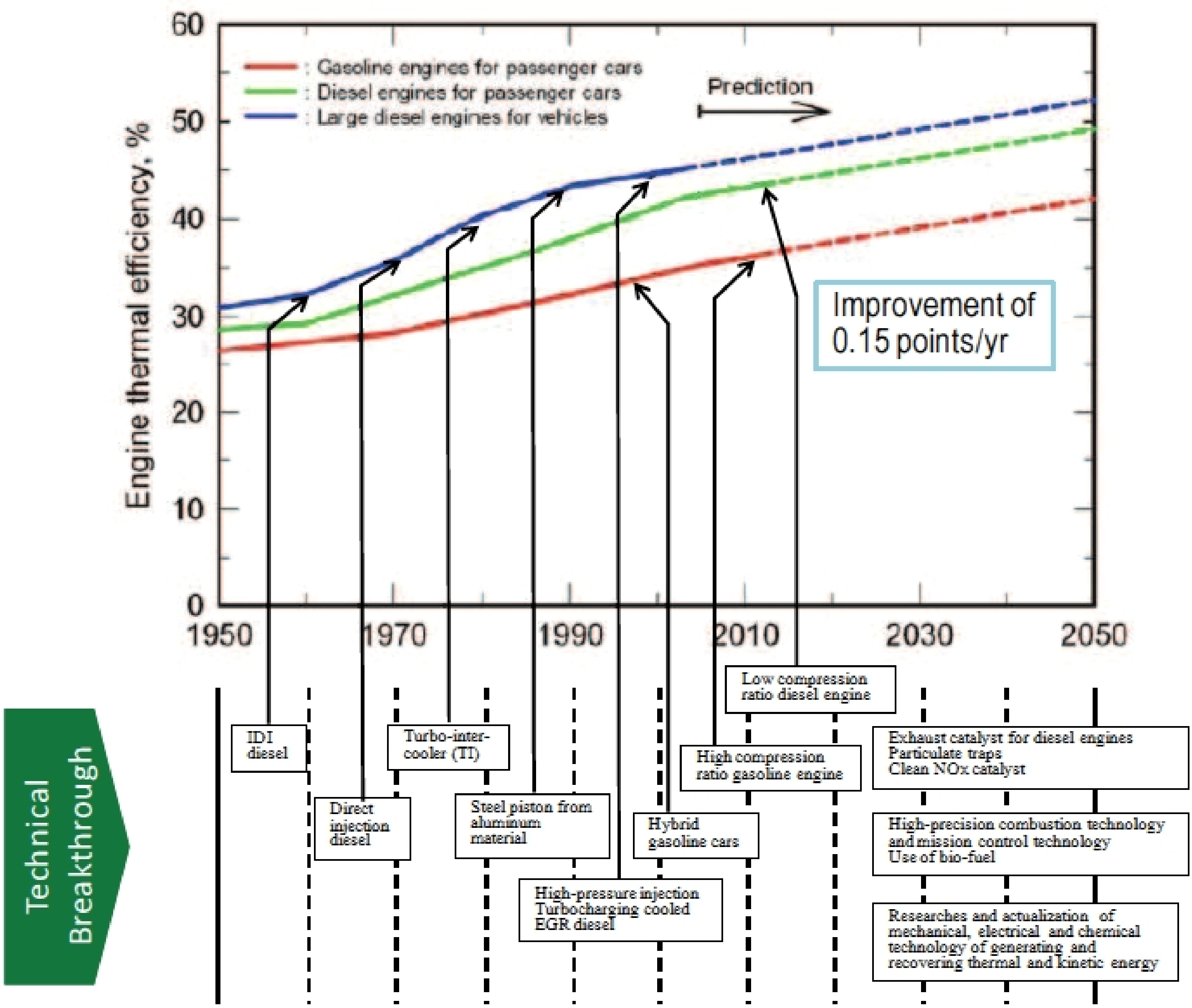
2012 年度版

# 第 90 期(2012 年)エンジンの熱効率技術ロードマップ

本年度のロードマップ更新点

2011 年よりマツダ(株)より，オットーサイクルとしては画期的な高圧縮比（圧縮比 14）のガソリンエンジン，および，ディーゼルサイクルとしては画期的な低圧縮比（圧縮比 14）のディーゼルエンジンである SKYACTIV-G，SKYACTIV-D が，相次いで市場に投入された．従来のハイブリッド方式に肉薄する低 CO2 排出を，エンジンの熱効率向上という手段で達成するというシンプルかつ新しい選択肢が提示されたことで，この年は低燃費・低排出乗用車の開発の方向性に幅が広がった年といえる．なお，推算された熱効率は，これまでに提示された将来予測の線上に位置し，技術ブレイクスルーが着実に進んでいることを示している．



