THE FUTURE CONTRIBUTION OF THE INTERNAL COMBUSTION ENGINE IN NATIONAL GDP

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ABSTRACT

This Bio-Oil can be upgraded catalytically to liquid fuels. As a result, fast pyrolysis of waste bio-mass can produce biofuels and could enable a reduced carbon economy. The use of alternative, synthetic fuels derived from waste biomass and renewable electric energy has also been proposed to produce an electro fuel (e-fuel) with net zero CO2 emission (i.e. carbon neutral). This approach is currently being investigated as a smart way to store renewable electric energy when a production peak occurs, thanks to a chemical process to generate hydrocarbons from H2 (produced by electrolysis of water) and CO_2 captured directly from the atmosphere or from other industrial- or bio-sources. Longer term, carbon capture technologies have been demonstrated to be able to collect and then dispose of or sequester CO_2 from vehicle tail pipes, and are projected to be cost effective which will be the key factor in improving national GDP.

Keyword: - GHG emissions, unburned hydrocarbons, global warming, zero impact emission vehicles

1. INTRODUCTION

Internal combustion (IC) engines operating on fossil fuel oil provide about 25% of the world's power (about3000 out of 13,000 million tons oil equivalent per year see Figure 1, and in doing so, they produce about 10% of the world's greenhouse gas (GHG) emissions Figure 2 [1]. Reducing fuel consumption and emissions has been the goal of engine researchers and manufacturers for years. Indeed, major advances have been made, making today's IC engine a technological marvel. However, recently, the reputation of IC engines has been dealt a severe blow by emission scandals that threaten the ability of this technology to make significant and further contributions to the reduction of transportation sector emissions. In response, there have been proposals to replace vehicle IC engines with electric-drives with the intended goals of further reducing fuel consumption and emissions, and to decrease vehicle GHG emissions. Indeed, some potential students and researchers are being dissuaded from seeking careers in IC engine research due to disparaging statements made in the popular press and elsewhere that disproportionately blame IC engines for increasing atmospheric GHGs .Without a continuous influx of enthusiastic, well-trained engineers into the profession, the potential further benefits that improved IC engines can still provide will not be realized. As responsible automotive engineers and as stewards of the environment for future generations, it is up to our community to make an honest assessment of the progress made in the development of IC engines over the past century, with their almost universal adoption to meet the world's mobility and power generation needs. Considering that the maturity of IC engine technology is something that many other technologies/possibilities do not have, we also need to assess the potential for future progress, as well as to assess the benefits offered by competitor technologies, in order to make responsible recommendations for future directions. Factors impacting that future are discussed in this paper and include the following [2]

- The fact that affordable energy has been instrumental in raising the standard of living in the world dramatically, particularly in poor countries, and the fact that so far in the history of humanity, the burning of fossil or bio-derived fuels has been the only reliable source of energy.

- The fact that the entire planet is linked by a massive transportation infrastructure that is largely based on the IC engine and that would require decades and tremendous expense to replace.
- The dramatic advancements in IC engine technology that have brought pollutant levels down a 1000-fold in past decades, and which now make particulate emissions from tire and brake wear a larger problem than engine emissions (in both IC engine powered and electric vehicles).
- The obstacles still faced by proposed alternatives, such as electric vehicles powered by batteries, which have tremendous cost, weight and other limitations, and which are hoped to be fuelled by renewables, such as wind and solar that currently represent only a miniscule fraction of the world's energy supply.

And the fact that concerns about the impact of IC engines on climate change have become politically charged, even as they need to be assessed partially. There is need for informed, data and science- driven government policies that promote a managed, realistic transition to sustainable future energy systems. The vast majority of automotive engineers, are optimistic about the continuing importance of the IC engine to meet the world's mobility and power generation needs. Certainly, exploring new and competing engine technologies, as well as new fuels, is important for a sustainable future for our planet. The inescapable conclusion reached in this editorial is that, for the foreseeable future, road and off-road transport will be characterized by a mix of solutions involving internal combustion engines (ICEs), battery and hybrid power- trains, as well as conventional vehicles powered by IC engines. Thus, there is a pressing need for recruiting the brightest young minds to engage in this effort.

