Energy and Material Co-production Systems for Minimizing the Exeregy Loss and CO2 Emission

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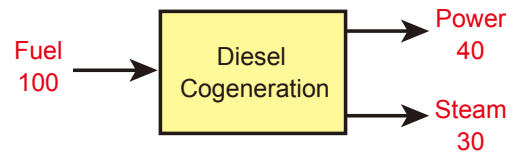
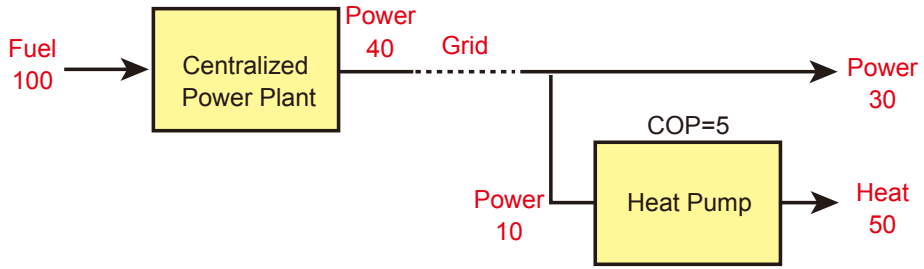
Evaluation Index of Energy System

1. Cogeneration vs. Grid Power + Heat Pump

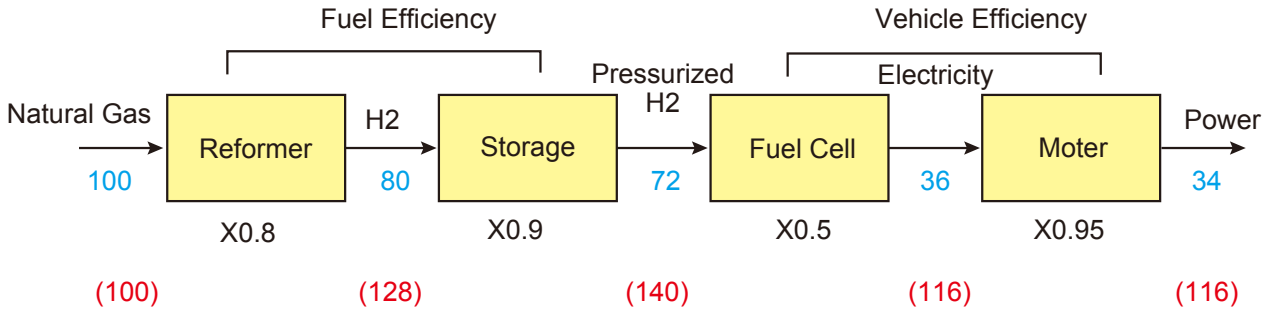


Cogeneration



Grid Power + Heat Pump

2. Well to Wheel Efficiency for FCV



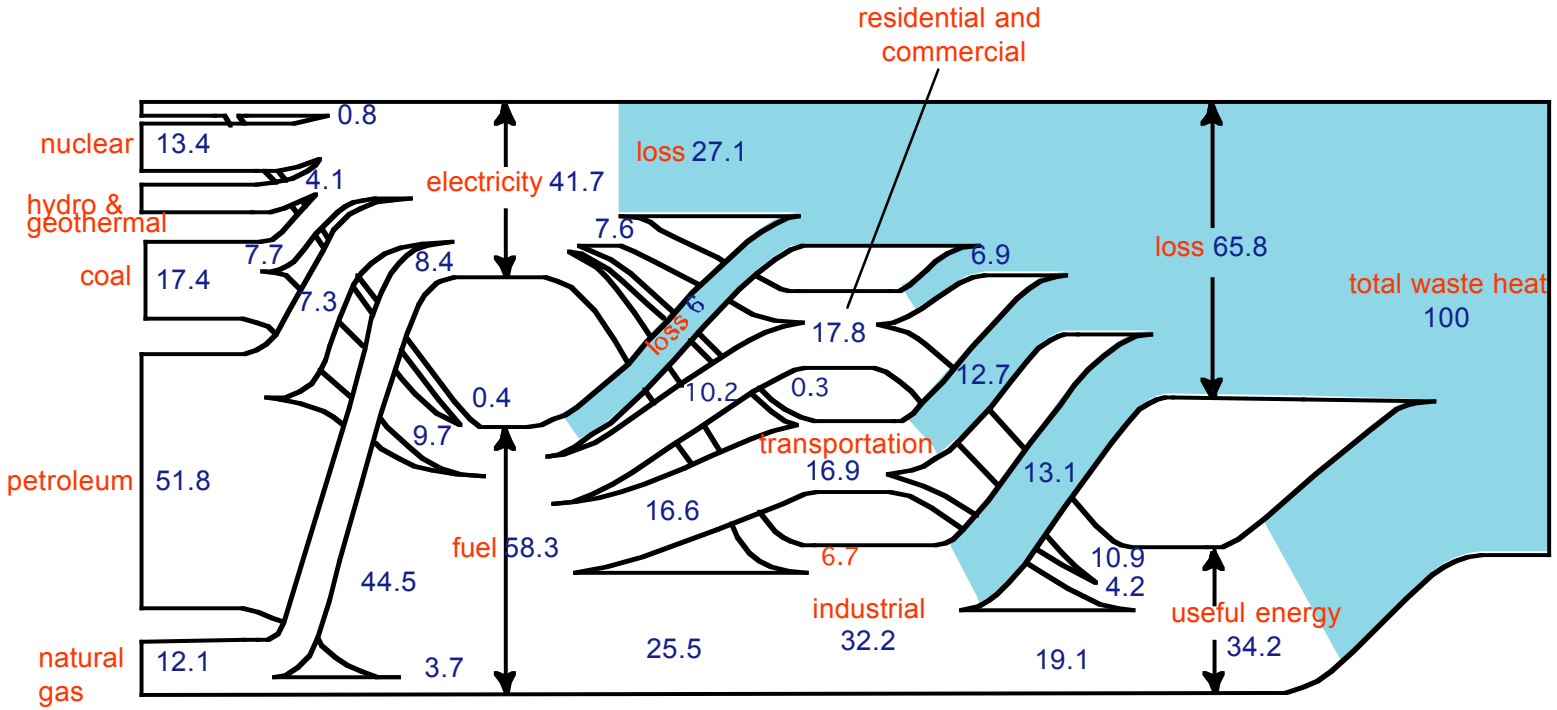
Measure of Energy Sustainability

- Energy Efficiency
- Energy Intensity

