RESEARCH & DEVELOPMENT for Energy & Internal Combustion ENGINES

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Thesis 00

Sustainable Mobility by use of H_2-fueled ICE

Milestones on the R&D path to VCSR ICE

Theses on sustainable mobility & sustainable energy system transition against global warming

→

An Alternative to Fuel Cells (FC) Electrical Vehicles (EV) (FCEV) and pure Battery EV (BEV) that is equally efficient, fully recyclable, inexpensive and significantly more reliable.

Updated on Dec. 2024

Why this presentation

How we should do it?

Friday for Future statement (FfF) to 5. "We profoundly appreciate all efforts to find solutions to the climate crisis. FfF does not have the capacity or the competence to evaluate solutions. If you have a solution, we therefore urge you to send your contribution to those who do, so that it can be put to use." On the other side, FfF has right with its mocking statement: Bla, Bla, Bla … about the actions and efforts of the Politic, Industry & Economy so far!

I believe that **together we can achieve** the following goals:

1. Sustainable mobility
2. Sustainable energy transition
3. Halting global warming
4. Maintaining the current standard of living
5. Avoid overburdening future generations with excessive costs

But only if we honestly and pragmatically choose the appropriate solutions!

We can achieve these goals **together** only when:

1. We all join forces to avoid committing more climate sins or damages!
2. All discussions, evaluations, detailed planning and implementation of the appropriate actions must be done factually, **free of ideology**!
3. Nonsensical subsidies should be stopped immediately!
4. The selected measures must be thoroughly analyzed (scientifically, technically and economically) and explained in detail to the public before implementation in order to secure broad popular support!
5. The education of younger people should be broadened and improved so that they can properly assess the sustainability and impact of the proposed measures to stop global warming. Protests and bold slogans will attract attention, but they cannot stop or slow global warming.

1. How we should NOT DO it, think about poor or hasty German implementations as an example!

Many scientists claim that the main questions now are no longer:
"Are the goals sufficient?" but:
"Are we achieving these goals at all?" and,
"What are the appropriate technical and policy measures to ensure that we actually achieve them?" and,
"How can policy & industry bring this issue to the forefront the way it needs to be?"
We all don't really see/recognize that yet.
But because the science says it's possible, we're basically optimistic, just like you?

We can NOT achieve the goals outlined above:

1. When existing solutions are **ideologically** eliminated from the outset without leaving room for their future development. The know-how and technology are constantly evolving and therefore further improvements are not just possible, but even expected.

   ### Best example to 1. is Nuclear power energy:

   a) The gut feeling of Chancellor Dr. A. Merkel was sufficient for stopping and canceling it, but of course only in Germany.

   b) Dr. Angela Merkel has a doctorate in physics/chemistry, but has not been an active scientist for a long time. To remain a scientist or even a politician, it is not enough to be active for a few years; you have to deal with it every day.

   c) Thus, enormous costs were incurred due to: 1st compensation paid to the operators, 2nd unresolved radioactive waste disposal and 3rd the loss of know-how and young researchers.

   d) In other countries, many nuclear power plants continue to operate with very low CO_2 emissions and new smaller ones of the new generations are being built, which can also continue to "burn" or process the radioactive waste of the first generations, making it much less harmful. E.g. propulsion of Earth 300 Research Vessel.

2. How we should NOT DO it, assume that ICEs are harmful to the climate only because they have been running mostly on gasoline and diesel –

What about ICEs that run on Hydrogen?

We can NOT achieve the goals outlined above:

2. **When existing solutions are ideologically eliminated from the outset, even if the know-how and technology needed to develop them are already available!**

   Best example here are Internal Combustion Engines (ICEs):

   a) **The demise of ICEs pronounced by biologists, lawyers, some green activists and similar "experts" has to be firmly rejected.**

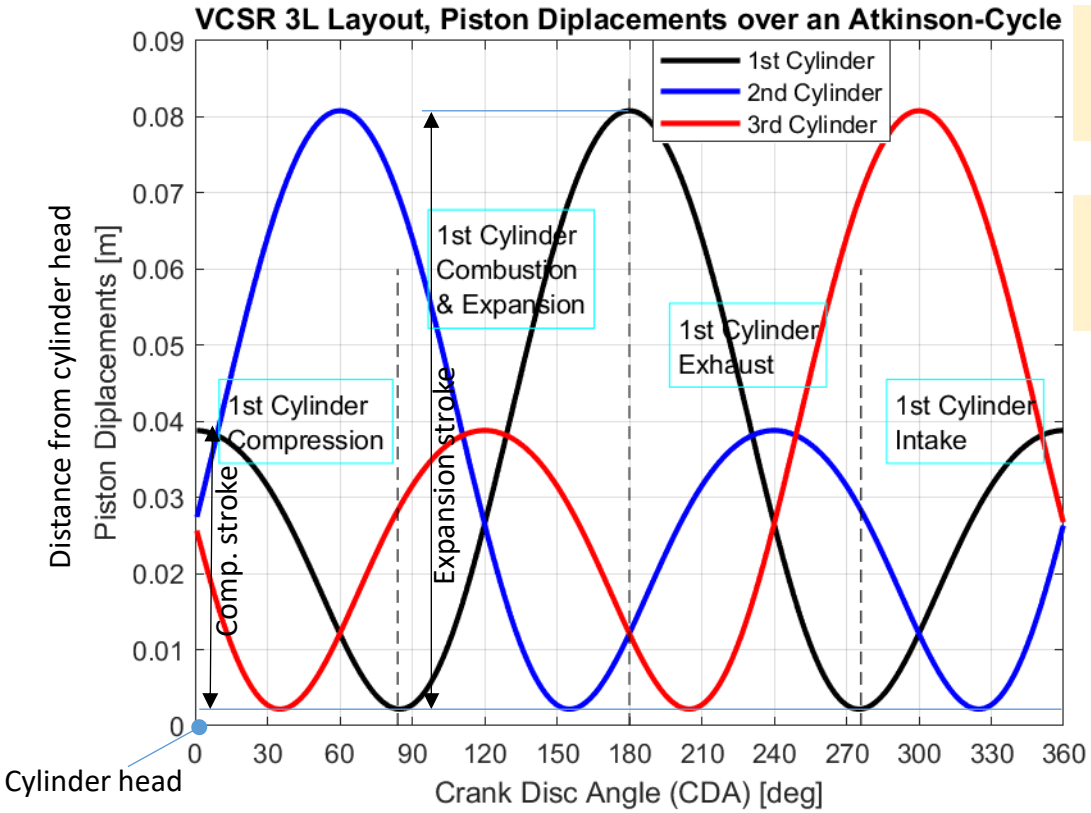
   b) **The development of ICEs and their internal processes has almost come to a standstill in the last 20 years.**

   c) **Although the legislature continued to reduce exhaust emissions, the Car Companies did not properly develop the principle construction, internal processes and control of their ICEs, but are engaged in deception and evasion. (e.g. Dieselgate, unnecessary Thermo-window, collusion on the capacity of add-blue tanks, etc., why, maybe out of vanity?!)**

   d) **The way to drastically improve ICEs and their internal processes is known as VCSR resulting in 25 to 45% efficiency improvement, presented in papers: [2015], [2021], [2024]**