### (1) Aims

The roadmap of the engine system department covers gasoline engines used for passenger cars and motorbikes and diesel engines for passenger cars, trucks, buses, and ships. Research on fuel batteries also started recently. Improvement in thermal efficiency is important in the mechanical engineering field. From this point of view, this roadmap predicts the future of fuel efficiency improvement. Refer to the roadmap of the fuel consumption in car.

### (2) Social and technical needs

Engines used in cars are closely related to our daily lives and used for inner- and inter-city transportation. It was necessary to clean exhaust gas from engines, so gasoline car emission control started in 1966, and emission control applied to diesel cars in 1974. Emission control is also applied to ship engines and off-road vehicle engines. Stringent exhaust emission regulation will be required in the future. Improvement in the thermal efficiency capable of CO2 reduction is needed and is an important factor. Improvement of the engine thermal efficiency is indispensable for preventing global warming in the future.

### (3) Future directions for determining key mechanisms and parameters

Taking an example of large diesel engines for vehicles, development of the direct injection (DI) systems, turbo inter-coolers (TI), 4-valve/cylinder engines, and steel pistons enhanced thermal efficiency improvement. Electronic-controlled pressure accumulating high-pressure fuel injection (common rail type), variable nozzle superchargers (VGT), and variable swirl systems are produced by vehicle needs. Downsizing of vehicle engines was achieved by TI engines in 1980 by utilizing output increase due to superchargers, resulting in remarkable fuel efficiency improvement.

The following may be promising breakthrough technologies for improving the thermal efficiencies of reciprocating engines:

(1) New combustion systems for reducing NOx and PM simultaneously like pre-mixed compression ignition combustion.

(2) Friction-reduced lubricant oil

(3) Synthetic fuel featuring improved thermal efficiency

(4) Mechanical, electrical and chemical technology of generating and recovering thermal and kinetic energies

(5) Transfer from de-fossil fuel to biomass fuel

The fuel cell is an important breakthrough technology currently under examination. It is expected to be put into practical use from 2015 to 2020.

### (4) Contributions to society

As global warming shows rapid progress at present, improvement of the engine thermal efficiency directly related to CO2 reduction will possibly be accelerated by stronger external impacts. Thus, researchers and engineers in this field should be ready to take proper means of improving thermal efficiency at any time as society requires.

Taking an example of passenger cars, if the thermal efficiencies of a car at operating-area in the case of fuel economy at 15 km/L is doubled, the car will run at 30 km/L with the same quantity of fuel, and CO2 emission is halved. In 2025, new fuel cell cars and hybrid cars will be used widely, exhaust emissions will become cleaner, and CO2 emissions from cars will be reduced by 20 to 30 %. As global warming shows rapid progress at present, needs for improvement of the engine thermal efficiency directly related to CO2 reduction will become greater. Technical innovation in this field may progress earlier than prediction. We expect that more active discussions will be made based on this roadmap.

