

#### Fushui Liu (Autor) CFD Study on Hydrogen Engine Mixture Formation and Combustion



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# Part I: Introduction

The invention of the automobile is a critical element of the social, economic, and cultural evolution of human civilization. The most important effect of the automobile's discovery is the fact that the automobile, and other means of transportation which have the combustion engine, increased the speed with which people and goods could be moved over land. This one consequence has led to a dramatic change in automobile economics and style over the course of the twentieth century and reflects the changing trends and scientific knowledge in the automobile industry.

Today ... transportation is an essential component of health care, education, employment, recreation, culture, maintenance of ties with family and friends, and all that makes life worthwhile. Transportation is what enables individuals to become full-fledged, participating, contributing members of society and what enables communities to work the way they could and should. In this day and age, and in this society, transportation is a necessity<sup>1</sup>.



Figure 1-1. Oil Energy Consumption by Sectors in OECD countries

The modern society is to a great extent dependent on combustion. 90% of the world's primary energy comes from combustion of fossil fuels - coal, oil and natural gas<sup>2</sup>. While more than half of the oil is consumed by transportation sectors (figure 1-1).<sup>3</sup> What an important role the transportation is playing for the energy consumption in the whole world!

Engine is the heart of a vehicle. Since almost all transportation modes depend on the internal combustion engine, either fueled with gasoline, or diesel, or kerosene (jet planes), internal combustion engine actually plays the key role in energy consumption and social activities.

# 1.1 Crisis of traditional Internal Combustion Engines

Over the years, ever since the boom of the industrial age, the advancement in vehicles and automobiles has been tremendous. From the slow and noisy open-air automobiles to the space-aged electric hybrid cars, the advancement of

technology has inspired us to have better and faster engines.

Unfortunately, the traditional internal combustion is facing more and more difficulties.

# 1.1.1 Pollutions and Greenhouse effect

"Plants and animals that lived ages ago have returned to haunt us with a vengeance. Their incinerated remains pollute both land and sea, and clog the air we breathe. Life from the past now threatens life of the present"4.

In the course of a century, the world's consumption of fossil fuels has grown at an exponential rate, increasing by a factor of  $20^5$ . This has led to a series of environmental problems such as local air pollution, acid rain, the risk of climatic changes and the release of polluting effluents to the soil and water.



Figure 1-2. General description of sources of the human-caused air pollution

Figure 1-2 gives the general description of sources of the human-caused air pollution <sup>6</sup>. Around 80% of carbon monoxide pollution is produced by combustion engines (including the engines in on-road vehicles and non-road vehicles) and 95% of nitrogen oxide is caused by fuel combustion in all type of engines. It can be concluded that engine is the main source of air pollution.

With the development of engine technology, the injurious pollutant from IC engine might be controlled. But  $CO_2$  emission, which is the fundamental product from fossil oil combustion, could never be significantly reduced in traditional engine. It is just the  $CO_2$  that contributes the most to the greenhouse effect of the earth.

According to research by IPCC (The United Nations Intergovernmental Panel on Climate Change)<sup>7</sup>, the concentration of greenhouse gases, especially CO<sub>2</sub>, has increased substantially since the beginning of the industrial revolution (Figure 1-3<sup>8</sup>), which leads to the continuous increase of the surface temperature of the earth because the greenhouse gases prevent significant amount of radiation and heat from escaping into space. An increase of  $0.6^{\circ}$ C of the surface temperature of the earth has been observed over the past 100 years (figure 1-4<sup>9</sup>).



Figure 1-3. Variation of Carbon Dioxide concentration in atmosphere

With global warming emerging, it has led to several chain events such as sea level rising, depletion of the ozone, and having too much radiation in the atmosphere. If the emission of greenhouse gases is not effectively controlled, the problems will be more and more serious.



Figure 1-4. Earth's temperature variation in the last century

The world now faces tremendous challenges associated with greenhouse gas emissions, climatic change, and the need for a sustainable development. IPCC has been studying these problems for over 13 years, and a general consensus has been achieved between researchers, industry leaders and politicians that dramatic reductions in greenhouse gas emissions must be achieved in order to prevent man-made climatic changes.

### 1.1.2 Legislations, cost and taxes

In order to reduce the pollution, the European Union and the EPA in the US have set increasingly demanding standards on the allowable emissions for new vehicles since 1970. Figure 1-5 gives a general impression of the intensity of legislations in European, US and Japan<sup>10</sup>.

In order to meet the stricter and stricter legislations, the carmakers must develop more and more new technologies, such as MPI/EGR/GDI/Catalyst for SI Engine,

to reduce the emissions. The application of new technologies has really helped a lot for the reducing of harmful gas emissions.



Figure 1-5. Emission Limits in Europe, US and Japan

Since 1987 the level of allowable hydrocarbons emitted is down by 90% with the level of nitrogen oxides decreased by 83% and the level of carbon monoxide decreased by 80%. This significant level of change is expected to continue in future years as public opinion and environmental needs force technology and car design to improve<sup>11</sup>.

But the introduction of new technologies also makes the car cost becomes higher and higher. Figure  $1-6^{12}$  presents the variation of new car expenditure in USA in the recent 30 years. It gives a very clear impression that the normal consumers are going to carry heavier and heavier burden.



Although the by-product emissions have been reduced significantly with the development of technology, the amount of carbon dioxide, which is the main cause of greenhouse effect, emitted worldwide has continued to increase. Carbon dioxide is a product of combustion and therefore only is reduced by better fuel consumption, or fuels the engine with carbon-free fuels.

The threatened environmental catastrophe can be avoided only by significant reductions vehicle-miles. in (which people will not accept), or by significantly improved miles/g of carbon dioxide (which fossil fuel technologies are unable to deliver). Only the development of low and zero vehicles emission offer a solution to this logiam and they are required in both the long and the short term.



Two ways are adopted by the developed countries to force both the customer and



producer to accept the environmental protect concept:

- To exact CO<sub>2</sub> emission tax. UK is an example country, which has executed this policy since July 2002. Up to 35% of the car price will be taxed for the CO<sub>2</sub> producer (refer to figure 1-7<sup>13</sup>), and the tax will be higher and higher. This policy adds an even heavier burden on normal consumer.
- To force the carmaker to produce CO<sub>2</sub>-free products. Table 1-1<sup>14</sup> lists the requirements for manufacturer's fleet sales, which is constituted by California Air Resources Board (CARB). This policy is disgusted by the manufacturers, but will lead the automobile industry into a new phase.

| Model Year | Conventional vehicle | TLEV | LEV | ULEV | ZEV |
|------------|----------------------|------|-----|------|-----|
| 1994       | 90                   | 10   |     |      |     |
| 1995       | 85                   | 15   |     |      |     |
| 1996       | 80                   | 20   |     |      |     |
| 1997       | 73                   |      | 25  | 2    |     |
| 1998-2000  | 48                   |      | 48  | 2    | 2   |
| 2001-2002  |                      |      | 90  | 5    | 5   |
| 2003       |                      |      | 75  | 15   | 10  |

Table 1-1. CARB requirements for manufacturer's fleet sales

# 1.1.3 Limit of fossil oil

Aside from problems relating to pollution, the limiting supply of natural resources has also come to attention – particularly the oil supply.