VCSR means Variable Compression and Stroke Ratios

Short animations of VCSR crank mechanism in two Principle Design Variants (PDV) & cylinder arrangements:



➢ [Paper2015], [Pres2019], [Paper2021]

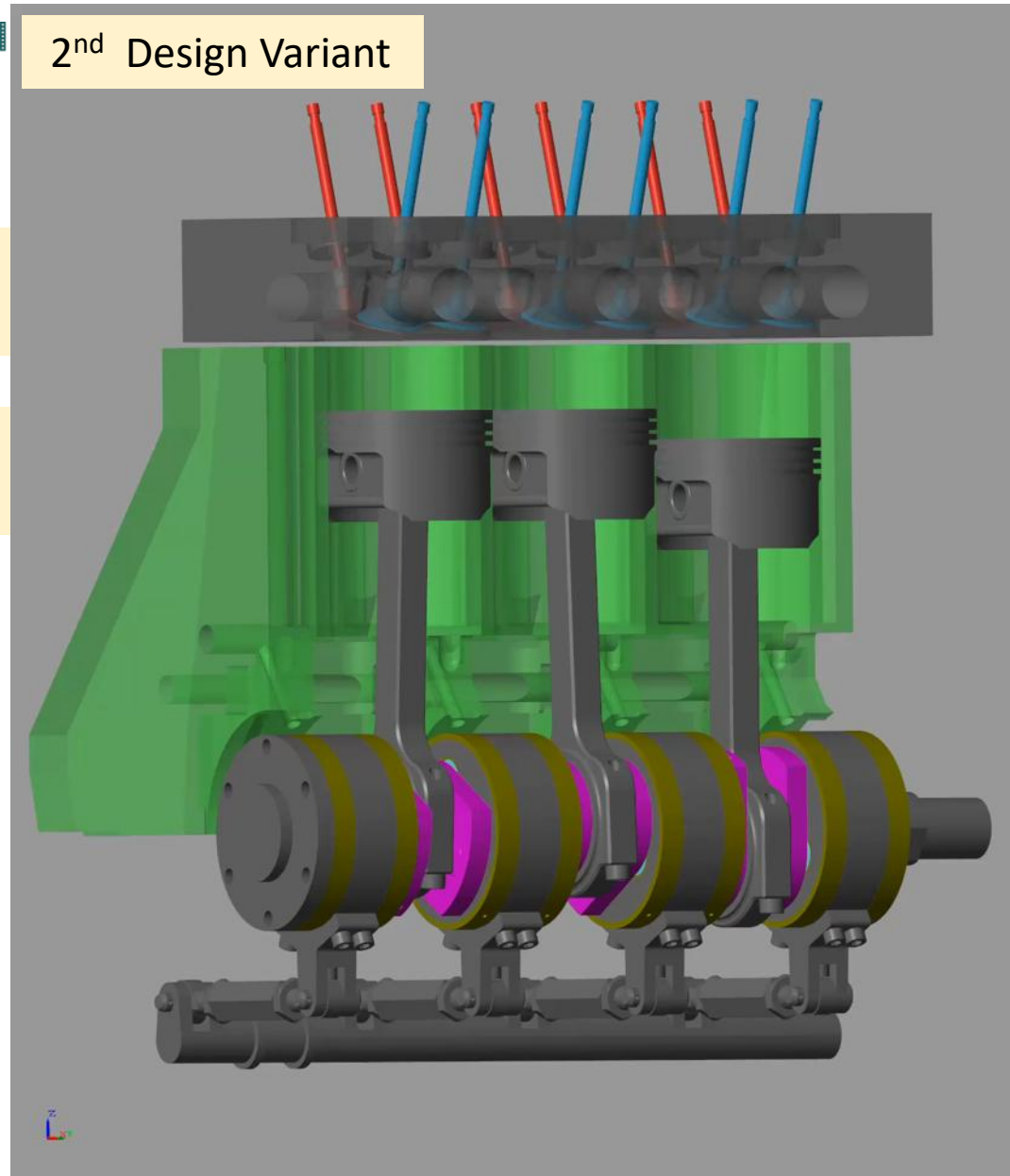
Click on icons > to play videos

2nd PDV for VCR: low, mean & high

1st PDV for VCR: low, mean & high

Due to the variable Volumetric Compression Ratio VCR, shortened compression & extended expansion strokes, the efficiency of the VCSR ICE is between 25 and 45 % higher than by the classic ICE.

3L - Cylinders arrangements, only exterior view

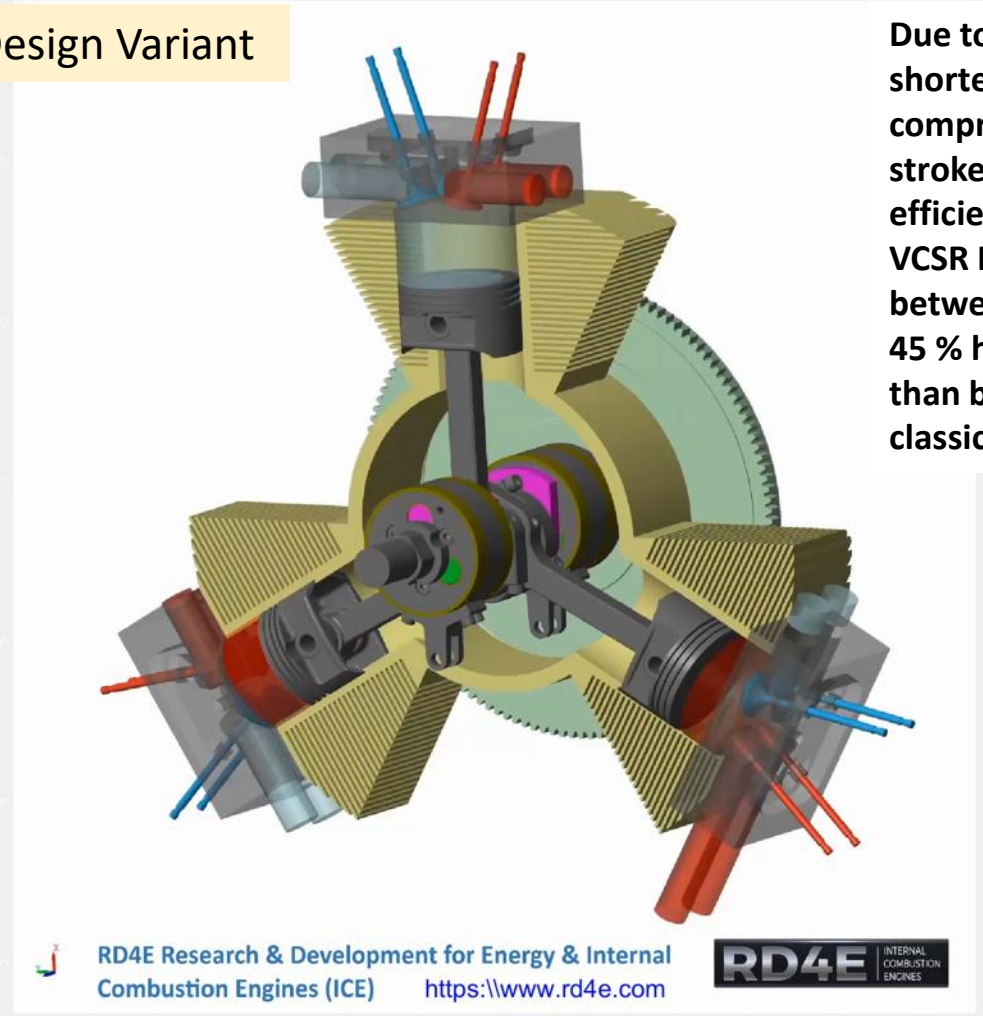


VCSR means Variable Compression and Stroke Ratios

3Y - Cylinders arrangements with exterior & interior views

Y-shaped Internal Combustion Engine (ICE) configuration in Variant 2 from DE 10 2013 003 682 B4 & EP 2 772 624 B1 Patents

