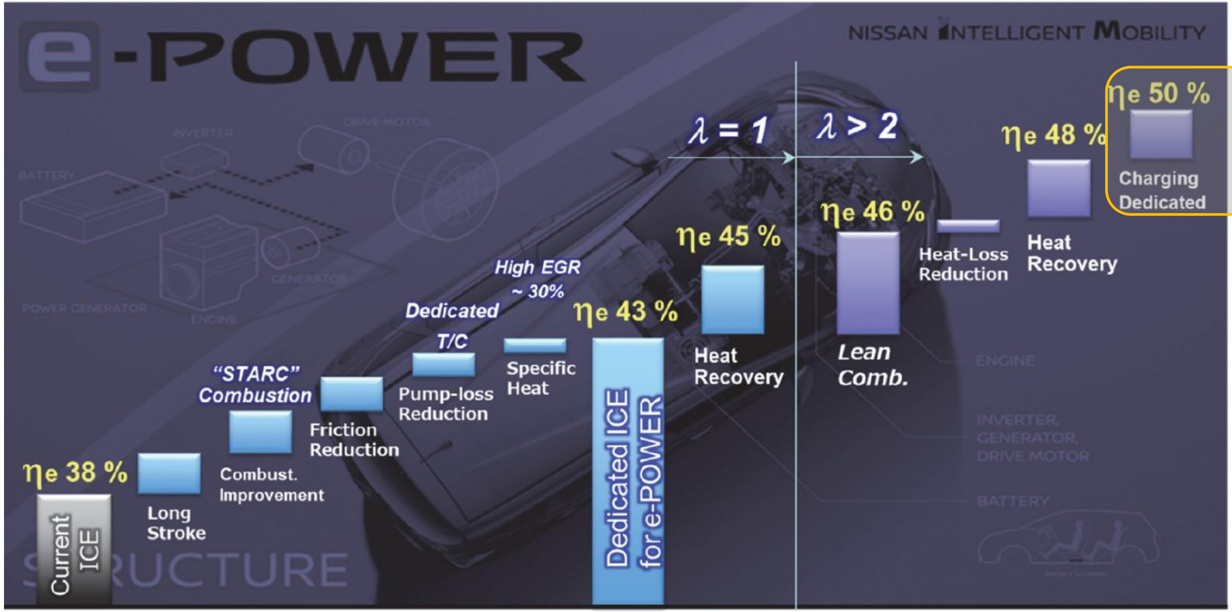
INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Improvement of ICE energetic and ecologic performance → “how-to-burn” a fuel

“Towards > 50% Brake Thermal Efficiency”

Brake Thermal Efficiency, η_e



η_e 50 %

Charging Dedicated

DHE / Serial hybrid

Sinergy with electrification of propulsion

How ?

- Use of fuels with ecologic potential → "what-to-burn" → Low-carbon fuels

Theoretical complete combustion reaction (stoichiometric combustion):

$$C_aH_bO_c + \left(a + \frac{b}{4} - \frac{c}{2}\right)(O_2 + 3{,}76N_2) \rightarrow aCO_2 + \frac{b}{2}H_2O + \left(a + \frac{b}{4} - \frac{c}{2}\right)3{,}76N_2$$

$$\frac{m_{CO2}}{m_{fuel}} = \frac{(12 + 2 \cdot 16) \cdot a}{(12 \cdot a + 1 \cdot b + 16 \cdot c)} = \frac{44}{12 + \frac{b}{a} + 16 \cdot \frac{c}{a}} = \frac{44}{12 + \frac{H}{C} + 16 \cdot \frac{O}{C}}$$

$$\searrow m_{CO2} = \searrow m_{fuel} \cdot \frac{44}{12 + \frac{H}{C} \nearrow + 16 \cdot \frac{O}{C}}$$

- 1 kg C_8H_{18} (~ gasoline) → 3.64 kg CO_2
- 1 kg C_4H_{10} (~ LPG) → 3.03 kg CO_2 (- 16.7% CO_2)
- 1 kg CH_4 (~ CNG/LNG) → 2.75 kg CO_2 (- 24.4% CO_2)
- 1 kg H_2 → 0 kg CO_2 ≡ - 100% CO_2

$$\nearrow \eta_{PWT} = \eta_{ICE} \cdot \eta_{EM} \cdot \eta_T$$

- → Electrification of propulsion/hybridization → "HEV"
- → Improvement of ICE energetic and ecologic performance → "how-to-burn" a fuel

SOCIETY OF AUTOMOTIVE ENGINEERS OF ROMANIA
SIAR
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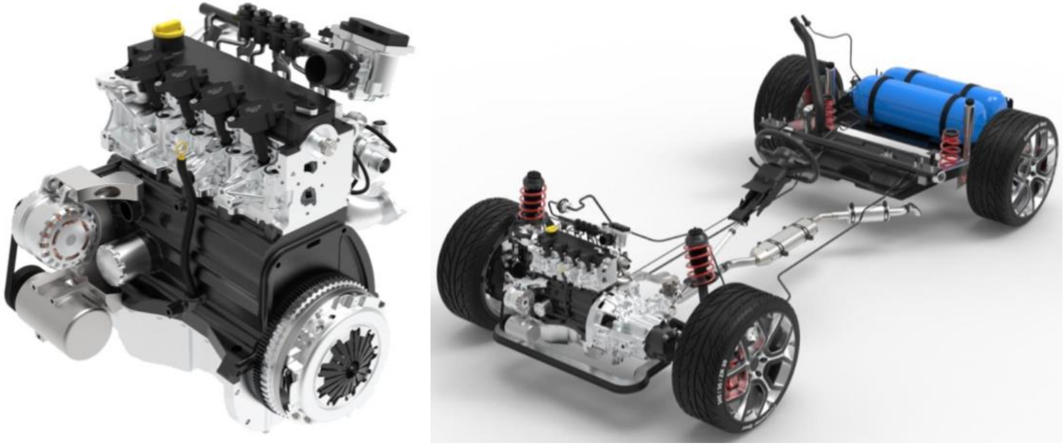
INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

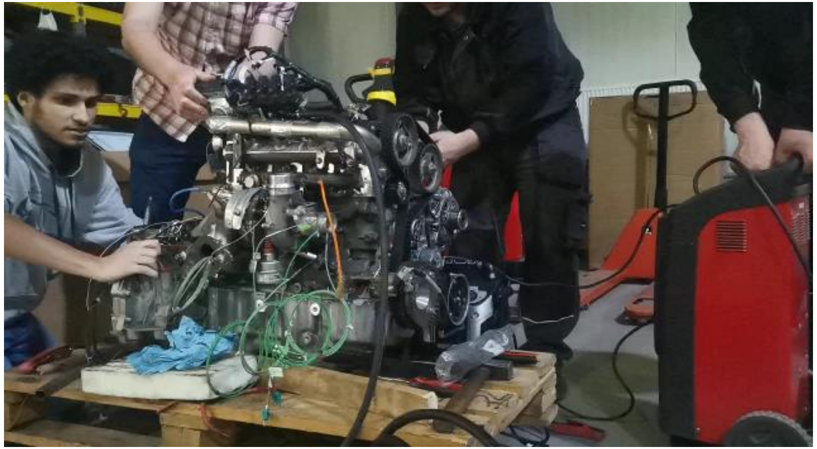
- Use of fuels with ecologic potential → "what-to-burn" → Low-carbon fuels

Sustainable Road Mobility with **Methane Gas** @ University Centre of Pitești (**UNSTPB**), **FEV** ECE Romania and **RTR**

by A. Clenci, R. Niculescu, M. Năstase, V. Iorga, Gh. Leasu (**UNSTPB**), J. Berquez, E. Peillon (**FEV**), N. Boicea, PhD. R. Popa (**RTR**)



Digital twins of the CNG fuelled SI engine and chassis - prototypes



First successful firing of the CNG fuelled SI engine prototype on 21st of April 2021