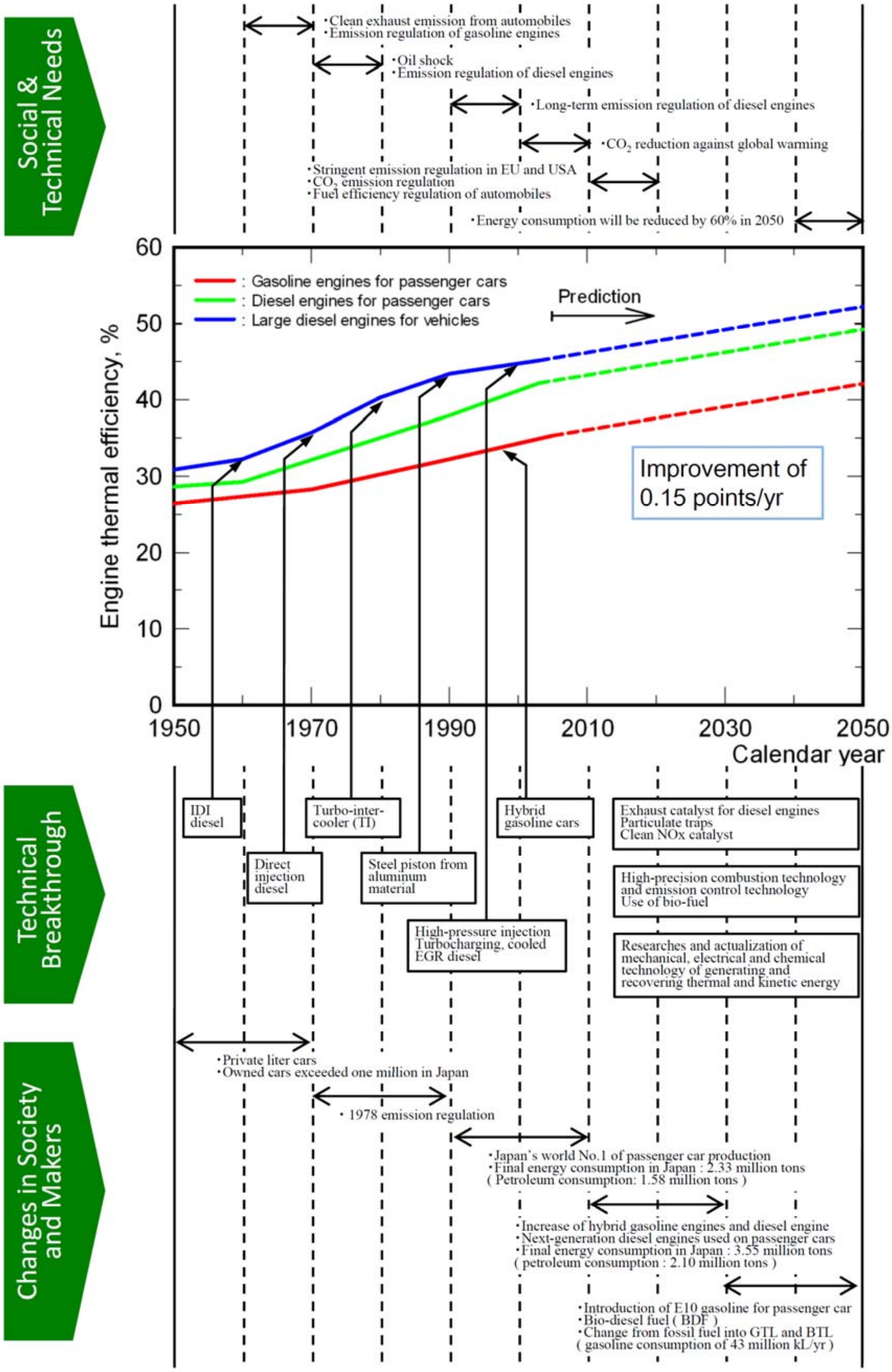
### (5) Estimates of carbon dioxide reductions by 2050

$CO_2$ emission reduction resulting from improving and maintaining the performance of automotive combustion engines, and using diesel engines on passenger cars, was estimated based on the following conditions:

Thermal efficiency of automotive combustion engine (see the figure)
Thermal efficiency increase rate: 0.15 point/year (see the figure)
Number of cars owned: assumed to be stable at 80,000,000
Number of cars replaced: 3,000,000/year (based on Ministry of Land, Infrastructure and Transport (MLIT) Statistics 2000-2006)
Car durability: Assumed to be 20 years
$CO_2$ emissions from cars in 2006: 222,000,000 tons (based on MLIT Statistics 2006)

The ratio of combustion engine types was assumed to be the same as in 2006, except for passenger cars. In the passenger car sector, the percentage of small diesel car sales was assumed to increase linearly from 10% to the EU level of 60% during the period from 2006 until 2050. The replacement of diesel cars with other diesel cars in this sector was ignored.