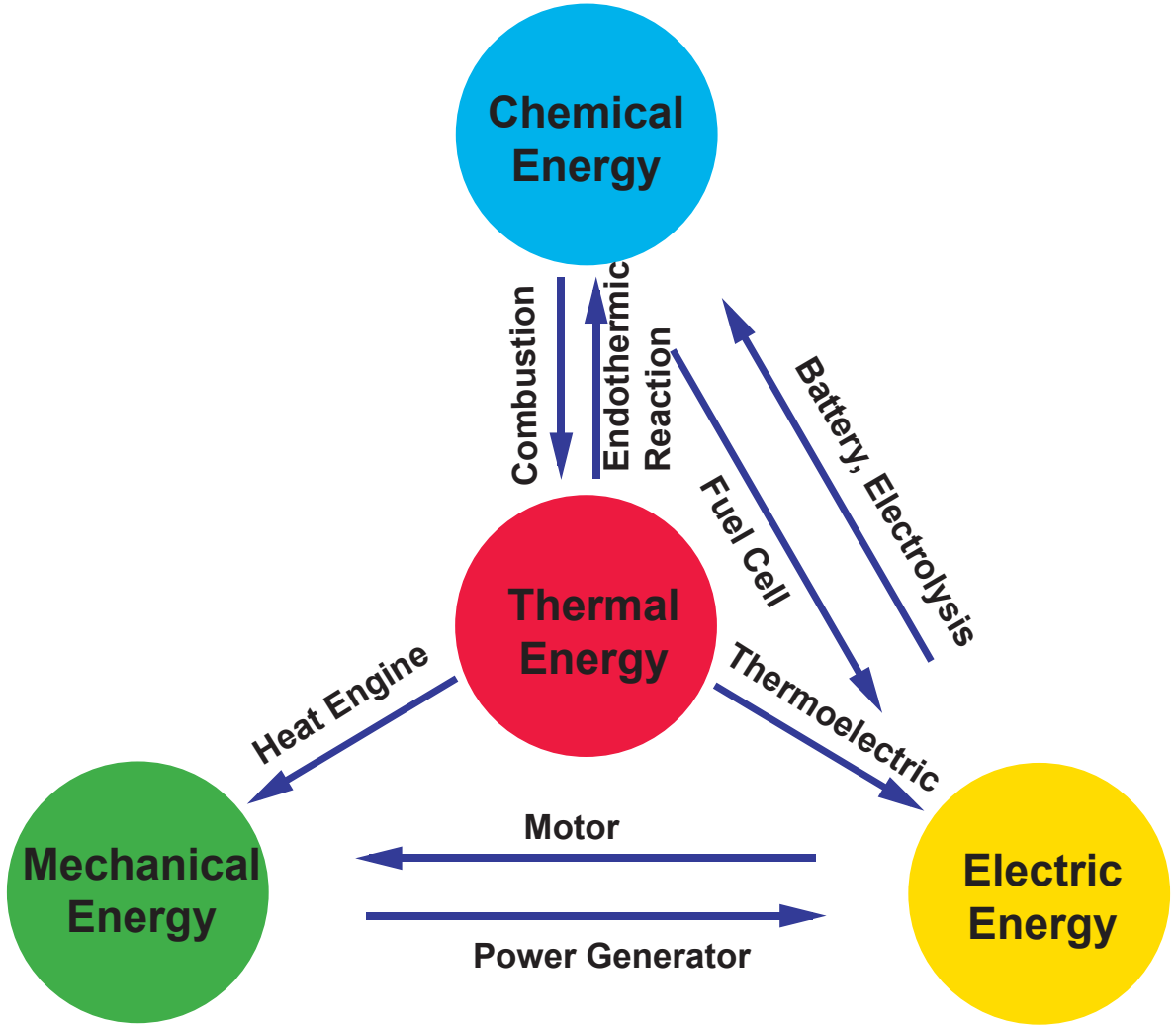
enthalpy basis

- What is exergy loss?
- Exergy Loss per unit Energy/Material Production
  - Material Production kJ/kg
  - Energy Production kJ/kJ
- Minimize the exegy loss through the whole process
- Exergy Recuperation Technology for Coproduction