2nd Design Variant

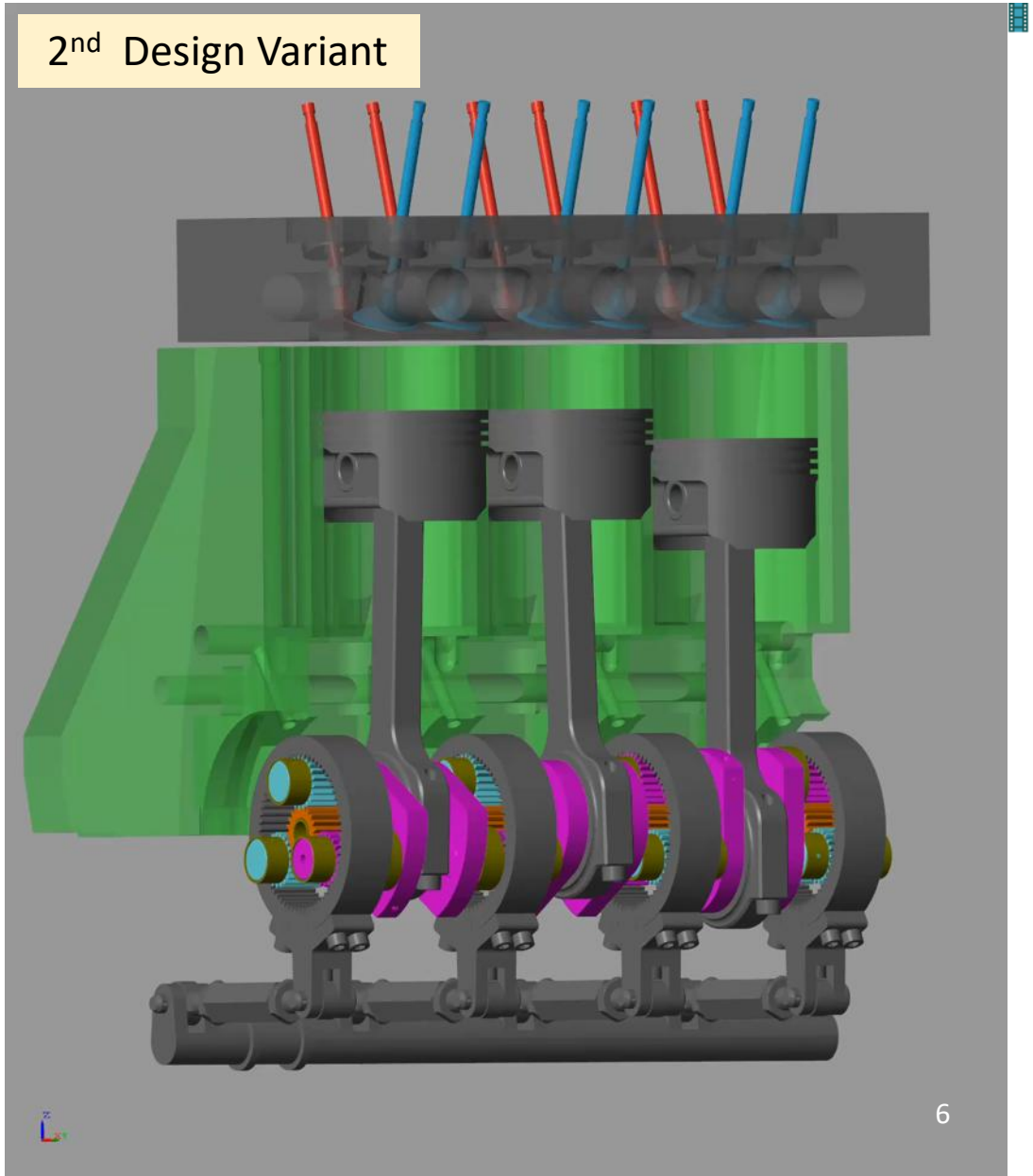


Due to the shortened compression stroke, the efficiency of VCSR ICE is between 25 and 45 % higher than by the classic ICE

- [Paper2015], [Pres2019], [Paper2021]

3L - Cylinders arrangements with interior view

2nd Design Variant



Sustainable Mobility

Applications on VCSR ICE basis

Using it in passenger cars, as a stand-alone drive, as BEV range extender or in a hybrid powertrain system s. 20

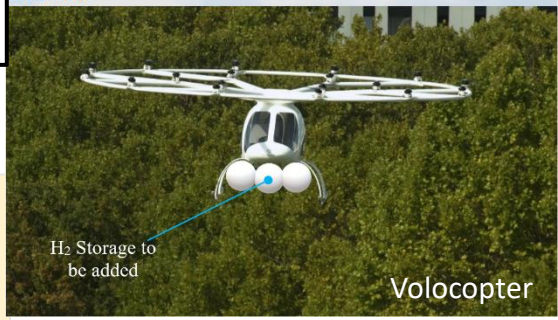


Using it in ships and in ICE Power Plants, as a stand-alone drive, or in a hybrid powertrain system



Using it in flying taxis, as a stand-alone drive, as eVTOL range extender or in a hybrid powertrain system





Using it in trucks and off-road vehicles, as a stand-alone drive, as BEV range extender or in a hybrid powertrain system