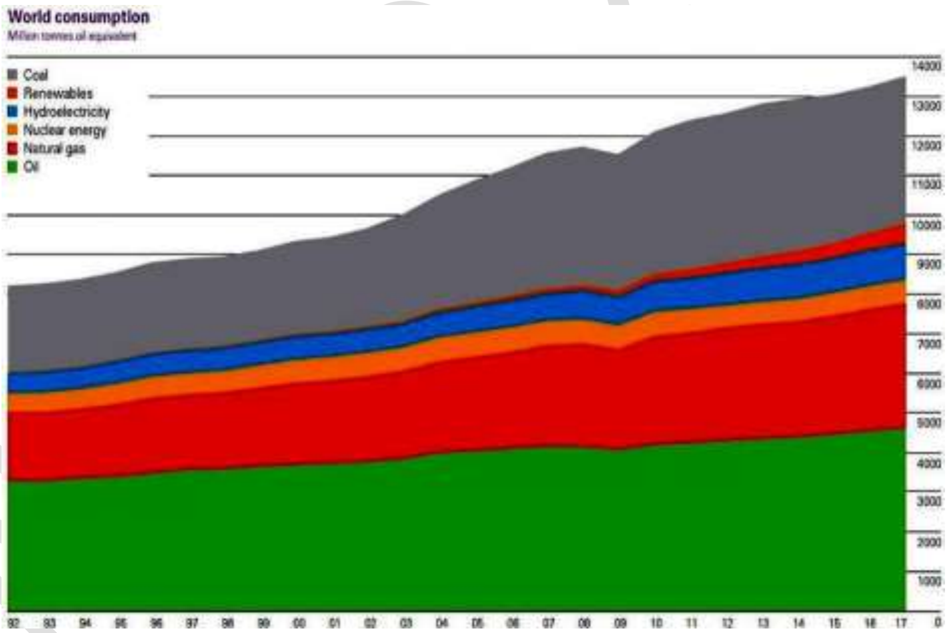

Figure-1: World energy consumption by source (millions of petroleum equivalent) in the last 25 years. About 70% of fossil oil is consumed in IC engines.

1.1 Internal Combustion Engine

The transport of goods and people are essential to modern society, and currently transport is almost entirely powered by ICEs using liquid fuels due to their plentiful supply, convenience and affordability. In addition, stationary combustion engines (e.g. generators, not those for transport or off-road applications) are ubiquitous in our industries and in power generation facilities, which also promote the world's standard of living. Indeed, the demand for available and affordable energy is increasing with the increase in global population and prosperity, particularly in developing countries. It is important to note that there are still no real alternatives that can compete with the IC engine over the entire range of applications that they cover and that, even today, IC engines are undergoing continuous further improvement [3, 4]. These developments make it even more challenging for competing technologies to gain advantage over the IC engine. Focusing on trans- port, the demand for energy is very large. There is still great scope for even further improvements in engines with advances in combustion technologies, especially when combined with electrification. This has been recognized by the major original equipment manufacturers (OEMs), and Brown describes Toyota's release of its patents aimed at making hybrid technologies accessible to more manufacturers, which they believe will encourage production of electrified vehicles, including IC engine hybrids, plug-in hybrids, fuel cell and even fully electric vehicles [5]. Indeed, it would be short-sighted if research and development on advanced power plant concepts slows, or is discontinued.