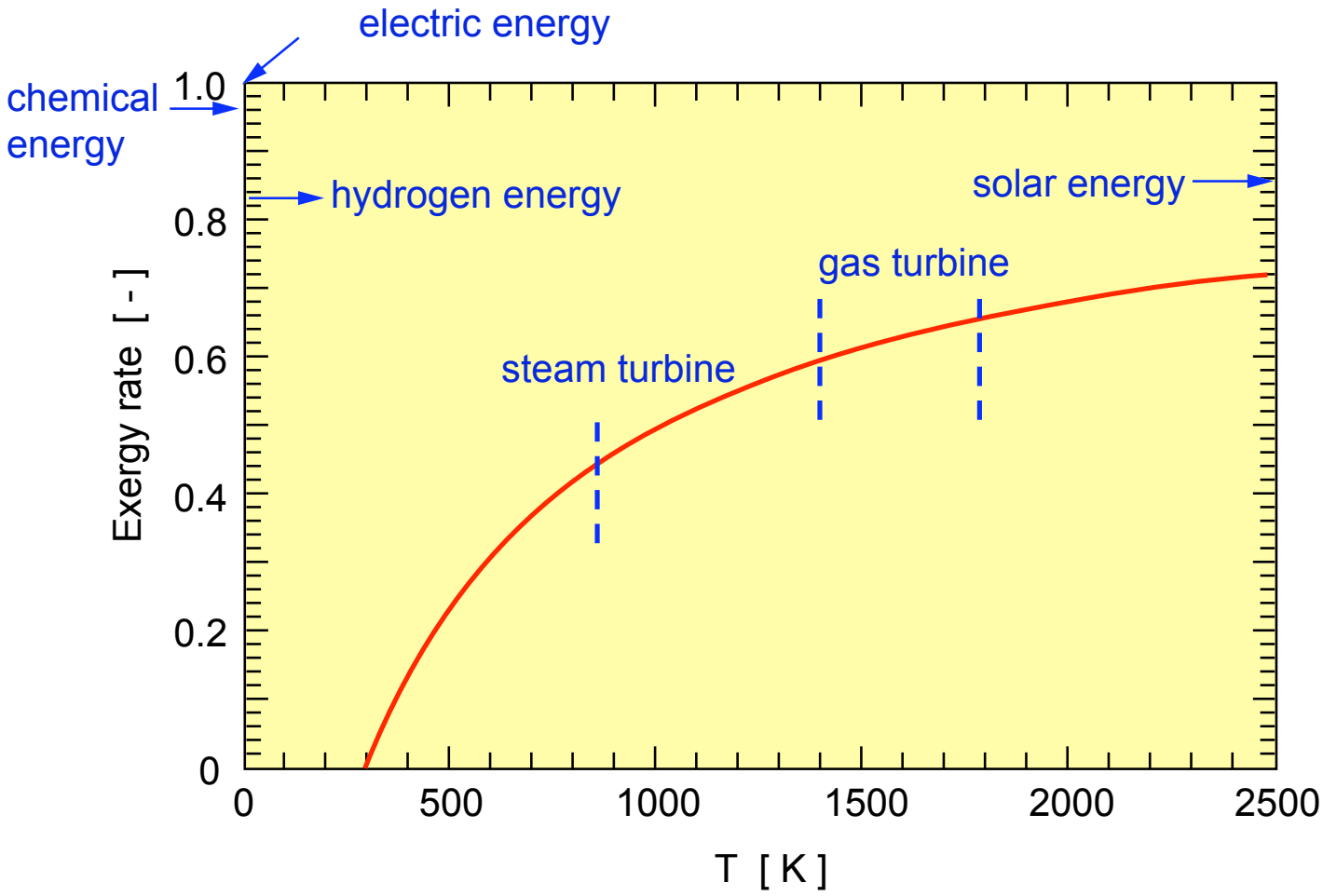
Energy flow diagram in Japan
Total energy consumption 5.4 x 10^{15} kcal (1997)



Energy Conversion and Energy Form



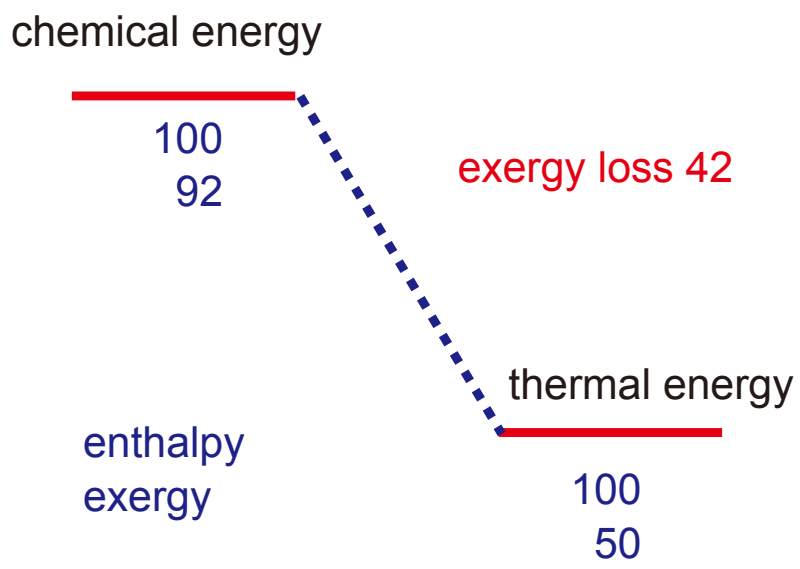
Exergy rate (Exergy/Enthalpy ratio)