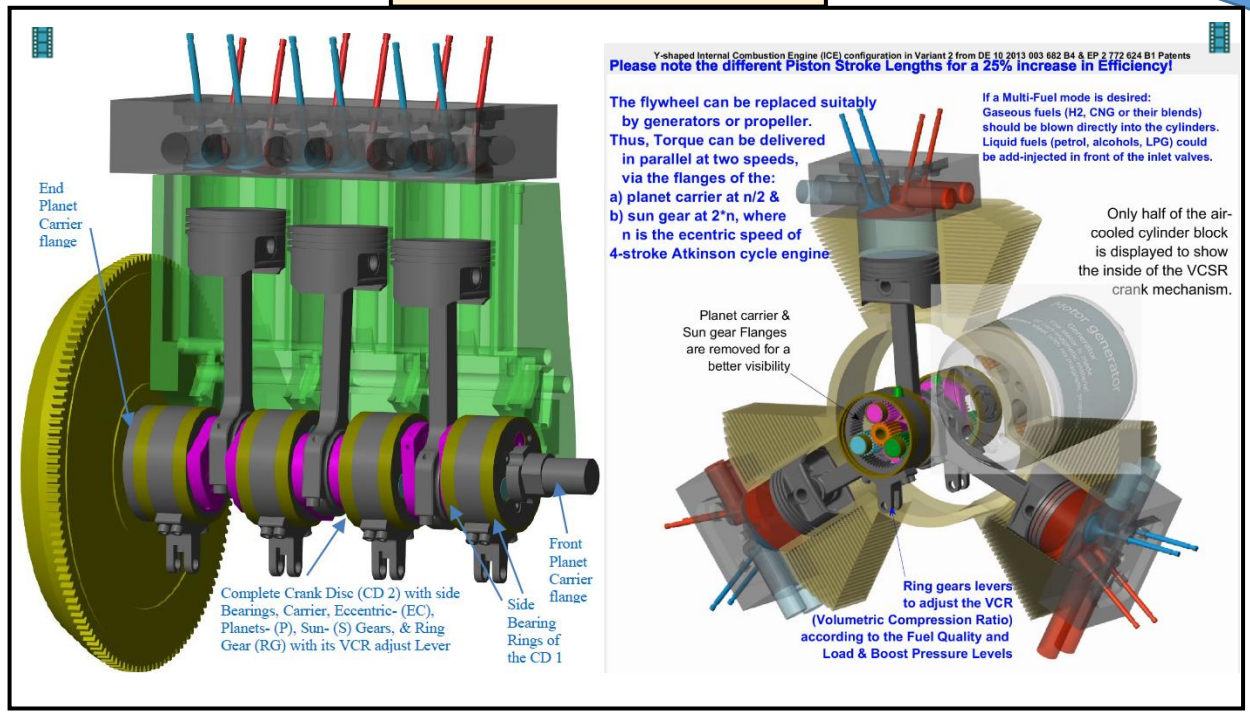






VCSR ICE with UD LC operated by Hydrogen, H_2, CNG etc. See Paper2021

Some of here used Abbreviations:
ICE = **I**nternal **C**ombustion **E**ngines
VCSR = **V**ariable **C**ompression & **S**troke **R**atios
UD LC = **U**ltra-**D**ownsizing **L**oad **C**ontrol
CNG = **C**ompressed **N**atural **G**as
= click on item to play videos



Using in freight or shunting locomotives, as a stand-alone drive or in a hybrid powertrain system on non-electrified rail lines



Sustainable Energy System Transition Applications

ICE power plants integrated into smart and innovative microgrid systems can eliminate the need for new national and supranational (EU) power lines.

The role of the ICE Power Plant has changed over the past few years. Today, it still serves to secure the base load, but it has also become an indispensable backup by means of the hydrogen production and storage that compensates for weather-related fluctuations of renewable energy sources. The engines are usually intended to run at 80% load and thus to generate electricity and district heating, with the remaining 20% serving as a variable reserve.

Every PV and Wind Turbine plants should be supplemented with electrolyzers, H_2 storage facilities & ICE power plants to continuously produce electricity. S. slides: 16, 17





VCSR ICE with UD LC operated by Hydrogen H_2, CNG etc. See Paper2021

Some of here used Abbreviations:
ICE = **I**nternal **C**ombustion **E**ngines
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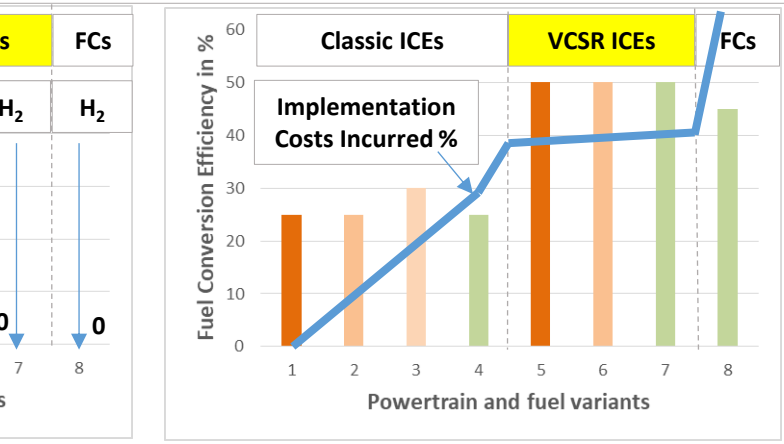
UD LC = **U**ltra-**D**ownsizing **L**oad **C**ontrol
VCR = **V**olumetric **C**ompression **R**atio
LPG = **L**iquefied **N**atural **G**as

Concrete Ways to Reduce CO_2 Emissions & to Increase the Efficiency



1. Classic ICEs powered by gasoline or diesel
2. Classic ICEs powered by CNG or LPG (methane)
3. As under 2., with VCR set accordingly
4. Classic ICEs powered by **Hydrogen H_2 Port Inj.**

5. VCSR ICEs powered by gasoline or diesel
6. VCSR ICEs powered by CNG or LPG (methane)
7. VCSR ICEs powered by **Hydrogen H_2 GasDI**
8. Fuel Cells (**FCs**) powered by **Hydrogen H_2**



