Sustainable Mobility Through the Use of Hydrogen-fueled Internal Combustion Engines (ICE) with Extended Expansion and Continuously Adapted Compression Ratio

Essential Features of this Solution, Especially Regarding Sustainability.

An Internal Combustion Engine ICE is only as sustainable and efficient as its process, control and fuel.

In Germany alone, around 31 million Euro 5 and Euro 6 passenger cars (as of 2020) are gasoline-powered, and about half of which are diesel-powered. Their existence alone is a challenge in our efforts to meet the Paris 2030 climate targets, as well as UN SDGs 7 to 13.

The question is therefore:

> Can the switch of German, EU, USA etc. drivers to (Battery Electrical Vehicles) BEVs and (Fuel Cell Electrical Vehicles) FCEVs, lead to a global net reduction of CO_2 emissions, when these many millions old ICE cars will not be retrofitted there but are sold elsewhere around the world and remain in use there for many years?

Scrapping them would cause even more serious damage to both the environment and the economy!

Independent of other efforts to achieve carbon neutrality, meeting the Paris 2030 climate targets requires a **sustainable RETROFIT strategy** that converts current fleets of land, air and water vehicles to **zero-carbon fuels** i.e. Hydrogen H_2 either in pure form (Compressed Gaseous CGH2 or Liquefied LH2) or for example bounded in Ammonia NH_3.

What goal should the Retrofitting have?

However, in the absence of a widespread hydrogen infrastructure, it is necessary to first convert current vehicle fleets to **low-carbon fuels** (e.g., to compressed natural gas CNG, liquefied natural gas LNG, biogas, e-fuels, etc. possibly **blended with various parts of Hydrogen**).
The best solution is to convert all of these vehicles to very efficient powertrains that allow both **low-carbon** (during the transition phase) and **zero-carbon** (as the ultimate goal) **fuels**, i.e., those that can run effective on multiple fuels with variable H_2 parts with few or virtually no emissions.

Which powertrains are capable of offering the following requirements simultaneously?

a) ensure high fuel conversion efficiency, i.e. run with low fuel consumption,
b) particularly fuel flexible, without high demands on purity of fuel and air,
c) fully recyclable and easy repairable,
d) without special demands on rare materials and too high employee qualifications,
e) based on known existing technology that enables immediate large-scale industrial production,
f) high power density in kW/kg or kW/m^3,
g) inexpensive and very reliable, i.e. with long service life.

The current situation is as follows:

- Unfortunately, **FCEVs can only meet** the requirement **a) of all!** This means a long time and great financial and R&D efforts are necessary to fulfill the other requirements. Assuming this will be possible at all one day? Justification: So far, the appropriate electrode materials and electrolytes are fuel specific (H_2, methanol CH_3OH, ammonia NH_3).
- In contrast, the **current ICEs cannot fulfill** the requirement **a) but more or less all the other!** The solution to fulfill also requirement **a)** and to meet the others even better has been available for about 10 years and is relatively easy to implement. Of course, only if politics and industry want it?

The author asked himself the following question more than 20 years:

How can innovative ICEs be developed, built / retrofitted, and operated to transform them from "climate sinners" to "climate savers"?

The solution is the innovative result of over 20 years of R&D work, high technological competence, and collaboration with the automotive industry, see Milestones on the R&D path to VCSR ICE.

The challenge was to solve the following core tasks simultaneously:

- Switch to climate-neutral fuels such as hydrogen H_2 or ammonia NH_3
- Replacing the classic **Load Control** (LC) of gasoline and diesel engines with a new one that retains their positive and eliminates their disadvantageous features. This topic is far too complex to be covered briefly, so if you are interested, more details can be found here.
- The new load control is named **UDLC** (Ultra-Downsizing Load Control) and based on:
  - continuously variation of Volumetric Compression Ratio **VCR** and of the Turbocharging (TC) level,
  - true implementation of Atkinson cycles with heat recovery capability
  - free from throttling or leaning of the air-fuel-mixture and always working stoichiometrically,
  - shortening of the compression and extending of the expansion strokes, by using of a special crank drive mechanism named **VCSR** (Variable Compression and Stroke Ratios), for more info see following sources patents DE 10 2013 003682 B4, EP 2 772 624 B1 , papers and presentations Paper2015, Pres2019, Paper2021, Pres2022
- Increase in fuel conversion efficiency by more than 25 % compared to classical ICEs, see a proof of concept (assuming thermodynamic knowledge) in Appendices A1 for ideal cycles and A2 for real cycles of the Paper2021.
- Flexibility in the choice of fuel enabled by VCR-variation to ensure the ICEs operation even during a necessary transition period for the development of a large Hydrogen infrastructure. Policymakers can encourage drivers to use only certain fuels by taxing the fuels accordingly.
- Low to zero emission of harmful substances, such as NO_x implemented by using of stoichiometric air fuel mixture and thus emission reduction by means of usual 3 way catalyst.
- Realistic retrofitting that can be done efficiently, see an example in Paper2021, P. 15
- Scalability to other vehicle types and sizes and other applications e.g. home block heating power plants, more examples in Pres2022
- Availability of knowledge, experience, technology, production capacities, suppliers and qualified personnel.

A Boost to Sustainability.

The outstanding advantages of H_2-fueled internal combustion engines using VCSR and UDLC compared to Fuel Cells (FC), are even higher efficiency, power density and durability, coupled with low emissions, very low manufacturing, maintenance and operating costs, unlimited retrofitting, scalability, no need for environmentally critical materials and high purity of air and fuels, and full recycling.

This solution is the innovative result of over 20 years of R&D work, high technological competence, and collaboration with the automotive industry, and is in particularly in line with SDGs 7 and 8, see Milestones on the R&D path to VCSR ICE.

The **VCSR ICE** is currently being further developed and adapted for use as a new twice more efficient core for replacing the annular combustor of the present turbofan and turboprop aircraft engines, see a proof of concept for ideal cycles (assuming thermodynamic knowledge) in Appendices A1 of the Paper2021. This new **VCSR ICE** core developments will be covered shortly in the Hydrogen Based Sustainable Mobility presentation (pending).

In any mobility sector, it acts as a multiplier for sustainability, cost efficiency, range, load capacity and reliability.

This solution, whether in H_2 or many-fuel operation modes, boosts industrial power and heat generation, resulting in environmentally friendly economic growth through its sector coupling capability. See more in Pres2022.

Existing know-how and technology will allow immediate industrial production in SME or large series, while creating well-paying jobs at the same time.