1.2 Engine Emissions and the Environment

Throughout the history of the IC engine and decades before climate-change concerns became prominent researchers have striven to improve its fuel efficiency, to reduce pollutant emissions and operating costs and to ensure the optimal use of finite fuel resources for current and future generations. Over the last four decades, in response to air-quality concerns, research on engine combustion, exhaust after-treatment and controls has led to a demonstrably cleaner environment thanks to a 1000-fold reduction in hazardous exhaust emissions (particulates, NOx, CO and unburned hydrocarbons (uHCs)). Recently, however, major increases in concern about both air quality and the impact of GHG emissions on global warming have begun to drive local, national and international policy. Several initiatives are calling for drastic changes, and vehicle electrification is being heavily promoted. For example, the C40 Cities Climate Leadership Group, a group of 90 of the world's cities, which represents more than 650 million people and one quarter of the global economy, is focused on driving urban action to reduce GHG emissions and climate risks. Demands include eliminating combustion engines from inner city transport and the use of wind and solar as primary energy sources. However, as shown in Figure 1, wind and solar supply only a very small fraction of current energy needs. Despite technical advances and cost reductions for wind and solar power, it appears very unlikely that most fossil-fuel energy sources will be replaced by alternative carbon-neutral sources over the next two or three decades [1].

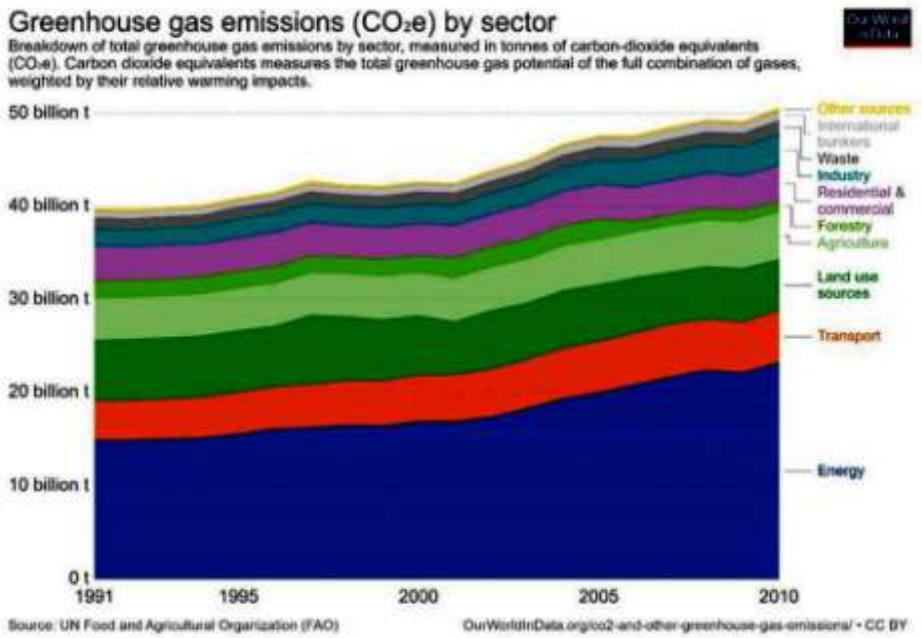

Figure-2: Global warming potential (GWP) in CO_2 equivalent tons by sector. Transportation contributes about 10%. [2]

1.3 IC Engine and Electrification

It is likely that future mobility will be characterized by a mix of solutions, involving battery electric and hybrid electric vehicles (BEV and HEV),fuel cell electric vehicles (FCEVs) and conventional vehicles, depending on consumer acceptance (e.g. cost), the country considered and the specific application (city, country, personal, freight, etc.). Thus, the combustion engine will still play a central role, whether used for power generation or for powering the vehicle itself, even in strongly electrified powertrain configurations. Because of this, there is great interest in improving the thermal efficiency of IC engines without significant increases in purchase and operating costs in the short-to-medium term. These goals can be achieved through improvements in combustion, after-treatment and control systems, and by partial electrification in the form of hybridization, together with vehicle weight reduction and more efficient ancillary systems.