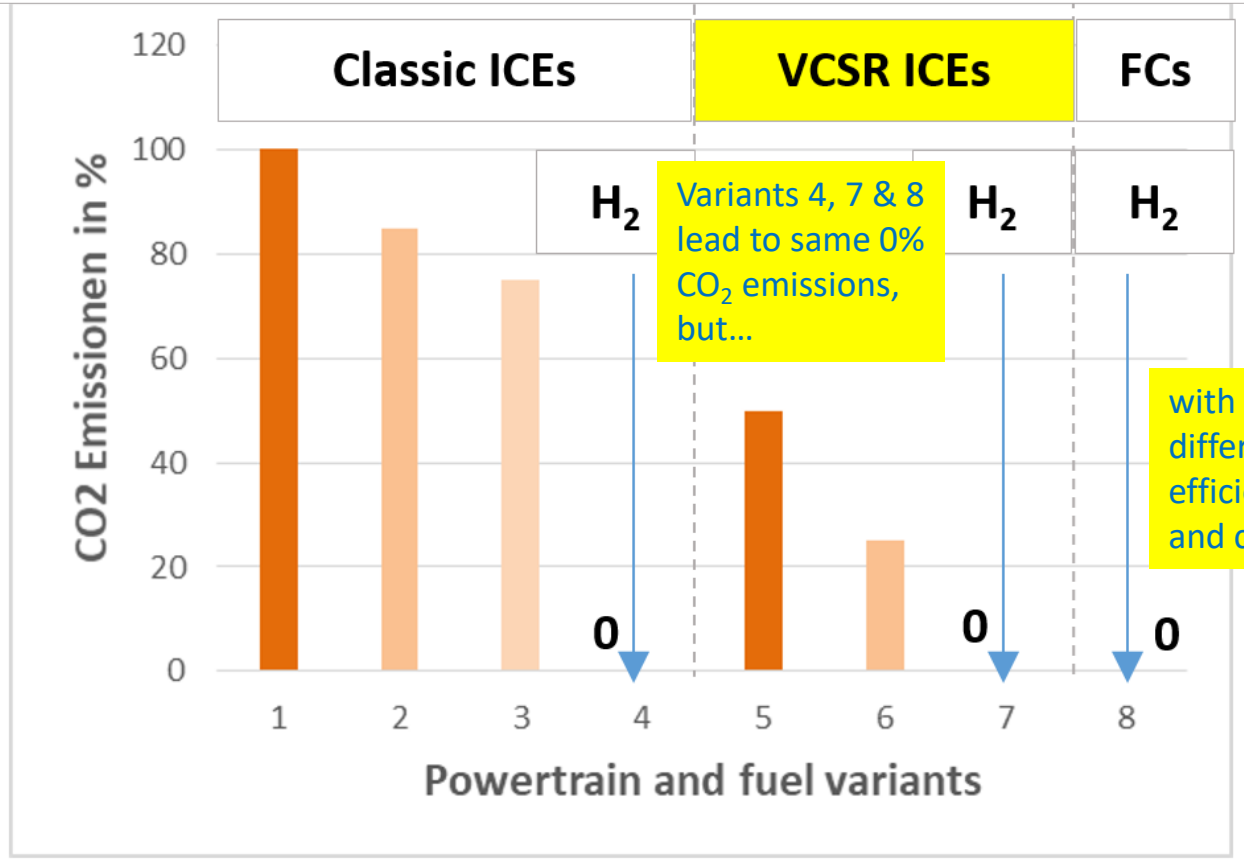




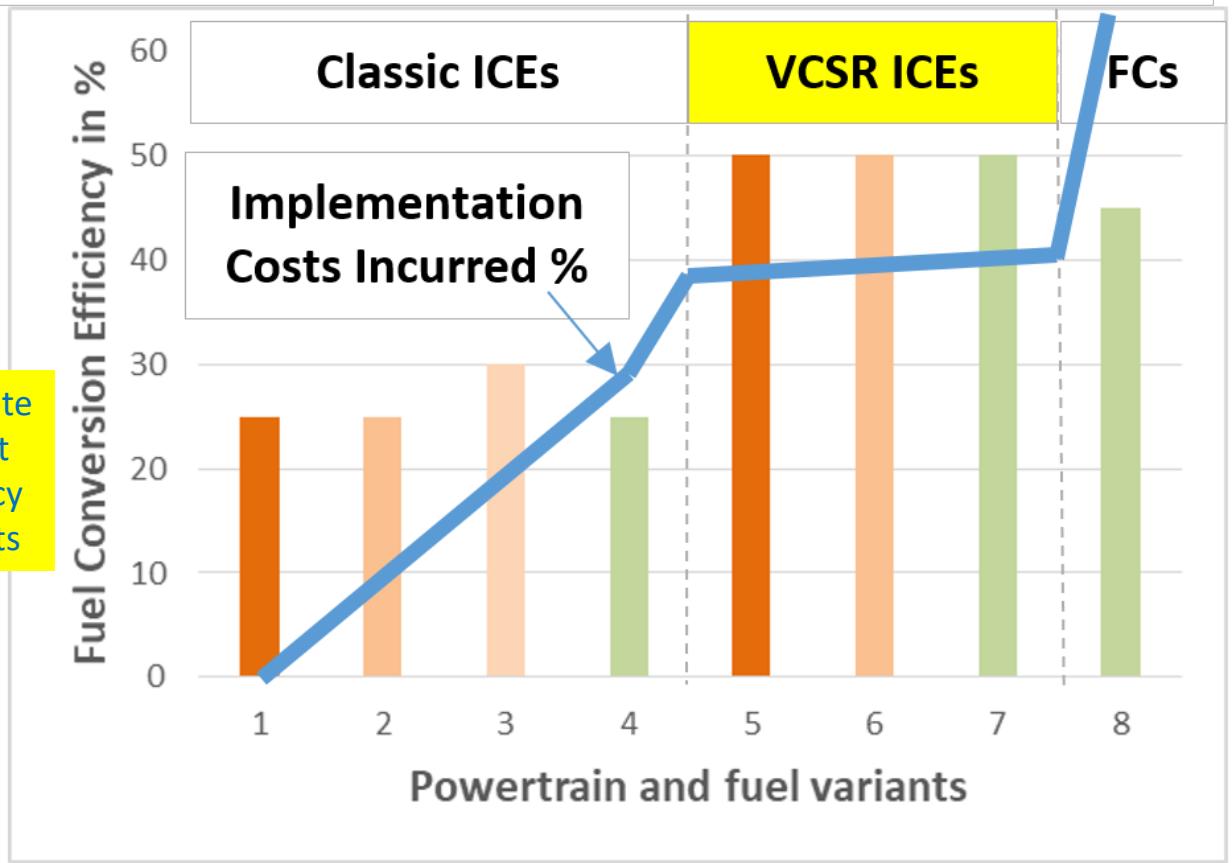
Sustainable Energy System Transition Applications

See rationales for VCSR Efficiency, for specialists only, in Paper2021, App. 1 & 2

Concrete Ways to Reduce CO_2 Emissions & to Increase the Efficiency



with quite different efficiency and costs



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5. VCSR ICEs powered by gasoline or diesel
6. VCSR ICEs powered by CNG or LPG (methane)
7. VCSR ICEs powered by **Hydrogen H_2 GasDI**
8. Fuel Cells (**FCs**) powered by **Hydrogen H_2**

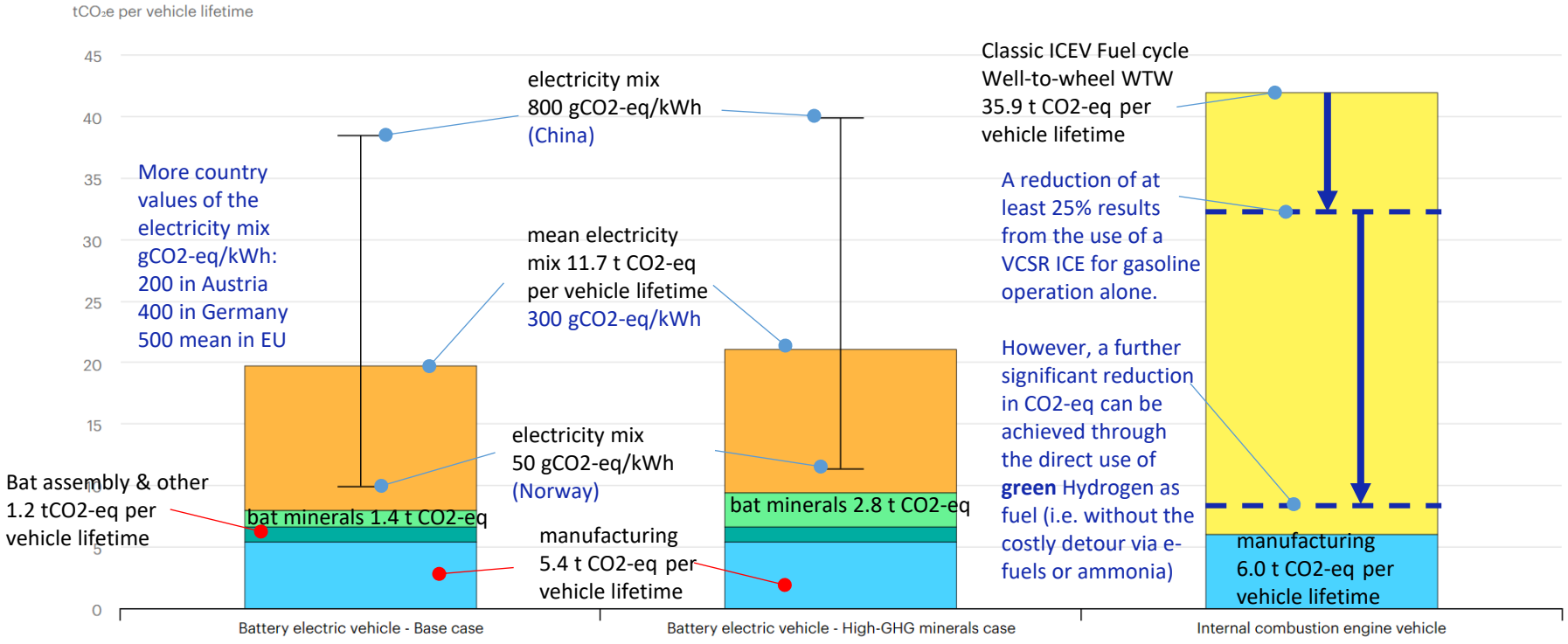
Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE vehicle