exergy $A = \left(H - H_0\right) - T_0\left(S - S_0\right)$

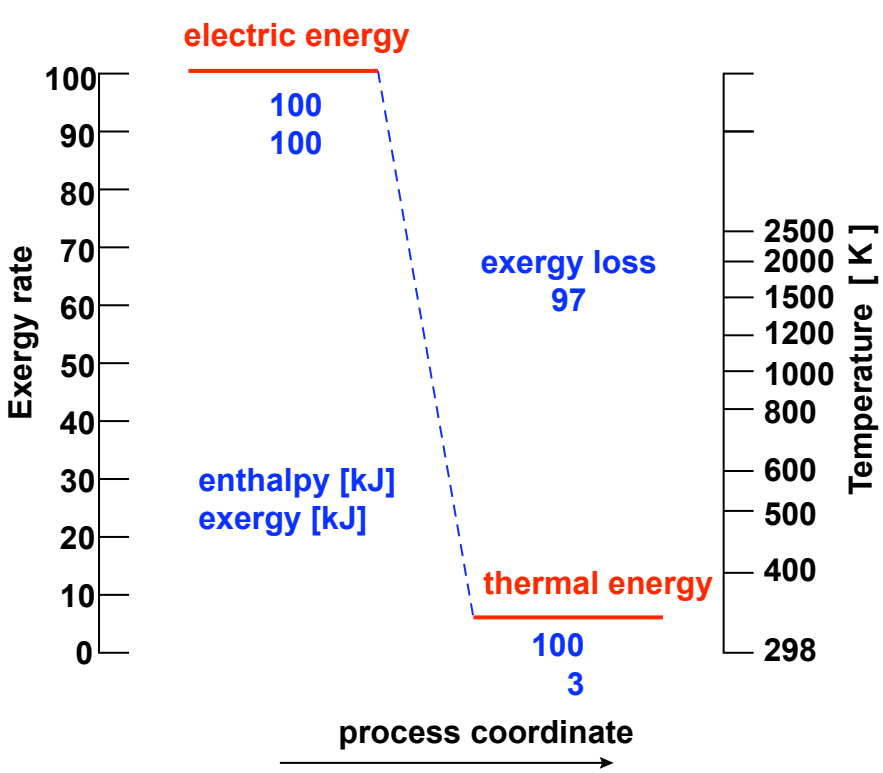
exergy rate $\varepsilon = \dfrac{\text{exergy}}{\text{enthalpy}}$

Exergy Dissipation in Combustion Process

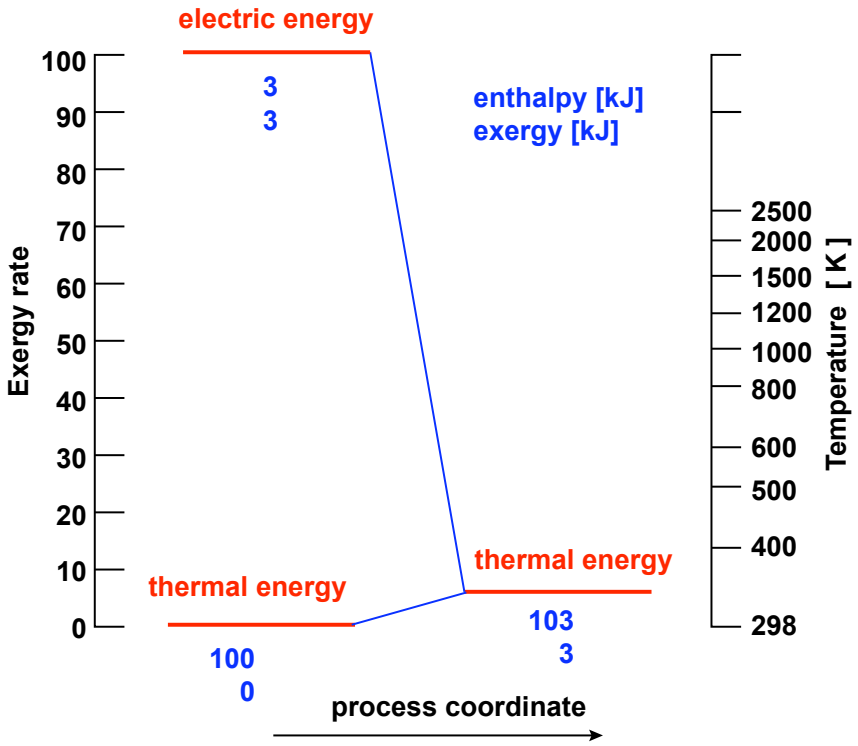


Exergy dissipation occurs in the combustion process because exergy rate of heat is lower than that of fuel.