Based on the above conditions, car replacement is expected to reduce $CO_2$ emissions by about 18,000,000 tons (−8.2% from 2006)and by about 35,400,000 tons (−16% from 2006) in 2050.If passenger car sales in Japan were limited to diesel cars, all passenger cars in Japan would be diesel-powered around 2030.Should that happen, $CO_2$ emissions would be reduced by about27,000,000 tons (−12% from 2006) in 2030 and by about39,000,000 tons (−18% from 2006) in 2050. If all cars were to be replaced with hybrid or fuel cell models and if biofuels were more commonly used, $CO_2$ emissions would decrease even further.



Social & Technical Needs
・Clean exhaust emission from automobiles
・Emission regulation of gasoline engines
・Oil shock
・Emission regulation of diesel engines
・Long-term emission regulation of diesel engines
・$CO_2$ reduction against global warming
・Stringent emission regulation in EU and USA
・$CO_2$ emission regulation
・Fuel efficiency regulation of automobiles
・Energy consumption will be reduced by 60% in 2050
: Gasoline engines for passenger cars
: Diesel engines for passenger cars
: Large diesel engines for vehicles
Prediction
Improvement of 0.15 points/yr
Engine thermal efficiency, %
0
10
20
30
40
50
60
1950
1970
1990
2010
2030
2050
Calendar year
Technical Breakthrough
IDI diesel
Direct injection diesel
Turbo-inter-cooler (TI)
Steel piston from aluminum material
High-pressure injection Turbocharging, cooled EGR diesel
Hybrid gasoline cars
Exhaust catalyst for diesel engines Particulate traps Clean NOx catalyst
High-precision combustion technology and emission control technology Use of bio-fuel
Researches and actualization of mechanical, electrical and chemical technology of generating and recovering thermal and kinetic energy
Changes in Society and Makers
・Private liter cars
・Owned cars exceeded one million in Japan
・1978 emission regulation
・Japan's world No.1 of passenger car production
・Final energy consumption in Japan : 2.33 million tons
( Petroleum consumption: 1.58 million tons )
・Increase of hybrid gasoline engines and diesel engine
・Next-generation diesel engines used on passenger cars
・Final energy consumption in Japan : 3.55 million tons
( petroleum consumption : 2.10 million tons )
・Introduction of E10 gasoline for passenger car
・Bio-diesel fuel ( BDF )
・Change from fossil fuel into GTL and BTL
( gasoline consumption of 43 million kL/yr )

*Demand side*

| | | | Base line 2006 | Climate plan 2015 | 2030 | 2050 |
|---|---|---|---|---|---|---|
| Thermal engines of automobiles | | | | | | |
| | Savings | Consumption if old technologies are sustained (BAU)(PJ) | | | | |
| | | Consuption (PJ) | | | | |
| | | Net saving (PJ) | | | | |
| | Cost (Investment, operation & maintenance, fuel)($ per PJ) | | | | | |
| | Cost per PJ saved | | | | | |
| | GHG reduction potential | Emissions of old technologies are sustained and with current trends (BAU) | 222,000,000 tons | 222,000,000 tons | 222,000,000 tons | 222,000,000 tons |
| | | Emissions after implementing new technology and measures | | 216,000,000 tons | 204,000,000 tons | 187,000,000 tons |
| | | Total reduction potential | | 6,000,000 tons | 18,000,000 tons | 35,000,000 tons |
| | Cost of GHG reduction ($/Tons $CO_2$-equivalent) | | | | | |

# Thermal Efficiency of Engines

## (1) Aims

The roadmap of the engine system department covers gasoline engines used for passenger cars, diesel engines for passenger cars, trucks and buses, and ships. Research on fuel cells also started recently. Improvement in thermal efficiency is important in the mechanical engineering field. From this point of view, this roadmap predicts the future of fuel efficiency improvement. Refer to the roadmap of the fuel consumption in passenger car..