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

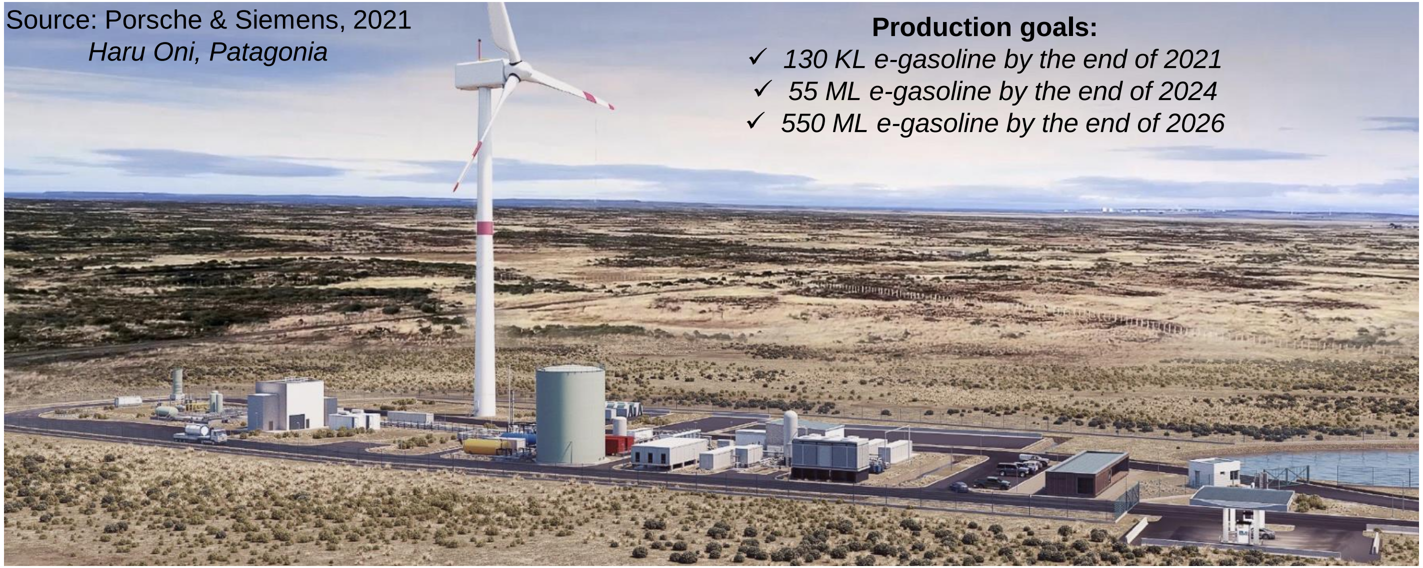
How ?

- Use of fuels with ecologic potential → “what-to-burn” → Biofuels & Synthetic fuels

2^{nd} & 3^{rd} gen. biofuels

e-fuels

- ✓ Rapid decarbonization (CCU)
- ✓ Energy independence
- ✓ Use of existing infrastructure
- ✓ No more range anxiety



Source: Porsche & Siemens, 2021
Haru Oni, Patagonia

Production goals:

- ✓ *130 KL e-gasoline by the end of 2021*
- ✓ *55 ML e-gasoline by the end of 2024*
- ✓ *550 ML e-gasoline by the end of 2026*

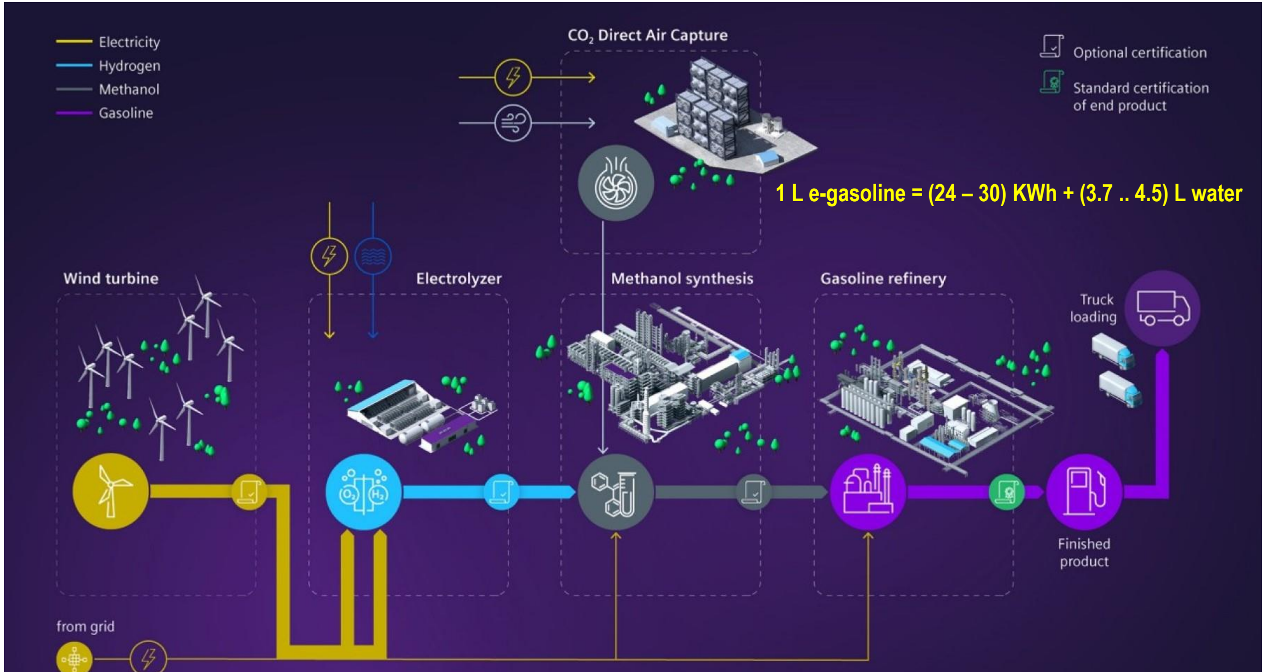
IEA (International Energy Agency):
Worldwide demand of gasoline in **2026** → 25 M barrel/day ⇔ 1.450.875 ML/year (1 barrel = 159 Liters)
⇒ total replacement of **fossil gasoline with e-gasoline** = **2.638 identical Porsche plants**!!

Franz **Fischer** & Hans **Tropsch** inventors of **F-T** synthesis (1925) – BTL, used to fuel the war machine of Germany in the 2^{nd} WW

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Use of fuels with ecologic potential → "what-to-burn" → Biofuels & Synthetic fuels



Source: Porsche & Siemens & ExxonMobil, 2021

2^{nd} & 3^{rd} gen. biofuels

e-fuels

- ✓ Rapid decarbonization (CCU)
- ✓ Energy independence
- ✓ Use of existing infrastructure
- ✓ No more range anxiety

η_{wind} = 40 %, η_{sun} = 15 %

$\eta_{H2\ via\ AWE}$ = (60-70) %, $\eta_{H2\ via\ PEM}$ = (80-85) %

(7.5 .. 11) L H_2O + (46 .. 70) KWh = 1 Kg H_2

$\eta_{H2 \rightarrow CH3OH}$ = 67 % …

!! Low efficiency !!

Well-to-Wheel assessment:

ICEV 5 L e-gasoline/100 Km = **135 KWh**

FCEV Toyota Mirai : **72 KWh**

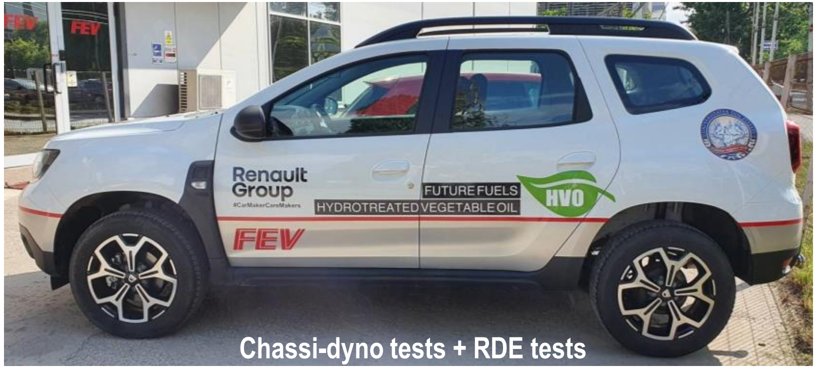
BEV = **22 KWh**

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- **Use of fuels with ecologic potential** → “what-to-burn” → Biofuels & Synthetic fuels

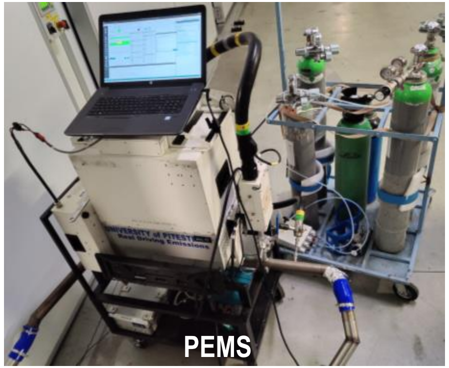
The effect of **HVO** using in diesel-powered vehicle @ University Centre of Pitești (**UNSTPB**), **FEV** ECE Romania and **RTR**
by A. Clenci, R. Niculescu, M. Năstase, PhD M. Oprea (**UNSTPB**), R. Bercu, J. Berquez (**FEV**), N. Boicea, G. Voicu, Al. Ciucă (**RTR**)



Chassi-dyno tests + RDE tests

Cold starting @ -20°C

Cold starting @ -20°C


PEMS

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- **Exhaust after-treatment system** → **"EATS"**

Complying with **EURO 7**:

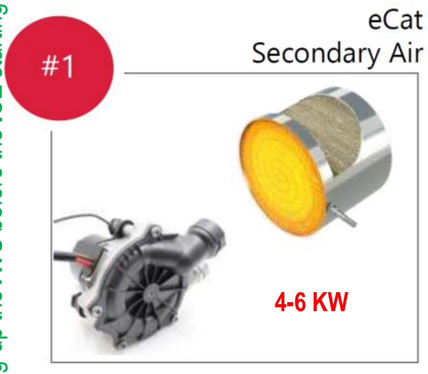
➢ *Increase size of **EATS** (**+50%**) + **OBM** (Emissions On-Board Monitoring)*

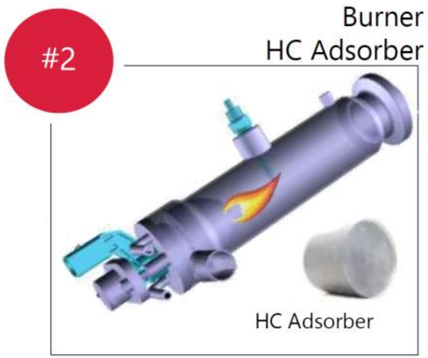
The biggest challenge at **(P)HEV-MAS** to comply with **EURO 7**:

➢ *Fast **TWC light-off** after a cold starting*

➢ *avoiding **TWC** cooling: « Transition from EV drive to engine assist with cold EATS can lead to **"hybrid cough"** » - **Mahle***

EURO 7 vs. **EURO 6**
Heating time of **TWC** must be halved
Heating-up the **ATS** before the **ICE** starting





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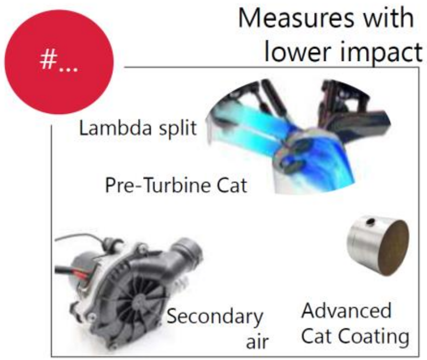


Source: FEV

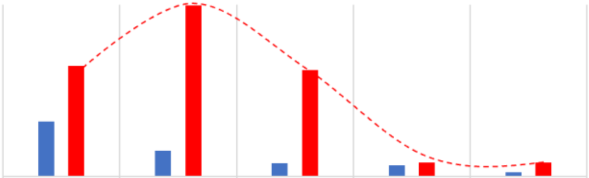
→ • **Improvement of ICE ecologic performance** → **"EATS"**

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Exhaust after-treatment system → "EATS"

Complying with EURO 7 via using an **afterburner** @ University Centre of Pitești (**UNSTPB**)
by A. Clenci, B. Cioc, V. Iorga, R. Niculescu, C. Zaharia, Gh. Leasu, PhD. R. Stoica (**UNSTPB**)



	IN_preTWC	MID_preTWC	IN_mainTWC	MID_mainTWC	OUT_mainTWC
without burner	228	106	56	47	18
with burner	458	708	440	59	58

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

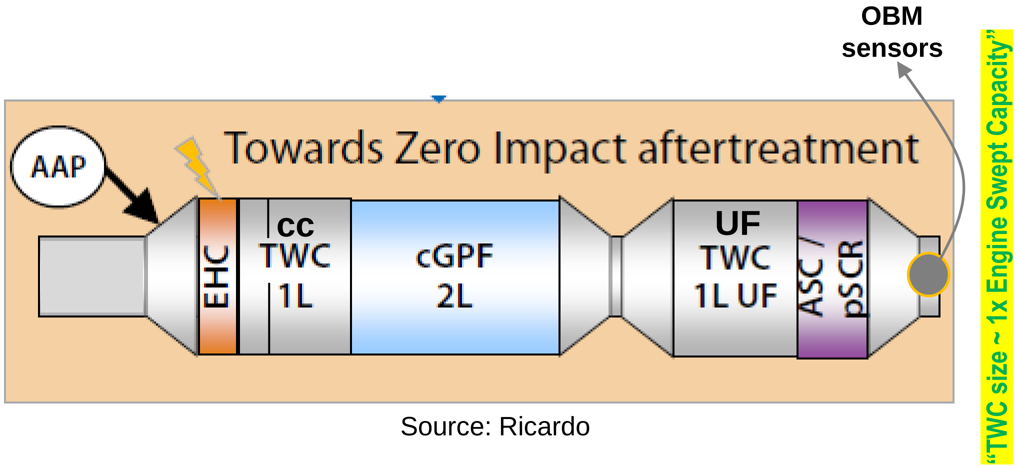
How ?

- **Exhaust after-treatment system** → **"EATS"**

Comply with **EURO 7**:

➢ *example of **EATS** → „**SIE** with **near-zero impact**"*

AAP: Auxiliary Air Pump (EATS pre-heating)
EHC: Electrically Heated Catalyst
ccTWC: closed-coupled Three-Way Catalyst
cGPF: coated Gasoline Particulate Filter
UF-TWC: underfloor Three-Way Catalyst
ASC: Ammonia Slip Catalyst
pSCR: passive Selective Catalyst Reduction
OBM: On-Board Monitoring
CF: Conformity Factor (RDE/EUx limit)



Source: Ricardo

- **CF_{NOX} = 0.02, i.e., 1.17 mg/km** ⟶
- **Improvement of SIE ecologic performance** → **"Near-Zero Impact EATS"**

Source: AVL

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

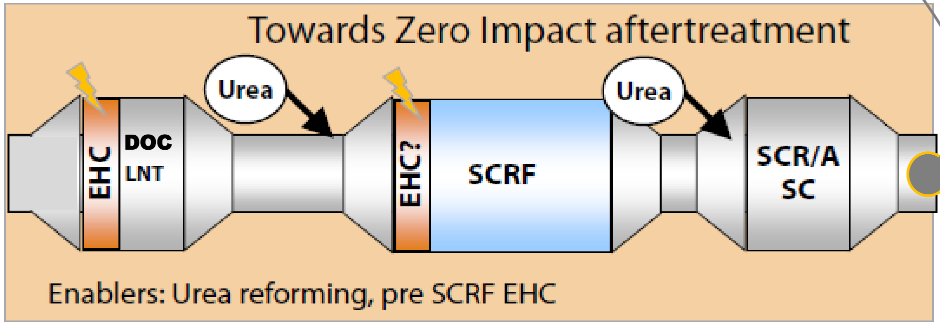
- **Exhaust after-treatment system** → **"EATS"**

Comply with **EURO 7**:

➢ *example of **EATS** → „**CIE** with **near-zero impact**"*

EHC: Electrically Heated Catalyst
DOC: Diesel Oxidation Catalyst
LNT: Lean NO_x Trap
SCRF: Selective Catalyst Reduction + Diesel Particulate Filter
SCR: active Selective Catalyst Reduction
ASC: Ammonia Slip Catalyst
OBM: On-Board Monitoring

OBM sensors



Source: Ricardo

"EHC position depends on warm-up req. (incl. shortest urban RDE distance req.)"

- **CF_{NOX} = 0.125, i.e., <10 mg/km** ⟶ • **Improvement of CIE ecologic performance** → **"Near-Zero Impact EATS"**

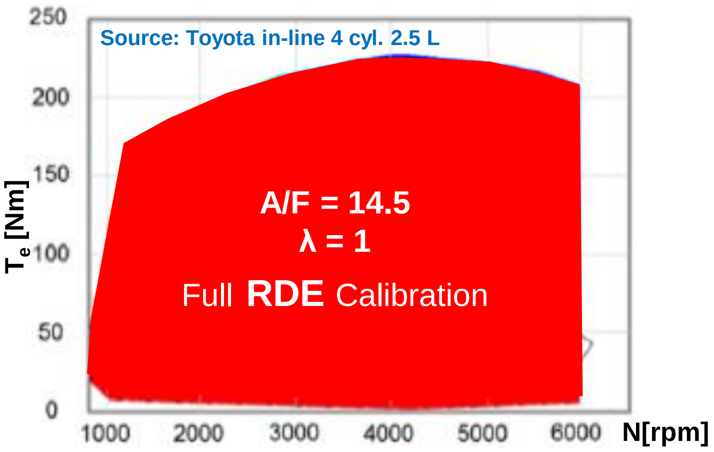
Source: FEV

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Exhaust after-treatment system → "EATS"

The consequence of **RDE** (**R**eal **D**riving **E**missions) introduction @ **SIE** : **λ = 1** on all operating area



Open loop operation

if $\boldsymbol{\lambda < 1} \Rightarrow$ *then* $\boldsymbol{T_{exhaust}} \downarrow$ *and* **knock mitigation** $\Rightarrow$ **Performance** ↑

but $\boldsymbol{\eta_{TWC}} \downarrow \Rightarrow$ ***EURO 7 Failure***

Exhaust protection and increased performance but on the expense of depollution (η_{TWC} ↓)

Closed loop operation

if $\lambda = 1 \pm 0.02$ *then* $\eta_{TWC} = max.(99\%) \Leftrightarrow$ ***maximum depollution!!***

