

# Current status and prospect of homogeneous charge compression ignition (HCCI) technology application of transportation

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**Abstract.** HCCI engine is a new concept in recent decades. HCCI is defined as a type of engine with little application and market proportion. HCCI engines have great potential and prospects in practical engineering applications. However, there is a lack of cognition of HCCI engine development. Therefore, this paper introduces the current status of HCCI technology application and the possible development in the future. Throughout collecting information of some parameters of engines and comparison and analysis, this paper researches the current status and prospect of HCCI engine application. Research shows that, HCCI engine has considerable merits, which are more eco-friendly, higher thermal efficiency and fuel economy, also HCCI engine is not be used in production. In the future, HCCI engine will expand the advantages and occupy market, eventually be the mainstream type of internal combustion engine. In addition, the analysis and research results of this paper will provide reference and reference for the future development of HCCI engine.

**Keywords:** homogeneous charge compression ignition (HCCI); HCCI engine; transportation.

## 1. Introduction

HCCI technology, as a new type of internal combustion, has some outstanding features. As for pollution, HCCI engine generate negligible value of NO<sub>x</sub> emission and a much smaller number of carbon dioxide emissions [1]. Working in relatively low temperature, heat loss is less than ordinary gasoline engines [2], resulting in the thermal efficiency of HCCI engines as high as 40%-45% [3], which is higher than ordinary gasoline engines [3]. In fact, there are few cars in production using HCCI technology [2]. HCCI, which has better performance in reducing pollution and fuel economy, is not used in mass production models [2]. As a worth studying new type of engine, automobile companies are pursuing improvements in HCCI technology, expanding the use of HCCI engines, and looking for the future of HCCI application. A reasonable expectation of HCCI application based on existing data is desirable to do a research. This paper explains the current development of HCCI engines in aspects of technology and marketing and the projection of HCCI application about the technological development and trend in market.

## 2. Current Status

### 2.1 Technological Factors

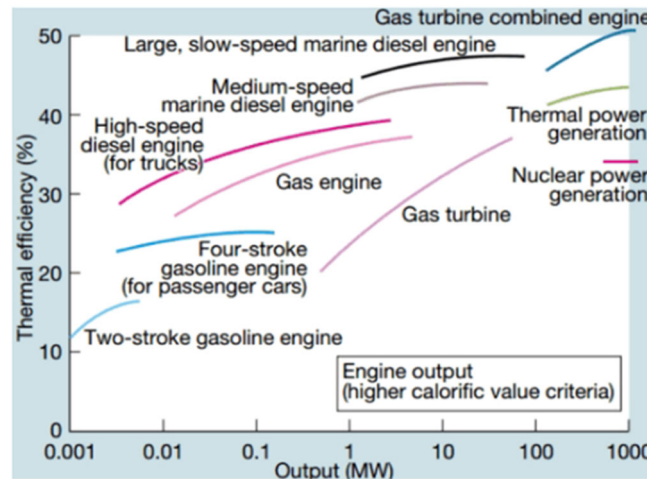
#### 2.1.1. Advantages. In comparison with other types of engines:

##### (1) Gasoline engine

The working principle of a gasoline engine is to compress the mixture of fuel and air, and then ignite it with a spark plug to make the mixture in the engine do work and provide power for the car [4]. The thermal efficiency of typical gasoline engine is around 25%-30% [5].

##### (2) Diesel engine

Figure 1 is a thermal efficiency-power output graph. The working principle of the diesel engine is to compress the air, then add diesel into the cylinder, ignite the diesel through the high temperature caused by compression, and then make the mixture in the cylinder do work to provide power for the car [6]. The thermal efficiency of typical diesel engine is around 30%-35% [5].



**Figure 1.** The graph of thermal efficiency-power output [7].

This table shows how much thermal efficiency different types of engines have.

HCCI engine: The working principle of HCCI engine is to compress the mixture of air and gasoline, ignite the mixture through the high temperature caused by compression, and then make the mixture in the cylinder do work to provide power for the car [8]. The thermal efficiency of HCCI engine is around 40%-45% [3].

Analysis: HCCI technology combines the features of gasoline engine and diesel engine, also has a higher thermal efficiency than two other types of engine.

HCCI technology reduces emissions, then the pollution caused by cars can decrease. The main kinds of automobile emissions are NO<sub>x</sub>, HC, CO and PM [9]. There is a comparison about emissions between HCCI engine and diesel engine.