Last updated 26 Oct 2022

Download chart ↓

Author comments are added in blue to this IEA comparison:

- The limits for ICEVs powered by **VCSR ICE** running on gasoline or, even better and more efficient, on **green** Hydrogen.
- The power grid losses of approx. 7% per 100 grid kilometers and the BEV charging losses at the charging stations of approx. 20% were not taken into account in diagrams.



Sources
IEA analysis based on IEA (2020c); Kelly et al. (2020); Argonne National Laboratory (2020).

Notes
The "High-GHG minerals" case assumes double the GHG emission intensity for battery minerals (70 kgCO2-eq/kWh compared to 35 kgCO2-eq/kWh in the base case; other assumptions are the same). The values are for a vehicle manufactured from today's manufacturing lines assuming dynamic global average grid carbon intensity in the SDS (including transmissions, distribution and charging losses, weighted for mileage decay over a 20-year lifetime). The ranges shown for BEV represent cases for charging with a static low-carbon (50 gCO2-eq/kWh) and high-carbon electricity mix (800 gCO2-eq/kWh). Vehicle assumptions: 200 000 km lifetime mileage; ICE fuel economy 6.8 Lge/100 km; BEV fuel economy 0.19 kWh/km; BEV battery 40 kWh NMC622. NMC622 = nickel manganese cobalt in a 6:2:2 ratio. Lge = liter of gasoline-equivalent.

A GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF COMBUSTION ENGINE AND ELECTRIC PASSENGER CARS, 2021

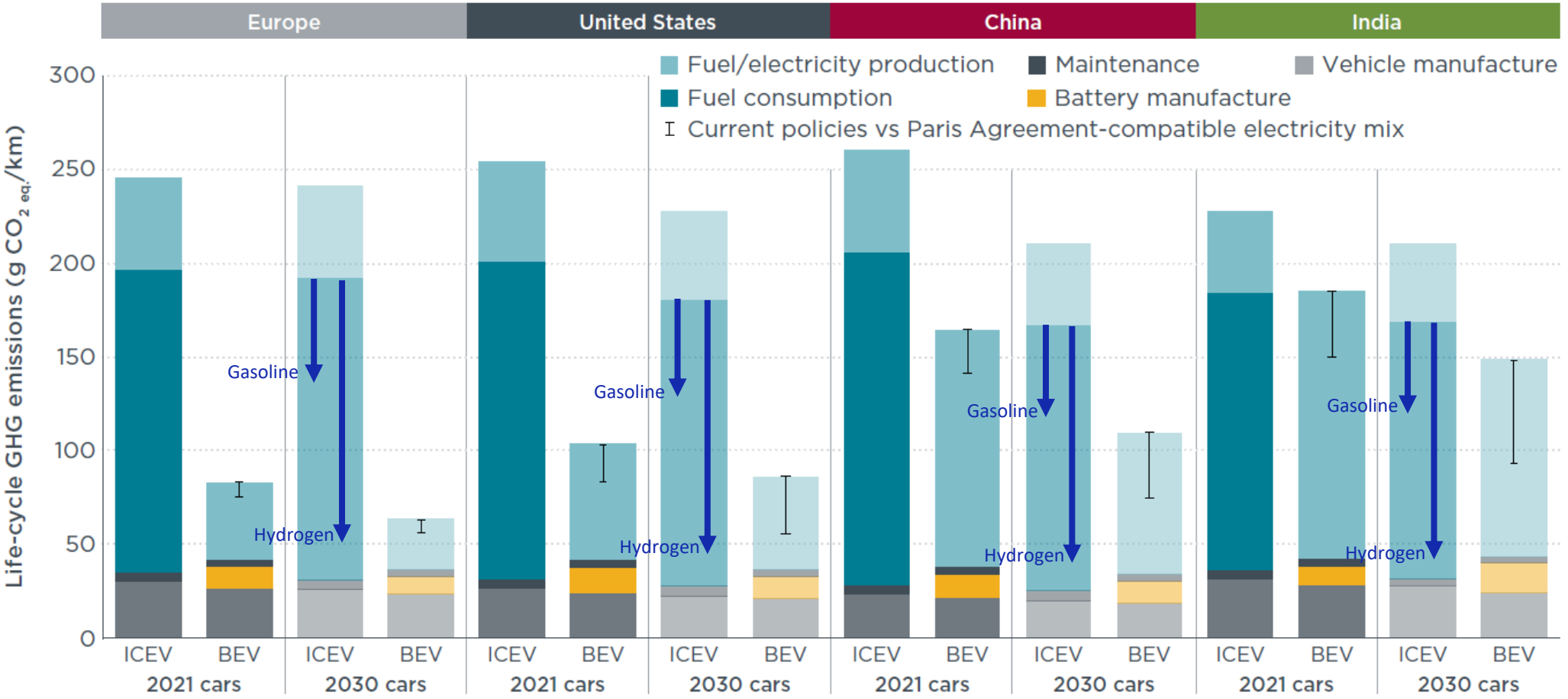


Figure ES.1. Life-cycle GHG emissions of average medium-size gasoline internal combustion engine (ICEVs) and battery electric vehicles (BEVs) registered in Europe, the United States, China, and India in 2021 and projected to be registered in 2030. The error bars indicate the difference between the development of the electricity mix according to stated policies (the higher values) and what is required to align with the Paris Agreement.

Author comments are added in blue to this comparison (s. the arrows):

- Potential reductions for ICEVs powered by **VCSR ICE** running on gasoline or, even better and more efficient, on **green** Hydrogen.

3. As a reminder the EU has funded a R&D project for using H_2 in ICEs, HyICE. In the USA has EERE done the same.
So far, there are no adequate series implementations of new H_2 fueled ICEs.
The funding has mainly been used for some PhD theses and for a book.
[D1], [D2], [D3], [D4]

We CANNOT achieve the above goals if the already funded and completed R&D projects are not used appropriately to achieve the set project goals: Best example is EU-CORDIS Project HyICE:

3. The goal of the 'Optimization of the Hydrogen Internal Combustion Engine' (HyICE) project was to optimize a concept for an internal combustion engine (ICE) which has the potential to outdo both gasoline and diesel engines with respect to efficiency and power density. For this purpose the two most promising principles of mixture formation, Direct Injection (DI) and Cryogenic Port Injection (CPI), have been studied.
   a) The attempt to use the BMW 760 Li to burnish BMW Group's sustainability credentials has failed because:
      I. No adequate adaptation of the ICE hardware and load control for H_2 operation was done.
      II. Cryogenic H_2 storage is ineffective, very costly, the vaporized H_2 as a result of boiling must be vented in the environment.
      III. The CPI's high-density mixture formation can be achieved using DI and turbocharging. [Paper2021, 4th Criterion, p. 9].
   b) Other Co. did even less; in their diesel engines, CGH_2 was blown in ahead of the intake valves & the quality of the mixture was set to very lean to avoid knocking combustion, by lower power density!