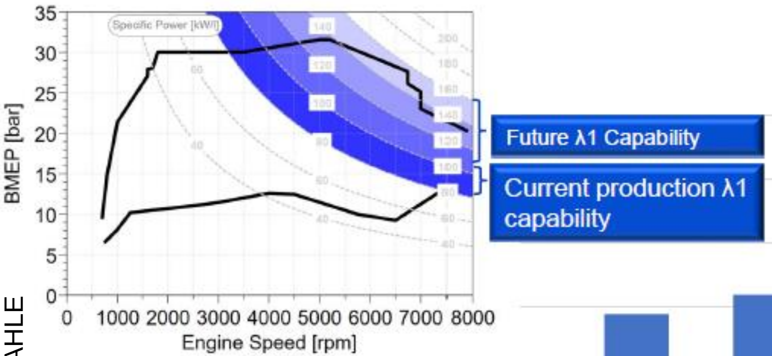
- Electrification of propulsion/hybridization ← "HEV"

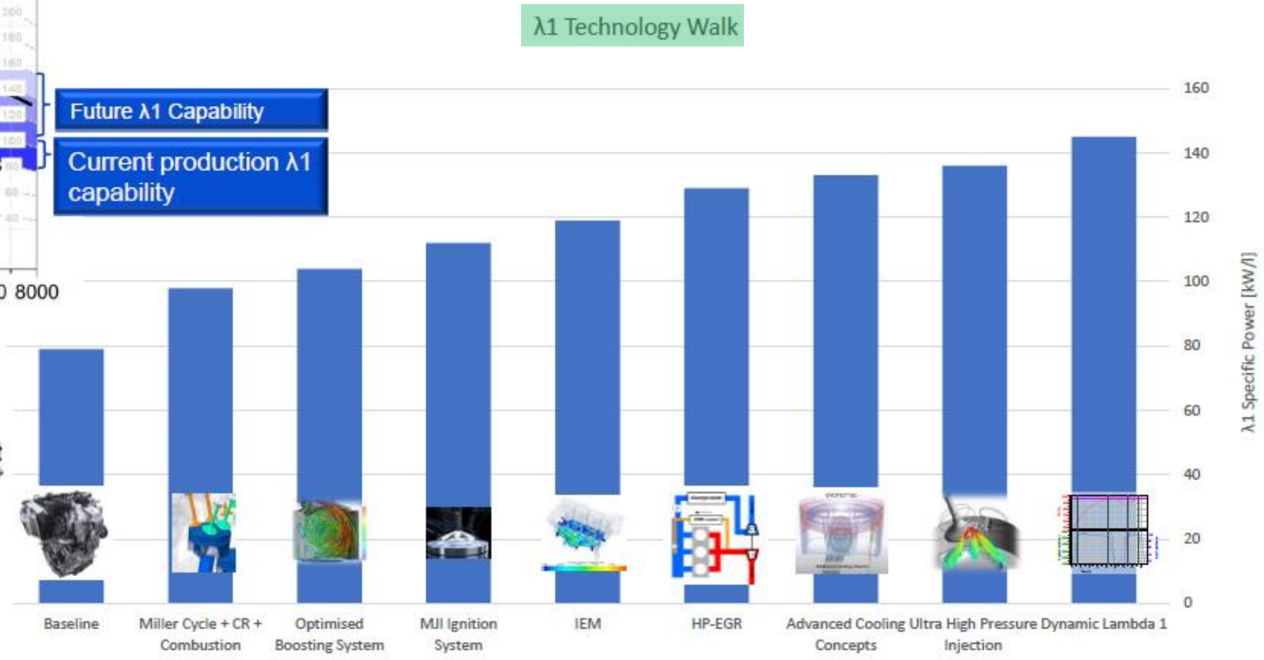
‼ Intense acceleration <u>without enriching</u> ⇒ cooled EGR HP & LP, VCR, Miller cycle, eTC, water injection (WPI), cooled compressor, integrated exhaust manifold, …

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Exhaust after-treatment system → "EATS"



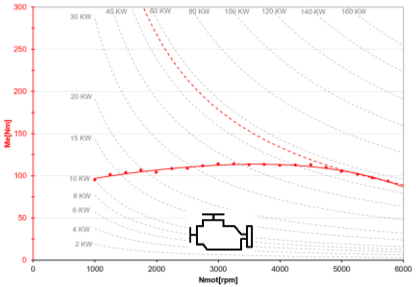


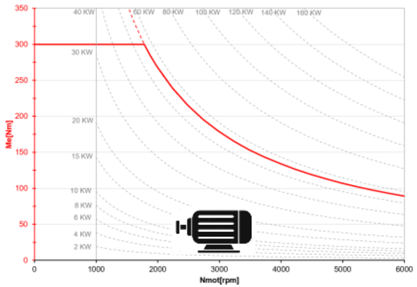
Source: MAHLE

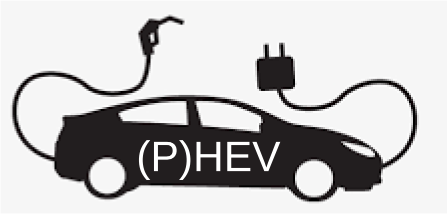
INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

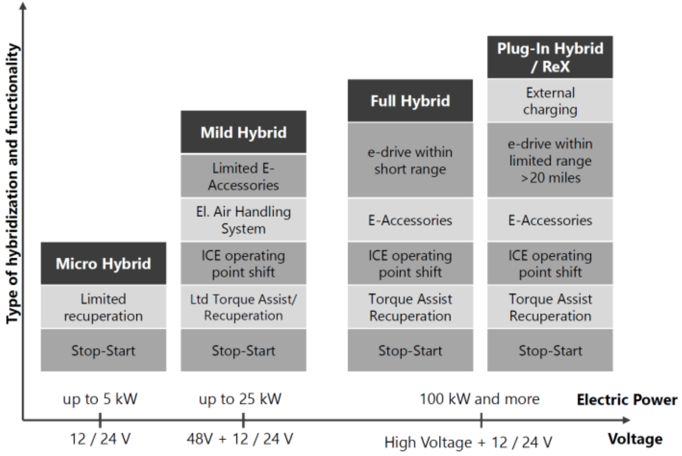
How ?

- Electrification of propulsion/hybridization → “HEV (Hybrid Electric Vehicles)”







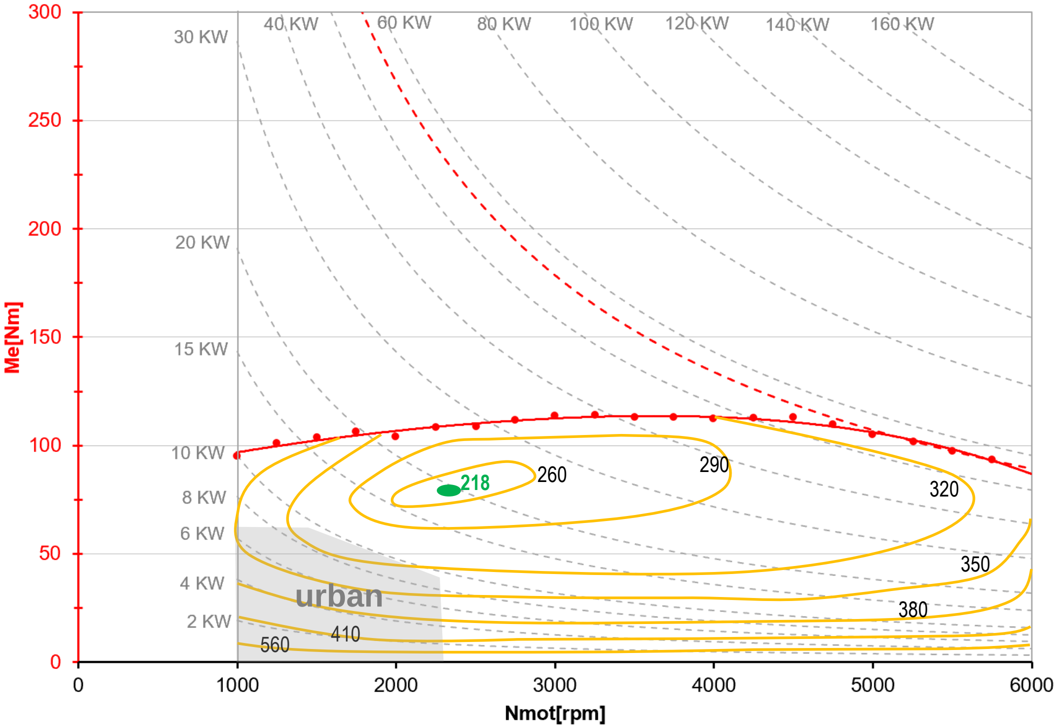


Source: FEV

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Electrification of propulsion/hybridization → "HEV (Hybrid Electric Vehicles)"