**Table 1.** Emissions data of diesel engine and HCCI engine

Type of emissions	Diesel engine	HCCI engine
HC	1	0.4~0.5
CO	1	0.05~0.1
NO <sub>x</sub>	1	0.02~0.1

This table 1 indicates that if the emissions data of diesel engine is 1, how much emissions does HCCI engine produce. It is evident that HCCI engine has significantly less pollution compared with diesel engine [10].

Compared with the data of SI combustion, or gasoline engine, HCCI:

Reduce 45% HC emissions.

Reduce 52% CO emissions.

Reduce 97% NO<sub>x</sub> emissions [11].

Consequently, HCCI engine is eco-friendlier than diesel engine and gasoline engine.

**2.1.2. Disadvantages. Upper and lower limits of operating load:**

(1) HCCI engines have upper and lower runnable loads. When the engine load becomes smaller, the amount of combustible mixture will decrease and the combustion temperature will decrease. When the temperature reaches the lower limit of the natural temperature of the mixture, the mixture cannot continue to burn, forming the lower limit of the stable operating load of HCCI engine. When the engine load increases, the amount of combustible mixture will increase. When a large amount of mixture is burned at the same time, the combustion heat release efficiency will be too high, resulting in too high internal pressure of the engine and damage to the engine [11].

(2) Lack of combustion control. Compared with gasoline spark plug ignition or diesel compression ignition, HCCI Engine lacks a direct and effective mandatory control method to control its combustion process. If the engine operating conditions change, HCCI engine can only be adjusted by changing the internal temperature and concentration, so the transient response of HCCI engine is worse than that of traditional engine.

### 2.1.3. Analysis of some products.

In fact, many automobile companies have carried out various research on HCCI engine and have launched concept vehicles, among which Mazda is a typical automobile company using HCCI technology. Mazda's HCCI engine combines the advantages of HCCI technology and SI combustion. Mazda's SPCCI engine has a spark plug [8]. When the temperature of the mixture in the engine is too low or too high, the work mode of HCCI cannot be used, and the mixture is ignited by the spark plug. When the temperature of the mixture in the engine is suitable for HCCI, the spark plug is not used, and HCCI is used for operation. This is a scheme that can effectively solve the problem that HCCI engines have upper and lower limits of operating load, and it is also a cutting-edge application of HCCI. Another one is Mercedes Benz's 2007 F700 concept car. After adopting HCCI technology, its diesel 1.8T direct 4 CGI direct injection engine has an output power of 238hp and a maximum torque of 400nm.

## 2.2 Status in Market

Even though the concept of HCCI technology has been put forward for more than 40 years, HCCI engines are still not fully mass produced at this moment. The first application of HCCI technology in production is Mazda 3, which is a car launched in 2019. It costs about US \$16000, and its fuel consumption reaches 6.3L/100km [12]. as the only one product in production applying HCCI engine. GM also produced HCCI concept car in 2007, but later stopped research in this area [13]. Honda started the research and development of HCCI technology as early as more than 20 years ago, but it has not adhered to today.

## 3. Prospects based on Analysis

### 3.1 A revolution of internal combustion engine

HCCI engine has the advantages of low fuel consumption, low emissions and high thermal efficiency, which can lead to higher fuel economy. At present, HCCI engine has both advantages and disadvantages compared with other internal combustion engines. Its disadvantages are its limited engine operating load and poor ignition control. Through the research and development of car companies, more solutions will be put forward, which can ensure that HCCI engines can make up for their shortcomings when giving full play to their strengths, and then occupy market share according to their significant advantages. As a new and more environmentally friendly and energy-saving engine scheme, HCCI engine will gradually become the mainstream of internal combustion engines [13].

### 3.2 Significance in development trend of automotive power train led by environmental protection

According to the current status, HCCI, as a new type of internal combustion engine being more environmentally friendly, is worthy to develop more. With global warming, the number of advocates of environmental protection and reducing carbon emissions is increasing.