4. The auto industry talks only about Fuel Cells (FCs) when it comes to the use of H_2 in sustainable mobility, Why is that?
The public may be ignorant of it, but the auto industry knows.
<u>The answer is:</u>
The use of H_2 in ICEs was funded for the HyICE project; in order to secure new funding, the auto industry must now offer something else, namely FCs etc.

We can NOT achieve the goals outlined above if we don't understand the industry's tricks to get funding & subsidies:

Best example to 4: Internal Combustion Engines (ICEs) versus Fuel Cells (FCs) by operating on Hydrogen (H_2):

a) Hydrogen-fueled ICEs, similar to fuel cells (FCs), emit no CO_2 emissions and are more efficient, fully recyclable, cost-effective, and significantly more reliable. Potential NO_x emissions are present in both cases. For ICEs, NO_x emissions can be drastically reduced, even completely, as shown in[Paper2021, 4th Criterion, p. 9].

b) The longer a product is in use, e.g. ICEs, the better that is for environment. This becomes an even bigger problem when products are both hard to repair and have a short lifespan, like FCs and Batteries. On top of that, components are becoming more tightly integrated, so it's becoming harder for anyone other than an authorized center to carry out complete repairs. Special tools and software are needed because of security and calibration measurements.

c) The FCs can be severely damaged by some few concentrations of carbon monoxide CO & nitrogen oxides NO_x in the atmospheric air.

5. How we should DO it,

Nonsensical subsidies should be stopped immediately!

How much CO_2 reductions does autonomous driving really bring, if any?

Most likely none at all!

We can achieve the goals outlined above:

5. **When Nonsensical subsidies are stopped immediately**

   Best examples to 5. :

   a) The production of the Batteries Electrical Vehicles (BEV) generate a big amount of CO_2 emissions, the necessary materials like lithium, cobalt, graphite and so on are obtained from China and some poor countries from Africa, South America etc. without respect for environment protection and human rights!

   b) The European countries with such deposits, such as Portugal and Greenland, have refused to mine these critical materials in order not to pollute their environment, i.e. to preserve and protect it.

   c) Not only BEV are subsidized, but also large SUVs as Plug-in Hybrid EVs (PHEV), which can only drive a few kilometers electrically and whose CO_2 emissions are on average about two to four times higher than the values allowed by regulations! For more details, see [Paper2021, 1st Criterion, from p. 2]

   d) FC vehicles are three to four times more expensive and less efficient, have a much shorter lifespan as those with ICEs, when both run on Hydrogen. The FCEVs are heavily subsidized. For more details, see [Paper2021, 2nd and the following Criterions, from p. 5]

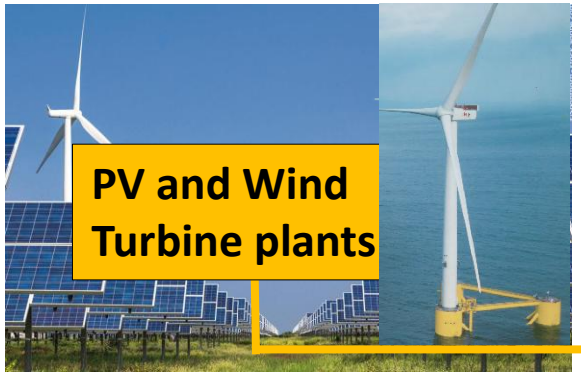
6. How we should DO it,

SMEs and even private INVENTORS must be supported financially until commercialization, on credit if necessary, so that they can build, test and optimize new prototypes and try out new approaches!
This would intensify competition with the large manufacturers and favor technical progress at low cost!

We can achieve the goals outlined above:

6. If we use and reuse all available hardware and know-how:
   a) Use RETROFIT capability to convert all old Euro 5 and current Euro 6 Vehicles to either CO_2-Neutral by H_2 fueling or, at least to CO_2-Low-Emission Vehicles by blends of H_2 & CNG fueling i.e. the ability to operate the Vehicles in Multi-Fuel Mode to Bridge the Time required to Build an EU Green Hydrogen H_2 Infrastructure, see [Paper2021, 6th and 4th Criterions, p. 15 and 9].
   b) Developing the tightest integration - sector coupling - of sustainable mobility and sustainable power generation through H_2-based coupling. USA counterexample of recycling of wind turbine blades.
   c) High Electrical Energy longtime Storage Capacity by H_2 Production & Efficient Re-Conversion on Demand of the Stored H_2 to Electricity by Means of ICE Power Plants based on VCSR ICE and driven Electrical Generators. Fueling the Vehicles from the stored H_2 by adjacent filling stations, see [Paper2021, 9th Criterion, from p. 25, and NEXT].
   d) Using the Availability of the required Materials and Employees Qualifications for an Immediate Largescale Industrial Production.
   e) A minimum of 90% recyclability & reparability, and a service life of at least 20 years for all products of sustained Mobility & Electricity production must be required by law and assured by producers.

Self-sufficient system with local buffering or storage of electrical energy based on **Hydrogen H_2** etc.



3 ways Cat
for H_2 & CNG

Dry Exhaust

Gas Cooler
Heat Q´ to DH

Power grid

Natural gas, biogas, CNG from the gas grid if stored H_2 is insufficient

Wet Exhaust

H_2O

Current connection

Condensate

If grid electricity is in surplus

O_2

HT Cooler for ICE, Gen, etc. Heat Q´ to DH

Q´

Gen-Set Container with 3 to 18 cylinders VCSR ICE

Rain and condensation water Reservoir, with treatment & used also as LT water Coolers

pure Water H_2O

PEM or alkaline electrolyzer

Generated O_2 can be aspirated with the air into VCSR ICE

CNG

HT / LT = High / Low Temperature
DH = District Heating Q´
Gen = Generator
PEM = Proton-Exchange Membrane

O_2

CNG

H_2 High pressure > 250 bar GasDI Injection

Low pressure H_2 feed

Pure H_2 or H_2 & CNG mixture filling station

High pressure H_2 feed

Return water pump

H_2 Storage & compressor

H_2 Storage & compressor

H_2 Storage & compressor

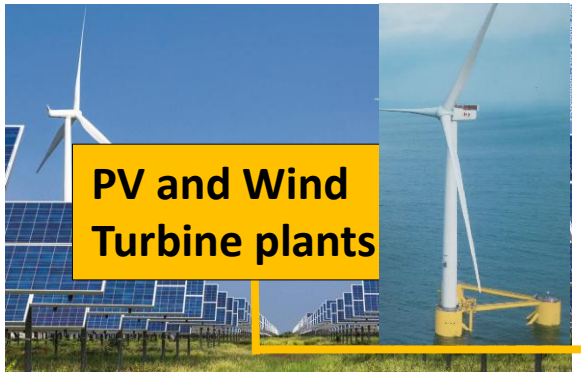
High pressure water pump up to 1000 bar

Water Return

The high turbocharged VCSR ICE is run with variable VCR, with always $\lambda = 1$, i.e. stoichiometric mixture formation and Ultra Downsizing (UD) Load Control (LC). The boost pressure is never limited, only the VCR is adjusted accordingly. Effective mean pressures of over 30 bar are thus possible!