- **ICEV**
- NA SIE 1.4 L
- $P_{e\ max}$ = 56 KW

sfc_{min} = 218 g/kWh

⇩

BTE = η_{e_max} = 38%

sfc_{max} > 560 g/kWh

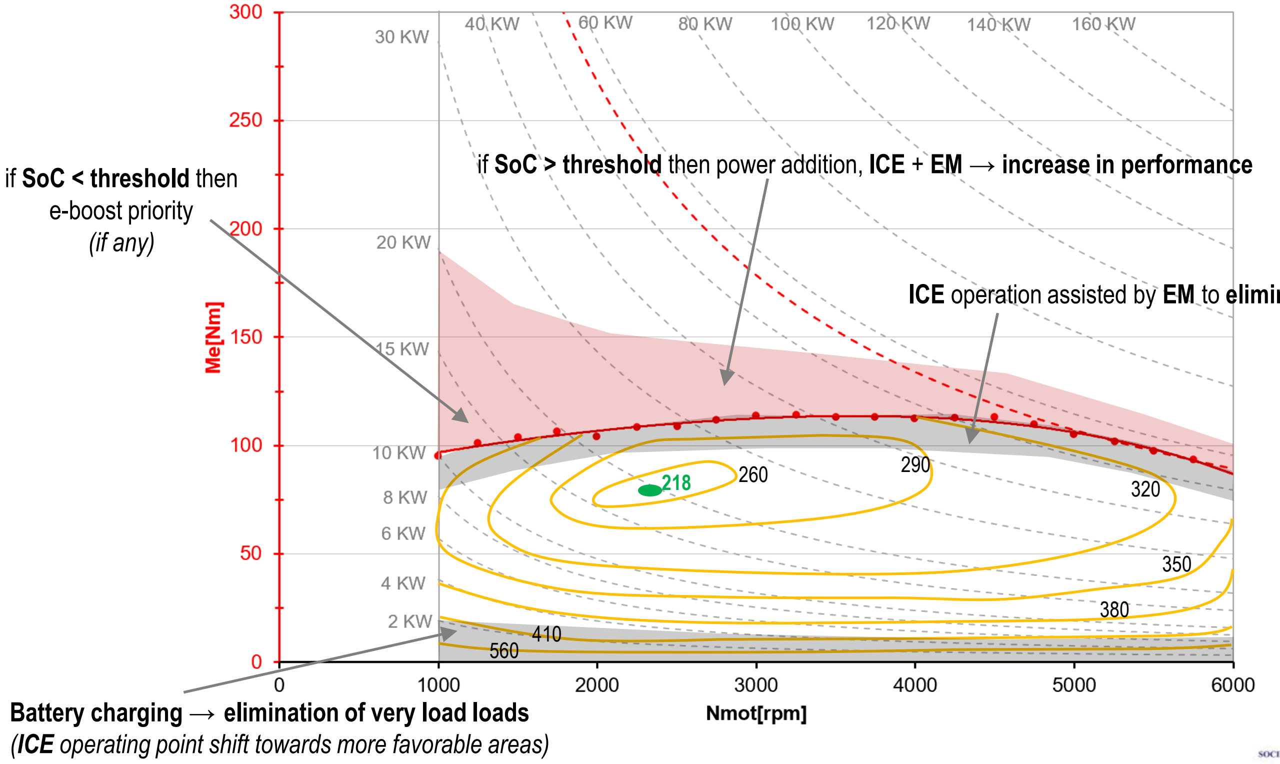
⇩

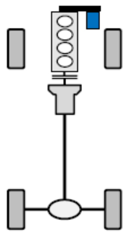
BTE = η_{e_min} < 15%

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Electrification of propulsion/hybridization → “HEV (Hybrid Electric Vehicles)”





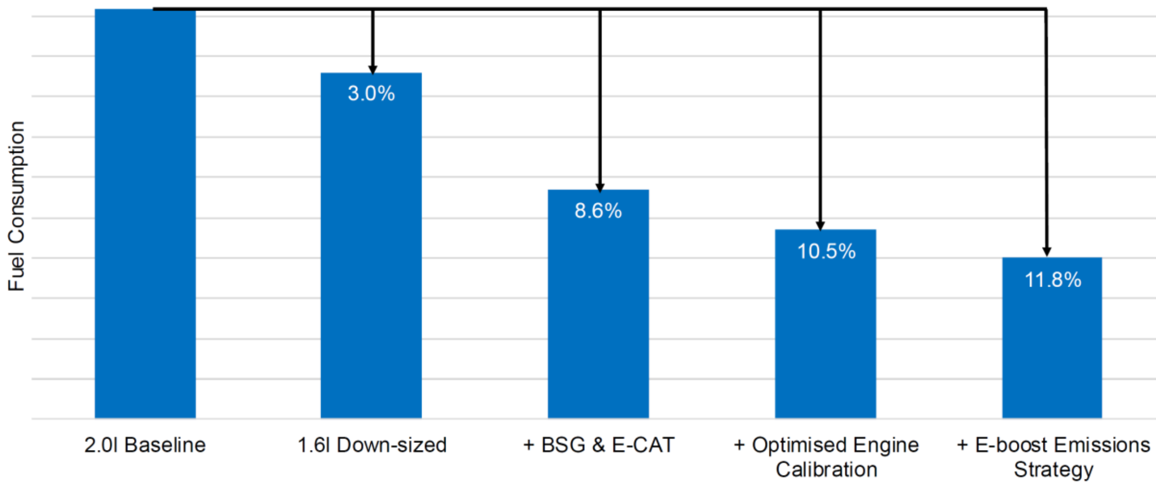
- **P0** hybrid architecture
- ME = **10 KW** (for instance)
- NA SIE 1.4 L

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- **Electrification of propulsion/hybridization** → **"HEV (Hybrid Electric Vehicles)"**

48V P0 Diesel Hybrid Passenger Car + E-boost
Source: Ricardo



BSG = Belt-Starter Generator = MicroHEV
E-CAT = Electrically Heated Catalyst for faster light-off
E-boost = electric assistance of the turbocharger in the transient Phases to maintain vehicle drivability

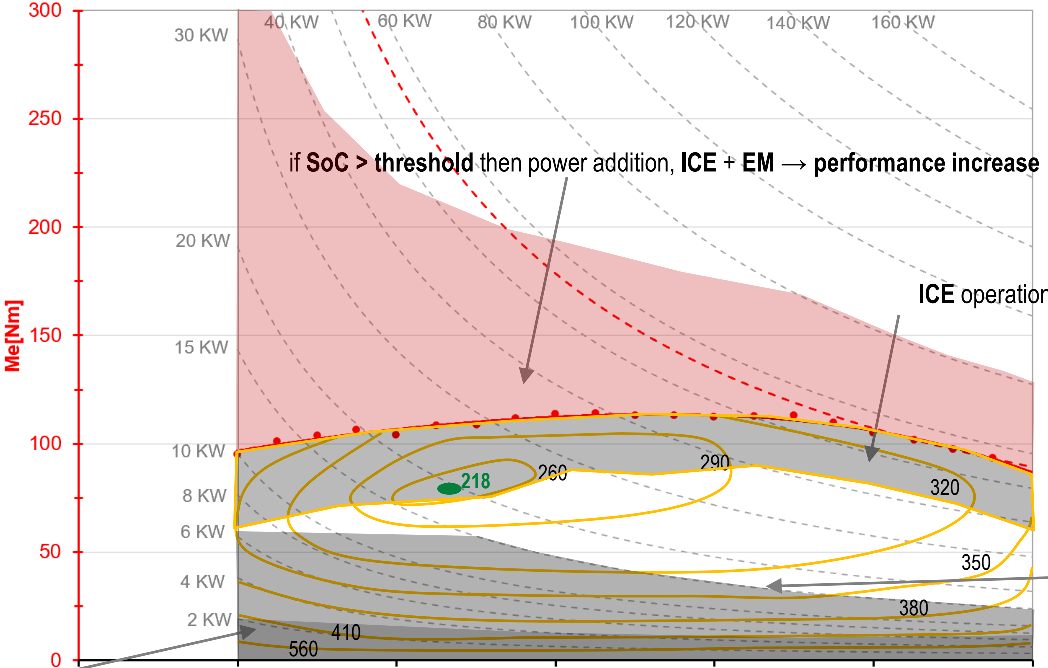
*if **Tip-in** then ↑ **smoke***
*if **EGR OFF** then **smoke** ↓ **but** NO_x ↑*
*if **E-boost ON** then* $t_{EGR\ OFF}$ ↓

EM may assist **ICE** to compensate the **downsizing** but puts much more strain on the battery than the **E-boost** → **SoC** ↓

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- **Electrification of propulsion/hybridization** → "HEV (Hybrid Electric Vehicles)"



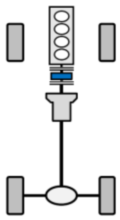
if **SoC > threshold** then power addition, **ICE** + **EM** → **performance increase**