**Table 2.** The Co2 emissions of Mazda 3 [14].

Model	Year	Body Type	Fuel Type	Transmission	Power	Co2 emissions
Mazda 3	2019	Hatchback	Petrol	Manual	122 hp	117 g/km
Mazda 3	2016	Hatchback	Petrol	Manual	120 hp	119 g/km
Mazda 3	2016	Hatchback	Petrol	Manual	100 hp	119 g/km
Mazda 3	2015	Hatchback	Diesel	Manual	150 hp	107 g/km
Mazda 3	2014	Hatchback	Petrol	Manual	100 hp	119 g/km
Mazda 3	2013	Hatchback	Petrol	Manual	120 hp	119 g/km
Mazda 3	2012	Hatchback	Diesel	Manual	185 hp	144 g/km

For environmental protection, hybrid car are becoming more and more popular. However, the technology of hybrid cars is still immature, and the problem of low battery density cannot be improved in a short time, which also shows that the internal combustion engine still occupies a large market share in the next few decades. For the trend of advocating environmental protection, HCCI is the future of economic and environmental protection for internal combustion engines.

Compared with gasoline and diesel engines, emissions from HCCI engines are significantly reduced, which is expected to meet the government's expectations for carbon emission control.

**Table 3.** Global comparison of standards for passenger vehicles [15].

Jurisdiction and first compliance year	Basis for standard	Future target year/s	Equivalent CO <sub>2</sub> target (g CO <sub>2</sub> /km)	Equivalent fuel economy target (L/100km)	Annualised percentage reduction (during each compliance period) ^	Annualised percentage reductions (various historical periods)
EU 2009	CO <sub>2</sub> emissions	2015 2020* 2025*	130 95 68-78**	5.6 4.1 2.9-3.3	Achieved in 2013 4.1 3.9-6.5	2000-09 1.8 2009-13: 3.4
United States 1975	Fuel economy and GHG	2020 2025	121 93	5.2 4.0	5.1 5.1	2000-13: 1.9
Japan 1985	Fuel economy	2015 2020	125 105	5.3 4.5	Achieved in 2011 1.4	2000-11: 3.2
Republic of Korea 2006	Fuel economy and GHG	2015	153	6.5	2.2	2003-11: 4.0
China 2004	Fuel economy	2015 2020**	161 117*	6.9 5.0	2.3 6.2	2002-12: 2.1
India 2016	CO <sub>2</sub> emissions	2016 2021	130 113	5.6 4.8	1.3 2.8	2006-12: 1.9
Canada 2011	GHG	2016 2025**	147 93*	6.3 4.0	5.2 5.0	2000-13: 1.3
Mexico 2012	Fuel economy and GHG	2016	153	6.5	3.8	2008-11: 2.6

According to Table 2 and Table 3, the emissions data of Mazda 3 fits the standard in China.

The high thermal efficiency of HCCI reduces the consumption of fuel. HCCI engines in production can reduce the fuel consumption of cars and people's spending on automotive fuel. Because of the advantages of environmental protection and fuel economy, Mazda took the lead in releasing models using HCCI, which is exactly the significant advantage of HCCI in the future internal combustion engine market. Mazda will still conduct more research and application of HCCI, which will enable HCCI technology to be invested and developed in the future.

The existing HCCI technology will occupy a share in the market with the advantages of low emissions and low fuel consumption, and attract more automobile companies to carry out the research and application of HCCI engines. The investment of more automobile manufacturers will make HCCI technology become more and more mature, and one day occupy the mainstream of the internal combustion engine market.

The trend shows that the internal combustion engine will be gradually replaced by electric vehicles, and the emergence of HCCI engine can make the internal combustion engine occupy the mainstream market for more time in the future according to its advantages.

#### 4. Conclusion

As an emerging type of engines, HCCI engine is now in the research and development stage. Throughout the comparison above, HCCI engine has two significant advantages, namely high thermal efficiency and low pollution. HCCI engine also has its drawback of upper and lower limits of operating loads. As for the application, some concept cars were posted by some automobile companies, and only one automobile corporation continues to develop HCCI engine now. In the

future, HCCI engine will expand its advantages in environment protection and fuel economy, also occupy a part of market. Environmental pollution is concerned, while HCCI engine is an advanced plan of internal combustion engine. Following the trend of reducing emissions and cost of road traffic, HCCI engine will become the best choice of internal combustion engine. This tendency will bring an effective alternative, which reduces pollution and economic cost of fuel. This paper demonstrates how the status of HCCI is nowadays and will be in the future, and benefits for people to get information of HCCI development today and in the future. Further research on HCCI engine will expand more and more on the technology and lead HCCI engine to apply its advantages for majority of people.

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