The H_2 storage and compressor tanks can be installed **underground** on land and under water in **offshore** areas. The tanks can be made of steel with thin internal carbon fiber coating to prevent embrittlement of the steel walls or 3D printed concrete.
H_2 compression with water as displacer is the most efficient way to do this and the water circulation also serves to cool the compressed gas.

Self-sufficient system with local buffering/storage of electrical energy based on **H_2 & Ammonia NH_3**



3 ways Cat for H_2 & NH_3

Gas Cooler Heat Q´ to DH

Dry N_2

N_2

Power grid

Electro-chemical synthesis of NH_3

O_2

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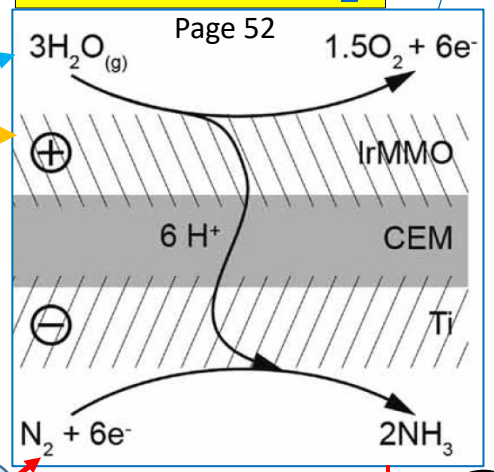

Wet Exhaust

H_2O Condensate

Current connection

If grid electricity is in surplus

HT Cooler for ICE, Gen, etc. Heat Q´ to DH

Q´

Gen-Set Container with 3 to 18 cylinders VCSR ICE

Rain and condensation water Reservoir, with treatment & used also as LT water Coolers

Q´

pure Water H_2O

PEM or alkaline electrolyzer

O_2

Generated O_2 can be aspirated with the air into VCSR ICE

HT / LT = High / Low Temperature
DH = District Heating Q´
Gen = Generator
PEM = Proton-Exchange Membrane

O_2

DI

NH_3

H_2 High pressure > 250 bar GasDI injection

Low pressure H_2 feed

N_2

NH_3

storage

Q´

Pure H_2 or/and NH_3 filling station

High pressure H_2 feed

thermal or Electrolysis NH_3 cracking reactor

Return water pump

H_2 Storage & compressor

H_2 Storage & compressor

H_2 Storage & compressor

High pressure water pump up to 1000 bar

Water Return

The high turbocharged **VCSR ICE** is run with variable VCR, with always $\lambda = 1$, i.e. stoichiometric mixture formation and Ultra Downsizing (UD) Load Control (LC). The boost pressure is never limited, only the VCR is adjusted accordingly. Effective mean pressures of over 30 bar are thus possible!
NH_3 burn needs at least 10% Gas H_2

The **NH_3** storage tank is a common one and is therefore no longer shown here.

Heat Q´ Storage Possibility for District Heating DH use

We can achieve the above outlined goals if we honestly and pragmatically choose the appropriate solutions (s. an example):

Note: In slides 14 & 15, the potential storage for the adequate use of Q´ as district heating DH is not shown for clarity purposes. An interesting alternative based on lime for storing the cooling heat Q´ of the ICE (e.g. VCSR) power plants, e.g. during the summer, for winter heating, i.e. for district heating DH, is presented below. Lime is an ideal medium for long-term heat storage. In its original form $CaCO_3$, it lies in the earth as a raw material. It is used as quicklime CaO and slaked lime $Ca(OH)_2$. In the transformation between these two forms, lime can either store heat or release heat. Moreover, it can do so as often as desired. If one kilogram of quicklime is brought into contact with liquid water or steam, it is transformed into slaked lime and about three hundred watt-hours of heat are generated.

This is about three times as much heat as is stored in one kilogram of liquid water when heated from zero degrees Celsius to one hundred degrees Celsius. When heated, the storage medium (slaked lime) begins an endothermic reaction that starts at about 450 degrees Celsius and creates calcium oxide i.e. quicklime. Water vapor escapes in the process. It can be imagined that quicklime has bound heat in chemical form. The special feature of this thermochemical heat accumulator is that the heat is stored in chemical form at room temperatures. It thus remains in the quicklime for any length of time and can be transported without loss. Storing heat thermochemically with lime is an interesting alternative in the fields of power plant technology and has potential for seasonal heat storage, for example, so as to support the supply of heat to households. With this objective, at the DLR (Germany Aerospace Center), Institute of Engineering Thermodynamics, in Economical, efficient, sustainable – thermochemical storage 'reloaded' are analyzing both the possibility of a local and a global circular economy of lime.

Homeowners need to set up a modern lime cellar with two bins instead of the old coal cellar. One bin would be used to store the heat-loaded substance quicklime, and a second bin would be used to store the heat-discharged substance slaked lime. Since the volumetric energy storage density in the conversion of quicklime to slaked lime is only about one-tenth that of coal briquette, ten times the volume of lime would have to be stored. This is less dramatic than it sounds. Since the third root of 10 equals 2.15, the lime bin would not have to be ten times the size of a coal bin, but only twice the size.

7. How we should DO it,

The EU & USA are only a low part of the whole world, so its approaches to reducing its own CO_2 emissions must be careful not to increase them in other countries! Their CO_2 reduction solutions should be so good, effective, cost efficient, recyclable and durable that the whole world would want to import and use them!

We can achieve the goals outlined above if we honestly and pragmatically choose the adequate solutions to do it:

7. Only if we answer all following questions in the affirmative will we choose the right path to zero CO_2 emissions:
   a) The EU world share of CO_2 emissions is approx. 15%. Will global warming be stopped if the EU reaches zero CO_2 emissions in 2050?
   b) Are battery-powered vehicles (BEVs) and fuel cell vehicles (FCEVs) the adequate solutions to achieve zero CO_2 emissions in the EU and worldwide in 2050?
   c) Can the materials required for b) be obtained without destroying the environment elsewhere in the world?
   d) Is it really possible to build charging stations for BEVs on EU & USA freeways, every 60 km, powered only by renewable energy?
   e) The above question also applies to the rest of the world, e.g. in Africa, South and Central America, India, South-East Asia etc.? These regions are not known for their adequate electricity generation capacities, nor reliable power grids.
   f) Can the switch of German drivers to BEVs and FCEVs, lead to a global net reduction of CO_2 emissions, when the 31 million old ICE cars (2020 figures) will not be retrofitted in DE or EU, but will be sold elsewhere in the world and remain in use there for many years?

Conceptual differences between Hybrid Drive (HD) and BEV with Range Extender.

Note that the Range Extender (RE) is mechanically completely separated from the BEV drive and is only electrically integrated, i.e. it can be removed when not needed.

Batteries capacities can be reduced by up to 90% in BEVs with RE, as used by Toyota in the HD Prius II, for example.