## (2) Social and technical needs

Engines used in automobiles are closely related to our daily lives and used for inner- and inter-city transportation. It was necessary to clean exhaust gas emissions from engines, so gasoline engine emission regulation started in 1966, and emission regulation was applied to diesel engine in 1974. Emission regulation is also applied to ship engines and off-road vehicle engines. Stringent exhaust emission regulation will be required in the future. Improvement in the thermal efficiency capable of $CO_2$ reduction is needed and is an important factor. Improvement of the engine thermal efficiency is indispensable for preventing global warming in the future.

## (3) Future directions for determining key mechanisms and parameters

Taking an example of large diesel engines for vehicles, development of the direct injection (DI) systems, turbo inter-coolers (TI), 4-valve/cylinder engines, and steel pistons enhanced thermal efficiency improvement. Electronic-controlled and high-pressure fuel injection (common rail type), variable nozzle superchargers (VGT), and variable swirl systems are produced by vehicle needs. Downsizing of vehicle engine was achieved by TI engine in 1980 by utilizing output increase due to turbochargers, resulting in remarkable fuel efficiency improvement.

The following may be promising breakthrough technologies for improving the thermal efficiencies of reciprocating engines:

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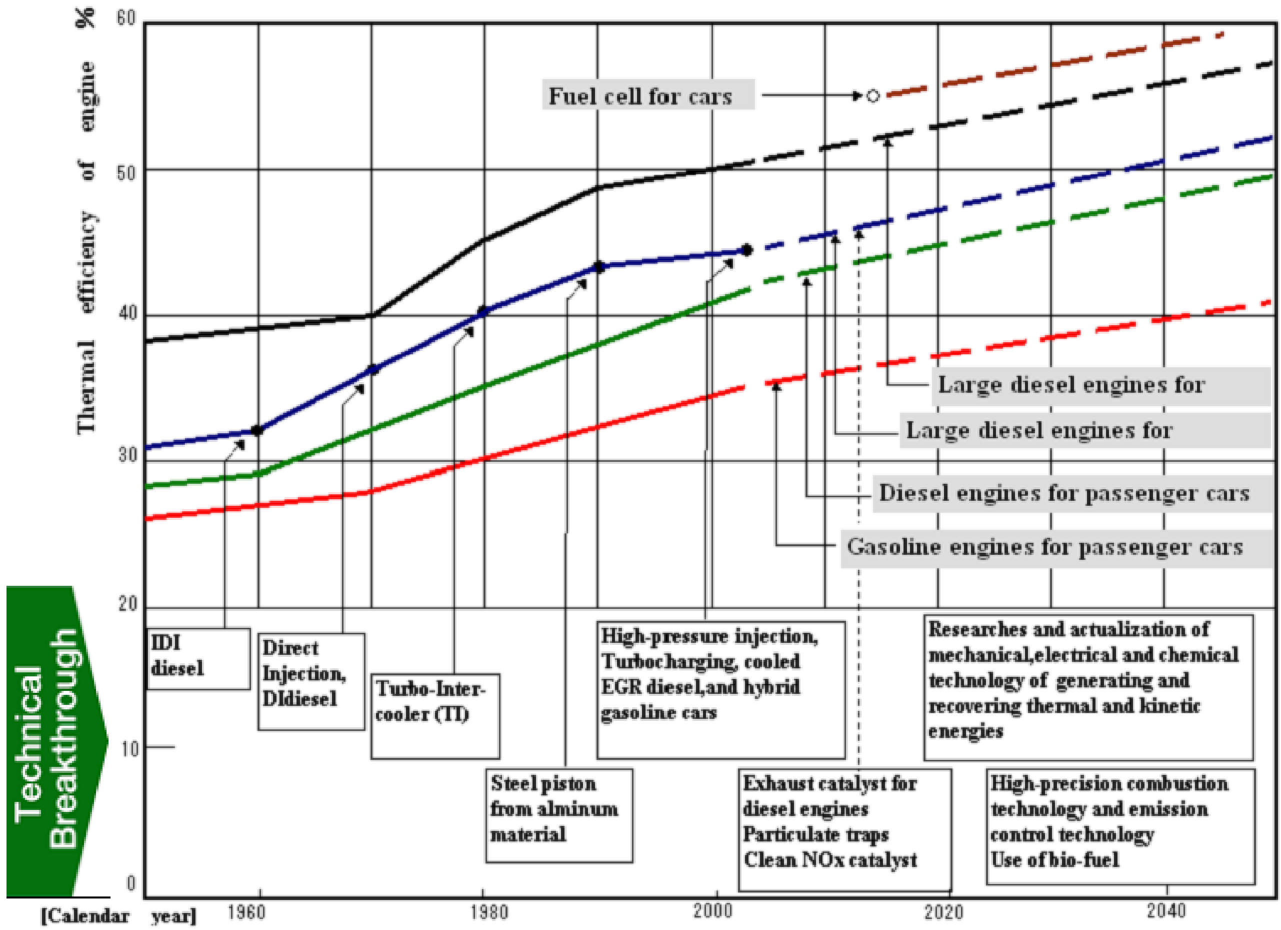
**Social & Technical Needs**