Although there is great current interest in the electrification of transport, only BEVs eliminate the need for an IC engine. However, life-cycle analyses of the GHG impact of BEVs that consider the energy used in electricity generation and battery manufacture show that their true benefit is significantly less than is apparent at first sight. Many analyses ignore the upstream CO2 in fuel extraction, refining and transportation, as well as in the production and distribution of electricity. Large amounts of energy are required to extract the critical raw materials needed for batteries and electric motors (cobalt, lithium, rare earths, etc.), together with huge amounts of water. End-of-life disposal toxicity in particular also needs to be factored into life-cycle analyses. Moreover, the construction of a new electricity infrastructure, capable of recharging millions of BEV's, will require further raw materials and energy consumption (with consequent CO_2 emission), and may be limited by the availability of critical materials. The high cost of BEV's, as compared to IC-engine- powered vehicles (conventional or hybrid), is also driving the development of effective, but previously deemed uneconomical, methods to increase the IC engine's efficiency with advanced combustion modes, and to further reduce pollutant emissions. In this sense, the competition between electric motors and IC engines is stimulating beneficial evolution of the thermal engine itself.

1.4 Zero Emissions

It has been estimated that the fuel consumption in spark-ignition (SI) vehicles could be reduced by as much as 50% in the United States compared to the cur- rent average, [4] and tailpipe CO_2 emitted will be reduced correspondingly. With existing catalysts and control systems and these continue to be improved particulates, NOx, HCs and CO could also be reduced to negligible levels from both SI and diesel engines. Frequently, pollutant emissions and CO_2 emissions from combustion are presented as being entirely equivalent, so that even engines with exceedingly low criteria pollutant emissions (NOx, CO, HCs, and particulates) are also regarded as polluting. Technically and practically, there is an important distinction. CO_2 emissions necessarily accompany any hydrocarbon combustion or chemical oxidation process, including human and animal life. The CO2 emitted from an engine is directly proportional to the hydrocarbon fuel consumed, which is continually being reduced by technological improvements. In terms of the criteria pollutants, the goal to achieve ''zero impact emission vehicles'' is very close, thanks to advanced combustion modes and innovative after-treatment systems, including extensive use of catalysts and high-filtration-efficiency diesel and gasoline particulate filters (D/GPF) in the after-treatment system, while the use of urea injections and selective catalytic reduction (SCR) is leading to extremely low NOx emissions (e.g. 0.02 g/bhp-h or 15–20 mg/km). Indeed, there are even examples of vehicles having tailpipe unburned HC emissions below those in the ambient air at the engine's intake, so-called negative emission vehicle.

1.5 Fuels

In the medium-to-long term, there is even greater scope for improving engines by co-designing fuel/engine systems for optimal performance. Single- and dual-fuel technologies, such as homogeneous charge compression ignition (HCCI), premixed controlled compression ignition (PCCI), and reactivity-controlled compression ignition (RCCI) [10] offer significant promise for improving efficiency and reducing unwanted exhaust emissions. These advanced combustion modes can also benefit from available fuels or fuels whose composition is optimized for each application. To also reduce dependence on fossil fuels and for a decarbonization transition, progress is being made in the introduction of CO_2-neutral biofuels and synthetic fuels. Often, criticism of the ICE is not about the engine, but about the source of the fuel, and the use of bio or synthetic fuels can mitigate total carbon emissions. Indeed, some marketed biodiesels are more than 70% net-carbon neutral today. Some countries and states have even implemented a low- carbon fuel standard (LCFS) and provide monetary incentives to encourage the biofuel market.

2. FUTURE RESEARCH DIRECTIONS

Since its inception almost 20 years ago, this journal has chronicled advances in research in engines [6]. The journal's goal continues to be to provide a stimulating forum to encourage progress in IC engine R&D. In this spirit, the final section of this editorial provides a (possibly incomplete) list of potentially fruitful research topics that would be helpful to the field of engines. Advances in these areas would certainly benefit from worldwide collaborations between researchers in industries, government laboratories and academia.