ICE operation assisted by **EM** to **eliminate the high loads**

if **SoC > threshold** then operation in **PEV / ICE OFF** = **ZEV**

Battery charging → elimination of very low loads

*(**ICE** operating point shift towards more favorable areas)*

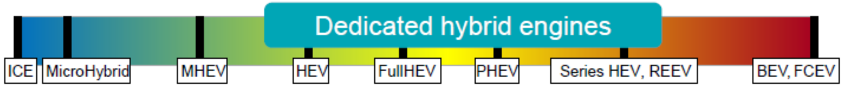


- **P2 hybrid architecture**
- EM = **25 KW** (for instance)
- NA SIE 1.4 L

INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

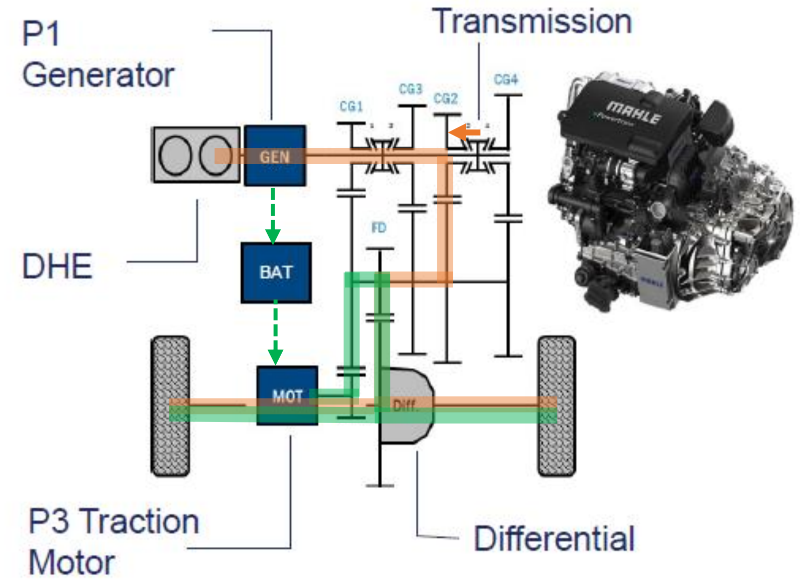
How?

- **Electrification of propulsion/hybridization** → **"HEV" via "DHE" + "DHT"**



Dedicated Hybrid Engine (DHE) + Dedicated Hybrid Transmission (DHT)

Source: Mahle



DHE:

- Very limited/narrow operating area
  (within the area of high values of BTE)

DHT:

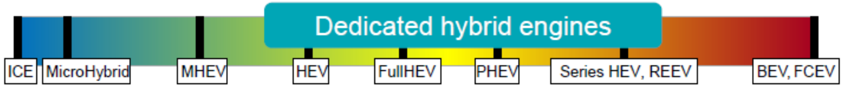
- AMT; 1/2/4 gears w/o clutch; NEUTRAL is decoupling the **DHE**
- Electric generator mounted at the entrance to the transmission
- Allows direct drive in pure electric mode, i.e., **BEV/PEV/ZEV**

BEV/ZEV:	**DHT** in NEUTRAL
Series HEV:	**DHT** in NEUTRAL → **DHE** = **Range-Extender**
Parallel HEV:	**DHE** assists the **EM**

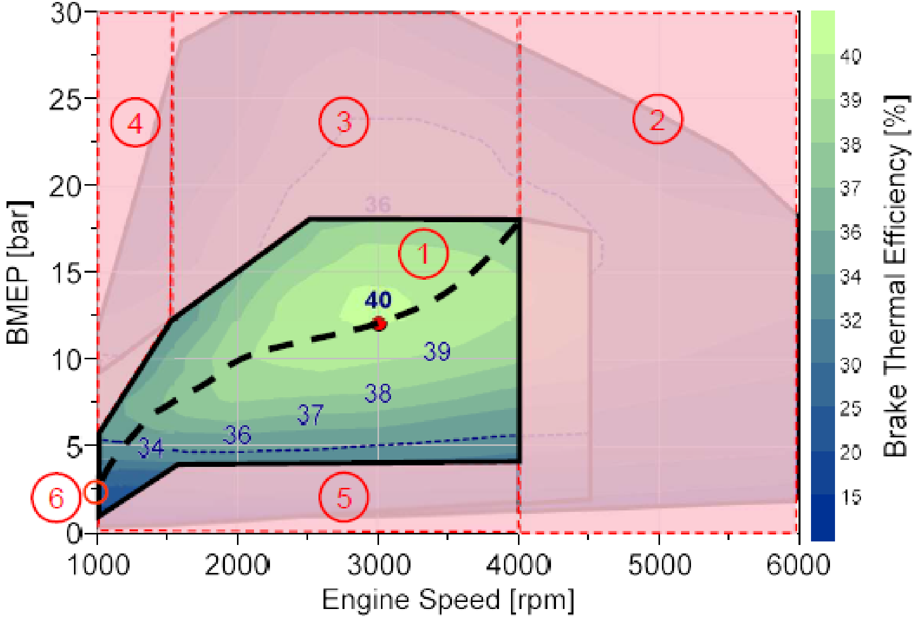
Mahle: *"Dual mode hybrid – best of **Parallel** and **Series** hybrids plus direct **eDrive** for seamless torque delivery"*

How?

- **Electrification of propulsion/hybridization** → **"HEV" via "DHE" (Dedicated Hybrid Engine)**



Dedicated Hybrid Engine (DHE)
Source: Mahle



Specifications DHE:

- ✓ 2 or 3 cylinders, fixed valve actuation
- ✓ Port-Fuel Injection (**PFI**), λ = 1 on all operating map + **MJI**®
- ✓ 950°C max. upstream the turbine
- ✓ Miller cycle + VCR + EGR
- ✓ SOHC + 2 valves/cyl.
- ✓ Reduced complexity
- ✓ Optimized for hybrid operation

Particularities:

1. Power control in a small area characterized by high efficiency
2. N_{max} ↓ ⇒ NVH
3. Maximum load ↓ ⇒ Higher torque@low rpm no longer needed ⇒ NOx ↓ + NVH
4. Reduced area of N_{min} ↓ ⇒ no idling
5. Elimination of low loads ⇒ no idling
6. TWC heating-up

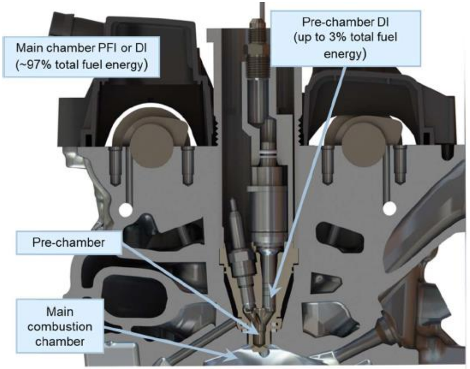
How?

- **Electrification of propulsion/hybridization** → **“HEV” via “DHE” (Dedicated Hybrid Engine)**

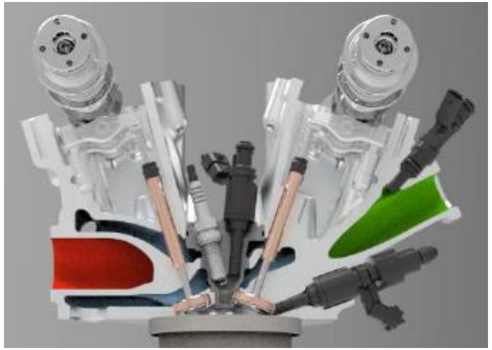
Passive **Mahle** Jet Ignition (MJI®)

(finalized development)

Active **Mahle** Jet Ignition (MJI®)



Ricardo Magma xEV



(in development)

Allows the increasing of the lean limit → $\lambda > 2 \Rightarrow \varepsilon \rightarrow 17 \Rightarrow$ ***$\eta_e > 42\%$***

Max(NO_x) & Min(PN@23nm) @ $\lambda = 1.2$

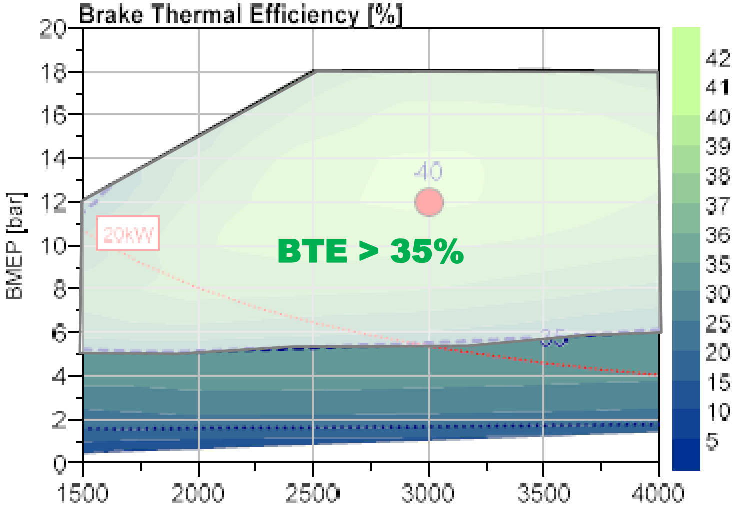
NO_x @ $\lambda = 2 = 50$ ppm !!