| | |
|---|---|
| 1950～1960 | |
| 1960～1970 | ・Clean exhaust emission from automobiles<br>・Emission regulation of gasoline engines |
| 1970～1980 | ・Oil shock<br>・Emission regulation of diesel engines |
| 1980～1990 | |
| 1990～2000 | ・Long term emission regulation of diesel engines |
| 2000～2010 | ・$CO_2$ reduction against global warming |
| 2010～2020 | ・Strengthened emission regulation in EU and USA<br>・$CO_2$ emission regulation<br>・Fuel efficiency regulation of automobiles |
| 2020～2030 | |
| 2030～2040 | |
| 2040～2050 | ・Energy consumption will be reduced by 60% in 2050. |




## Changes in Society and Markets

| | |
|---|---|
| 1950～1970 | ・Age of private liter cars<br>・Number of owned cars in Japan exceeded 1 million.<br>・Transistor TV sets were released first in the world.<br>・Apollo 11 landed on the moon. |
| 1970～1990 | ・1978 emission regulation<br>・Word processors and PCs were released.<br>・Weather and broadcast satellites were launched.<br>・Personal computer communication started. |
| 1990～2010 | ・Japan is No.1 of passenger car production in the world.<br>・Final energy consumption in Japan: 3.33 million tons.<br>(petroleum consumption: 1.58 million tons)<br>・BS high vision test broadcasting started.<br>・Internet was used widely. |
| 2010～2030 | ・Hybrid gasoline engines and diesel engines will increase.<br>・Next-generation diesel engines will be used passenger cars.<br>・Final energy consumption in Japan: 3.55 million tons<br>(petroleum consumption: 2.10 million tons ) |
| 2030～2050 | ・Introduction of E10 gasoline for passenger car<br>・Bio-diesel fuel (BDF)<br>・Change from fossil fuel into GTL and BTL<br>(Gasoline consumption of 86 million kL/year will be reduced to half.) |

2007年度版

# エンジンの熱効率技術ロードマップ

エンジンシステム部門 技術ロードマップ委員会 委員長 （株）新エィシーイー 青柳友三

## 1. 趣旨

乗用車，二輪車に使われているガソリンエンジン，トラック，バス，鉄道，船舶などに広く使われているディーゼルエンジンの排出ガスクリーン化の社会要請，今後の燃料電池の実用化に鑑み，$CO_2$ 低減に有効な熱効率の向上に関し，技術的な将来予測を行う．

## 2. 排出ガス低減と熱効率向上を実現するメカニズム

特にディーゼルエンジンは，1974 年の車両に対する規制に始まり，舶用エンジンやオフロードエンジンにも適用の範囲が拡大している．車両用ディーゼルエンジンでは排出ガス低減と熱効率向上を目的に，以下の技術が開発された．

1）燃料のシリンダ内直接噴射（DI）化，
2）ターボインタークーラ（TI）化，
3）シリンダ当り 4 バルブ（4V）化，
4）スチール材のピストン（Steel P）