2.1 Engine Efficiency

Combustion system. The development of novel combustion systems, including use of ultra-high fuel injection pressures, and new mechanical layouts, possibly beyond the slider crank, should be encouraged. This could be paired with combustion technologies with highly diluted combustion (stoichiometric with exhaust gas recirculation (EGR) as well as lean burn with excess-air ratios above 2). For this combustion improvement, mixture formation and charge motion, and ignition technologies including installation of pre-chambers need to be investigated.

2.2 Gas Exchange

Improvements in engine breathing are of interest, potentially via exhaust gas turbochargers to realize fast response and low temperature combustion with ultra-high-pressure supercharging, large quantities of EGR, and further improvements in the Miller cycle with variable valve systems, while maintaining the required oxygen levels. Further development of exhaust gas energy recovery systems with turbo-compounding and possibly chemical reforming should be encouraged.

2.3 Electrification

Electrification offers significant improvements in system efficiencies, as well as GHG control, possibly leading to thermal efficiencies beyond 50%. The development of more efficient engines specifically for hybrid and range-extender systems (which enable the engine to run over a limited speed-load range) would also be helpful.

2.4 Engine Lubrication

Reduction in mechanical loss should be achieved by improving lubrication systems with less oil consumption, especially for new engines with restricted operational areas in loads or speeds.

2.5 Fuels

The efficient utilization of dual-fuel combustion, and combustion of diesel/natural gas should be researched. In addition to ultra-dilute burn and development of direct gaseous fuel injection systems, research is needed to reduce methane slip and to improve thermal efficiency and exhaust gas emissions on natural gas engines, especially for large ships and co-generation. Analysis of global fuel usage suggests that the use of surplus low octane number fuels will become an important topic in the near future. Also, intensified research on bio- and e-fuels for GHG mitigation would be helpful. ‘‘Designer’’ fuels offer the potential for efficiency improvements and near-zero pollutant emission. These could include admixtures of variable H_2-quantities to hydrocarbons, oxygenated components and even quite new chemical components (e.g. NH_3). Research tools needed for engine development include the following.

2.6 Engine Simulations

Supported by detailed experiments, there have been great advances in computational fluid dynamics (CFD) modeling of combustion processes. Simulation tools are now heavily used by most engine OEMs to help design and optimize engines, benefiting from the vast computational power available to both industry and academia. Thanks to the rapid development of AI, various automatic predictions and optimizations are also being put into practical use. However, the optimization of engine combustion relies on accurate sub- models, many of which need further development to increase their predictive capability, as well as to reduce the need for empirical calibration. This is an active area of research utilizing Direct Numerical Simulations with an imminent introduction of machine learning and data science technologies. In addition, engine combustion includes transient phenomena such as cycle-to-cycle variations that are not well understood or analyzed. Development of vehicle simulation models that include the power source together with its system components, transmission, peripheral devices, battery, motor, inverter and driving drag is needed.

2.7 Engine and Vehicle Control

Real-time combustion control to reduce control mar- gins and cycle-to-cycle variations requires calibration and control software innovation, possibly with on- board physical/statistical model-based control using AI. Onboard optimization of multi-input/multi-output systems with model predictive control is needed. Control of efficient fuel injection systems to optimize mixture formation temporally in the combustion chamber, and methods to ensure stable ignition in very lean or dilute mixtures in SI engines, possibly using pre-chambers, and low-temperature plasmas would be of interest.

CONCLUSIONS

In summary, the ICE, and IC engine research have a bright future, in contrast with some widely distributed media report. The power generation and the vehicle and fuel industries are huge, representing trillions of dollars (US) per year in turnover, with a massive infrastructure. We are certainly in revolutionary times, but it is clear that power generation sources will not become fully renewable and transport will not become fully electric for several decades, however, research to improve efficiency and methods to reduce dependence on fossil fuels are exciting directions for future IC engine research. It is very likely that highly efficient ‘‘fully flexible’’ engines with hybridized solutions will be a big part of sought-after efficiency improvements, as well as emission/GHG reductions. Finally, it must be acknowledged that, in practice, people select their choice of powertrain based on numerous factors, including low cost which will be the key factor in improving national GDP.

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