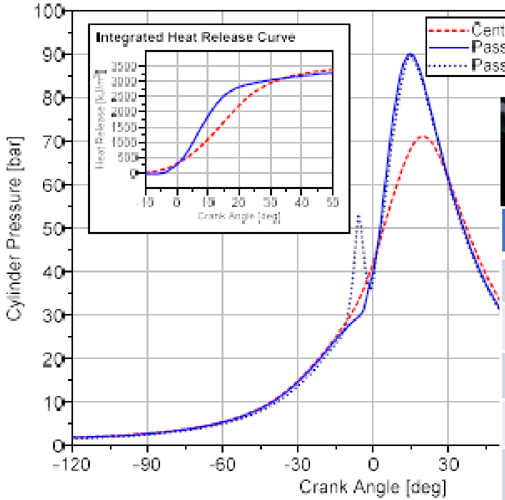
How?

- **Electrification of propulsion/hybridisation** → **"HEV" via "DHE" (Dedicated Hybrid Engine)**

Dedicated Hybrid Engine: Passive **Mahle** Jet Ignition (MJI®) – Passive pre-chamber

Source: Mahle





	CSP	MJI
MBF50[⁰RAC]	17.4	8.6
MBF(10-90) [⁰RAC]	25.9	15.4
p_{max}[bar]	71.2	90.9
R_{max}[bar/⁰RAC]	1.98	5.2
CoV_{NMEP}[%]	2.54	0.85

Results DHE MJI®:

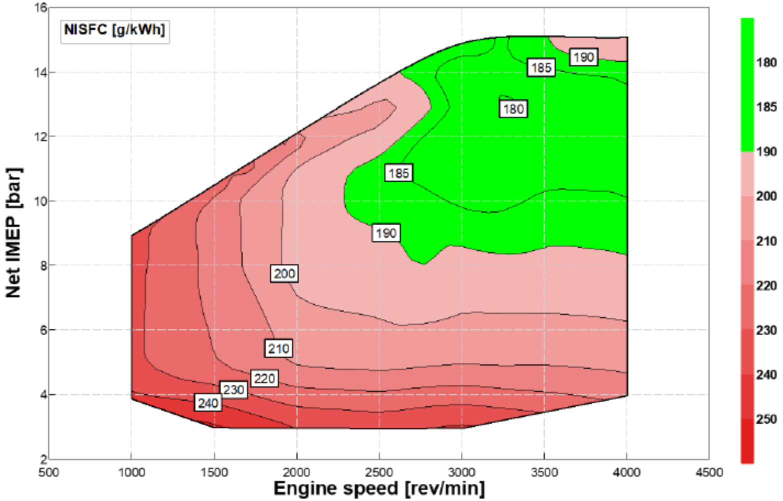
✓ Combustion stability ↑ +DoC ↓ + Reducing the knocking trend → ε ↑ ⇒ η_e **> 40%** & (+ **25 KW/l**) @ λ = 1 with low costs

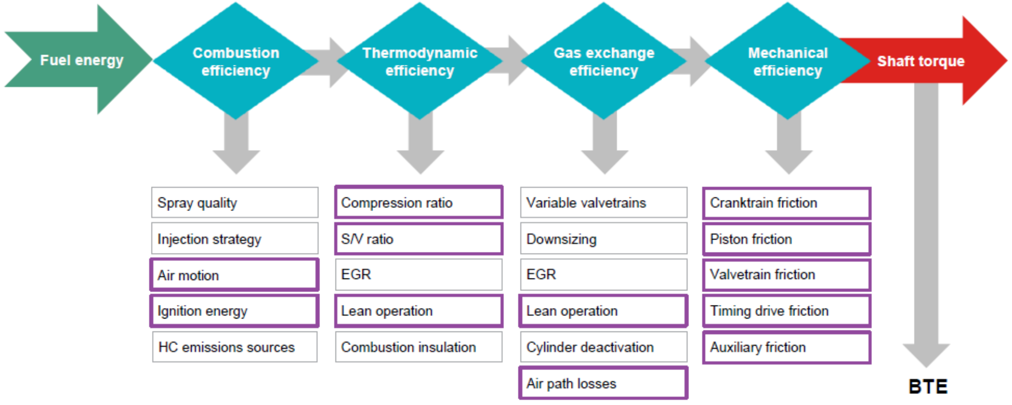
INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How?

- Electrification of propulsion/hybridization → “HEV” via “DHE” (Dedicated Hybrid Engine)

Dedicated Hybrid Engine: Magma xEV Passive & Active pre-chamber
Source: Ricardo





	Combustion efficiency	Thermodynamic efficiency	Gas exchange efficiency	Mechanical efficiency	BTE
Leading TGDI	97%	43%	98%	96%	39%
MagmaxEV Pre-chamber	96%	**51%**	97%	95%	**45.4%**

Particularities DHE Magma xEV Passive pre-chamber:

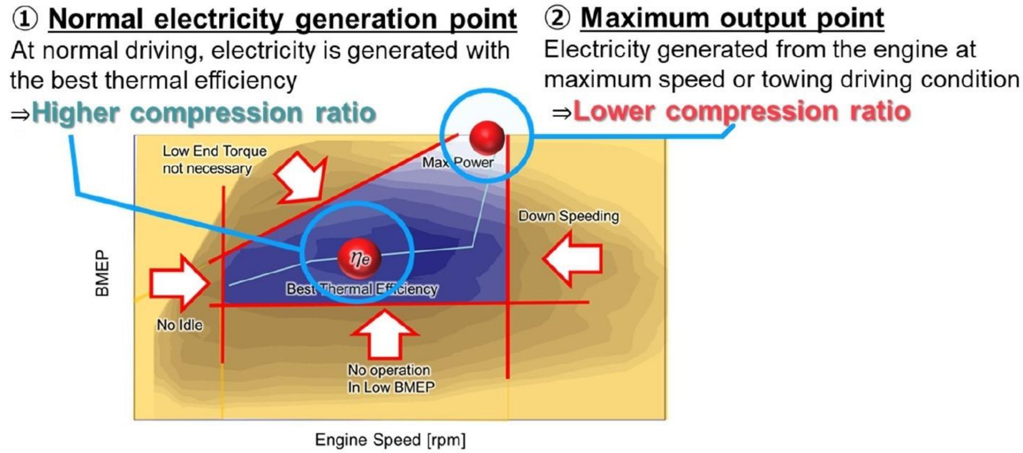
✓ D = 76.5 mm, S = 109 mm ⇒ **S/D = 1.42**, **ε =17**, RON = 95, **λ = 1.8**, Miller EIVC ⇒ **η = 45.4%**

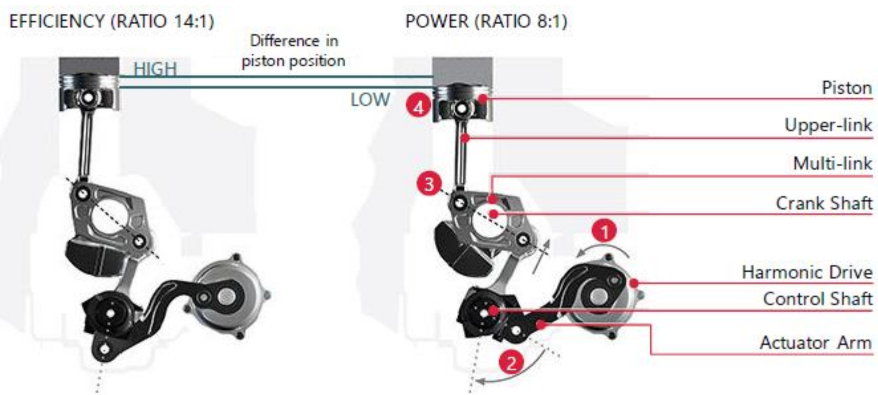
How?