また排出ガスの低減化の新技術は下記があげられる．

5）電子制御式蓄圧型の高圧燃料噴射（コモンレール式），
6）可変ノズル式過給機（VGT），
7）可変スワール方式（VSR），

過給による出力向上と TI 化で，車両用エンジンは 1980 年にダウンサイジング化が為され，大端な燃費向上を実現した．

## 3. レシプロエンジンの熱効率向上のためのブレークスルー

①予混合圧縮着火燃焼などのような NOx と PM を同時に低減する燃焼方式，
②摩擦低減オイル，
③熱効率向上合成燃料，
④機械的電気的化学的な熱・運動エネルギーの発生と回収，
⑤脱化石燃料からバイオマス燃料への移行，
⑥燃料電池．2015～2020 年に実用化が望まれる

## 4. 将来の社会に対する展望

例えば，熱効率 15% で走行している車は，10km/L の燃費程度であるが，熱効率を 30% まで高めれば，20km/L になる．これは，1km あたりの $CO_2$ 発生量が半分になることを意味する．

現在，地球温暖化が急速に進行する中で，$CO_2$ 低減に直結するエンジン熱効率向上のニーズはますます高く，この分野の技術革新は予想よりももっと早く進展する可能性が高い．

この今回のロードマップを起点に議論の活発化を期待する．

本ロードマップは部門内に委員会を発足させ，これまでの技術的な進展と進展状況を精査し，これを基に専門家が数値的にエンジンの熱効率の具体的な将来予測を実施したものである．今後とも改良を加えていく予定である．


参考文献

（1）Aoyagi, Y., Osada, H., Misawa, M., Goto, Y. and Ishii, H., *SAE Paper* 2006-01-0077（2006）.

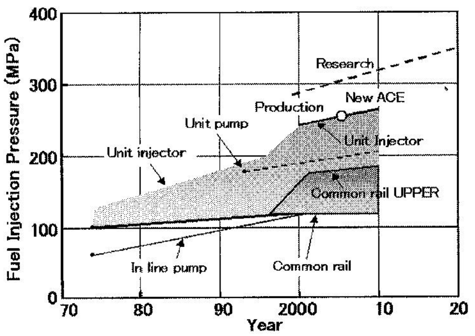




図 1 ディーゼルエンジンの噴射圧のトレンド

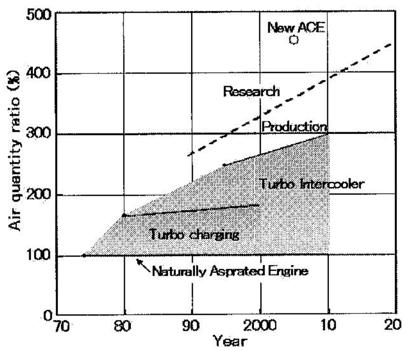



図 2 ディーゼルエンジンの過給圧のトレンド

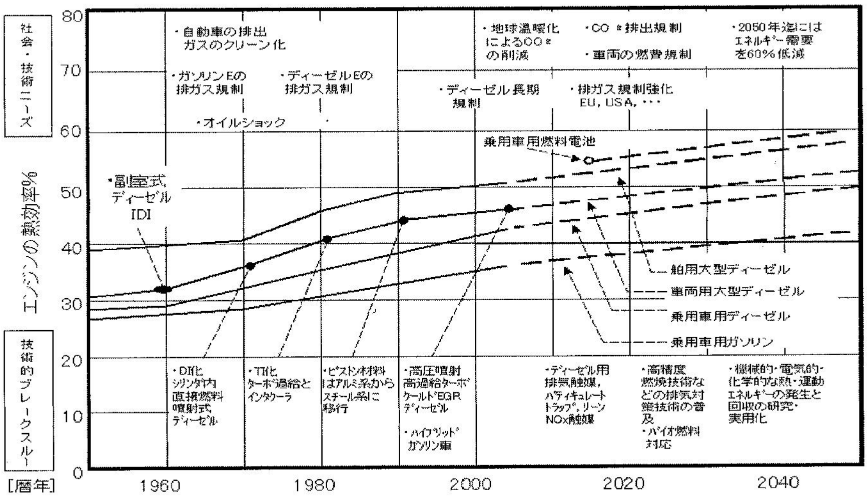



図 3 エンジン熱効率技術ロードマップ