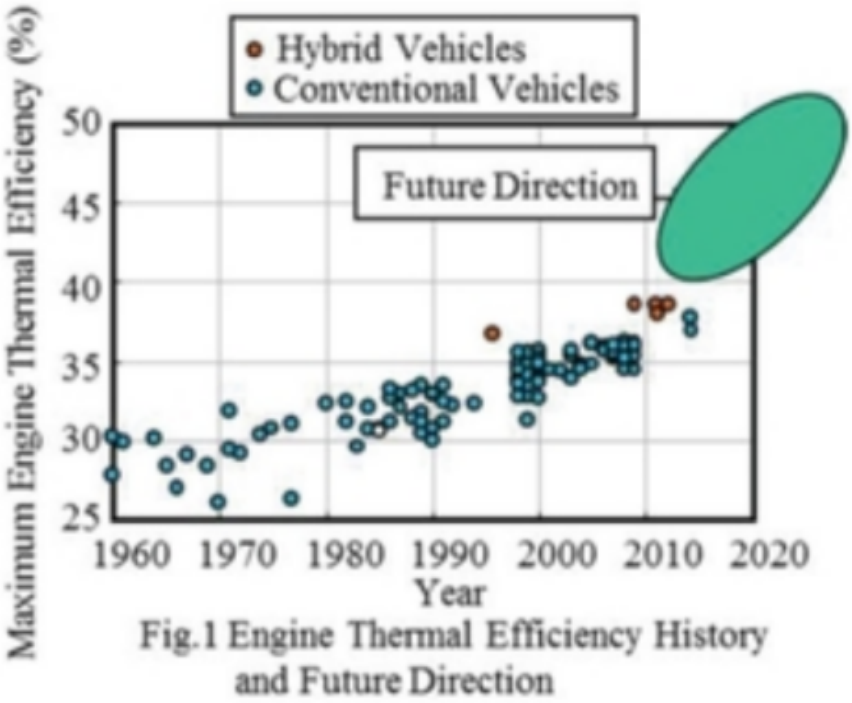
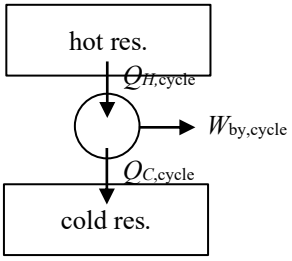


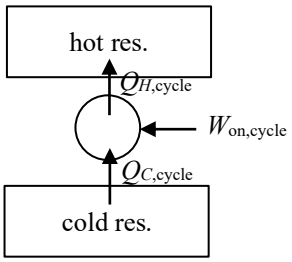
Fig.1. Engine Thermal Efficiency History and Future Direction

Figure from Nakata, K., Nogawa, S., Takahashi, D., Yoshihara, Y., Kumagai, A., and Suzuki, T., 2015, "Engine technologies for achieving 45% thermal efficiency of S.I. engine", *SAE International Journal of Engines*, Vol. 9, No. 1, pp. 179 - 192, doi: 10.4271/2015/01-1896.

Maximum Performance Measures



power cycle



refrigeration or heat pump cycle

Power cycle thermal efficiency

$$\eta = \frac{W_{by}}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

Refrigeration cycle coefficient of performance

$$COP_{ref} = \frac{Q_C}{W_{on}} = \frac{Q_C}{Q_H - Q_C} = \frac{1}{Q_H/Q_C - 1}$$

Heat pump cycle coefficient of performance

$$COP_{ref} = \frac{Q_H}{W_{on}} = \frac{Q_H}{Q_H - Q_C} = \frac{1}{1 - Q_C/Q_H}$$

If an absolute temperature scale is used, for a reversible cycle,

$$\eta_{rev} = 1 - \frac{Q_{C,rev}}{Q_{H,rev}} = 1 - \frac{T_C}{T_H} = \frac{T_H - T_C}{T_H}$$

$$COP_{ref,rev} = \frac{1}{Q_{H,rev}/Q_{C,rev} - 1} = \frac{1}{T_H/T_C - 1} = \frac{T_C}{T_H - T_C}$$

$$COP_{hp,rev} = \frac{1}{1 - Q_{C,rev}/Q_{H,rev}} = \frac{1}{1 - T_C/T_H} = \frac{T_H}{T_H - T_C}$$

These maximum values are sometimes referred to as the Carnot efficiency and Carnot Coefficient of Performance.