- **Electrification of propulsion/hybridization** → **"HEV" via "DHE" (Dedicated Hybrid Engine)**

Dedicated Hybrid Engine: Nissan e-Power **VC-T** (**V**ariable **C**ompression – **T**urbocharged)

Source: Nissan





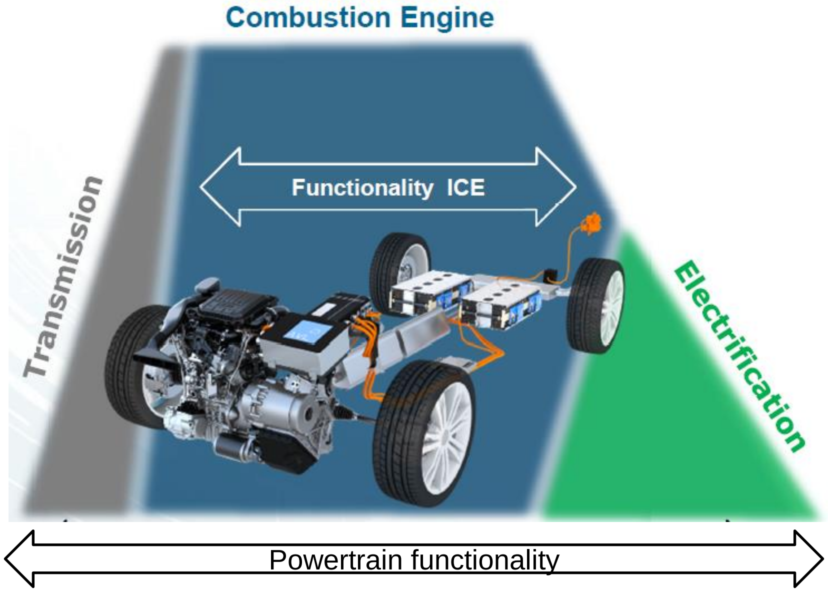
INTERNAL COMBUSTION ENGINE – Solution for sustainable road mobility

How ?

- Electrification of propulsion/hybridisation → "HEV" via "DHE" (Dedicated Hybrid Engine)

"From Fully Flexible ICE to… Fully Flexible POWERTRAIN"

Source: AVL



How ?

- Electrification of propulsion/hybridization → the disappearance of some ICE technologies

- ❑ Displacement on Demand (DoD) : except for the temperature rise in the EATS + CO_2 ↓
- ❑ Continuous Variable Valve Lift (CVVL)
- ❑ Combined fuel injection, PFI (Port-Fuel Injection) & DI (Direct Injection) : except for the MJI®
- ❑ Mechanical drive of accessories (water pump, air conditioning compressor)

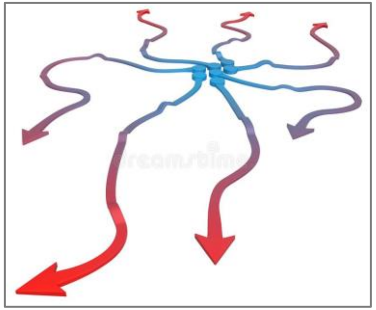
(PFI&GDI), DoD, CVVL, ViVL, Valvetronic, VVA…

SOCIETY OF AUTOMOTIVE ENGINEERS OF ROMANIA
SIAR
SOCIETATEA INGINERILOR DE AUTOMOBILE DIN ROMANIA

STRUCTURE OF THE PRESENTATION

- INTRODUCTION
- LEGISLATIVE CONTEXT
- INTERNAL COMBUSTION ENGINE
- CONCLUSIONS

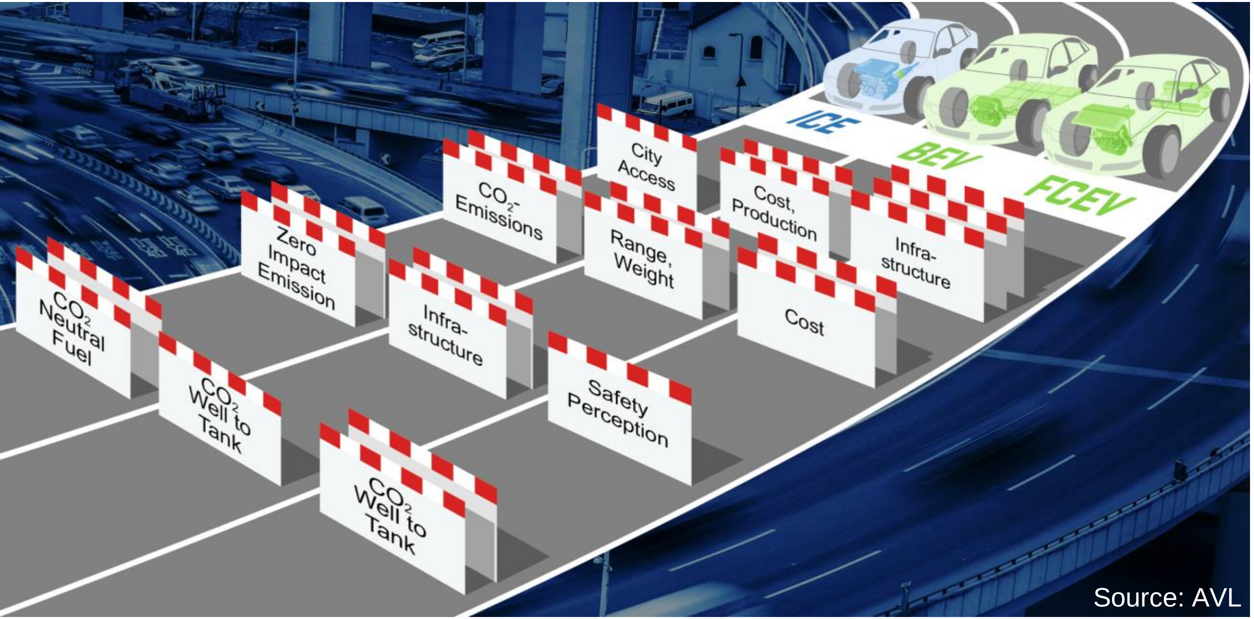
One future



Many routes

!

CONCLUSIONS – One future, many solutions



Dogma vs. Science

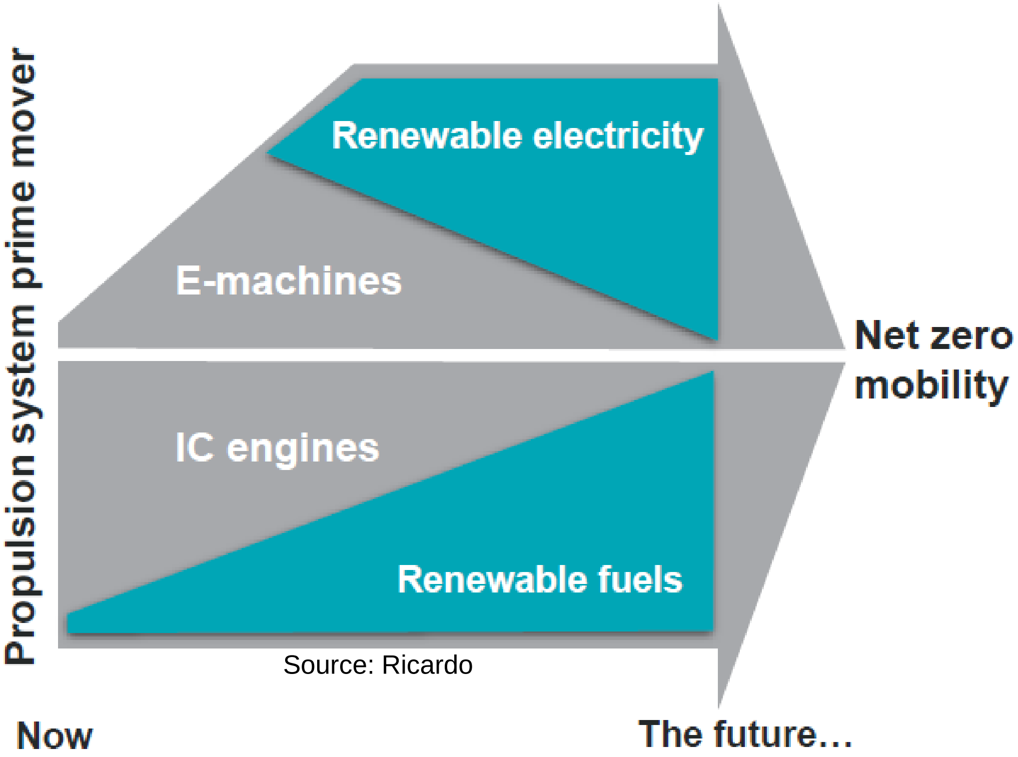
~~ICEV vs. BEV vs. FCEV~~

ICEV & BEV & FCEV

HEV

- different constraints…
- one future/goal:
  - **Zero global net** emission
  - **Sustainable** and **affordable** mobility

CONCLUSIONS – One future, many solutions



Source: Ricardo

Renewable electric energy

ICEV & BEV & FCEV

HEV

- different constraints…
- one future/goal:
  - **Zero global net** emission
  - **Sustainable** and **affordable** mobility

CONCLUSIONS – One future, many solutions

ICEV & BEV & FCEV

HEV

- different constraints…
- one future/goal:
  - **Zero global net** emission
  - **Sustainable** and **affordable** mobility

CONCLUSIONS – One future, many solutions

Individual road mobility (i.e., the passenger car) and sustainability: can they co-exist?

in urban and peri-urban areas

change of m i n d s e t

Public transport
Small BEVs
Car-sharing, Car-pooling
Bicycle with or without electric assistance (on dedicated ways)
Walking

Ultra-clean and efficient ICEVs especially for long distances

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One future, many routes…

…to reach global net zero emissions