Electric Heater vs. Heat Pump

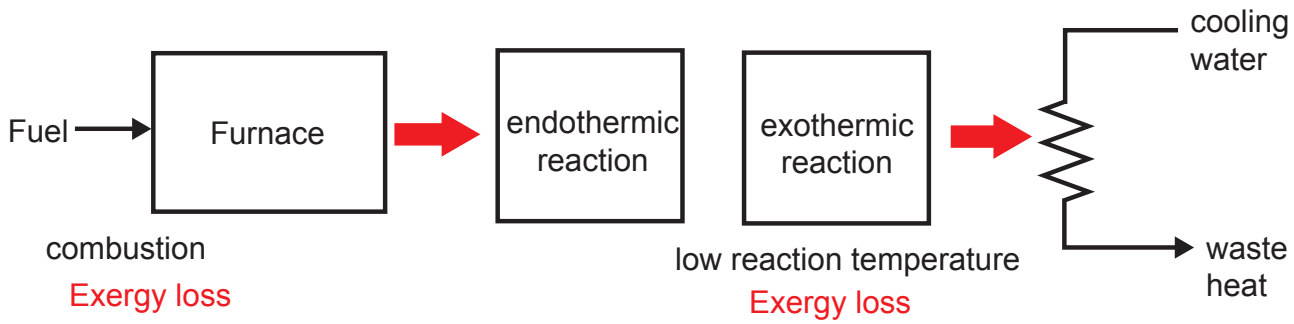


Energy conversion diagram of electic heater

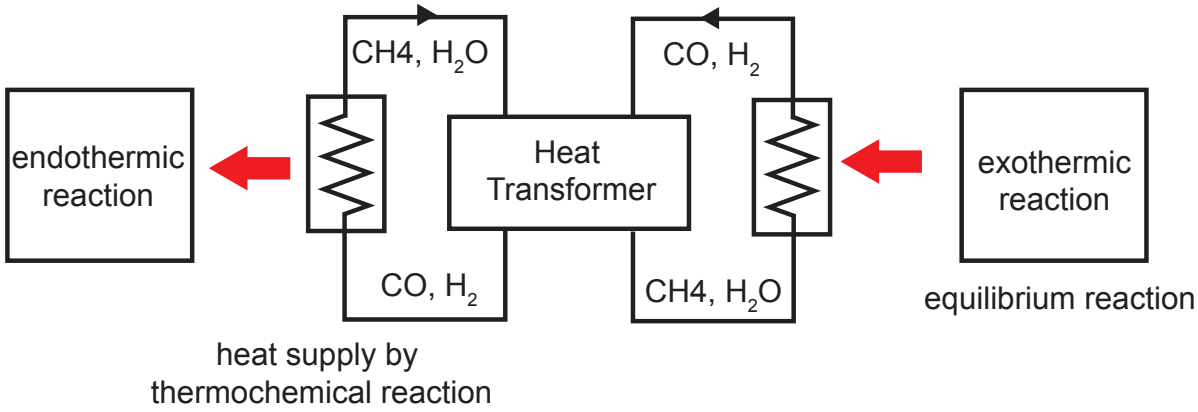


Energy conversion diagram of heat pump

Co-production by combination of endothermic and exothermic reactions

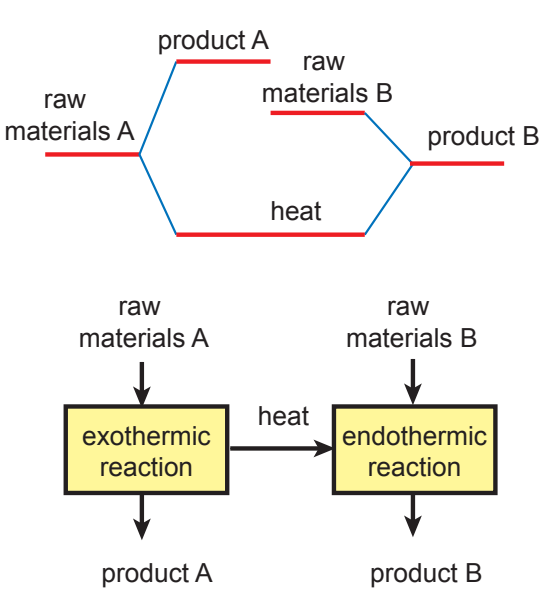


Conventional Material Production

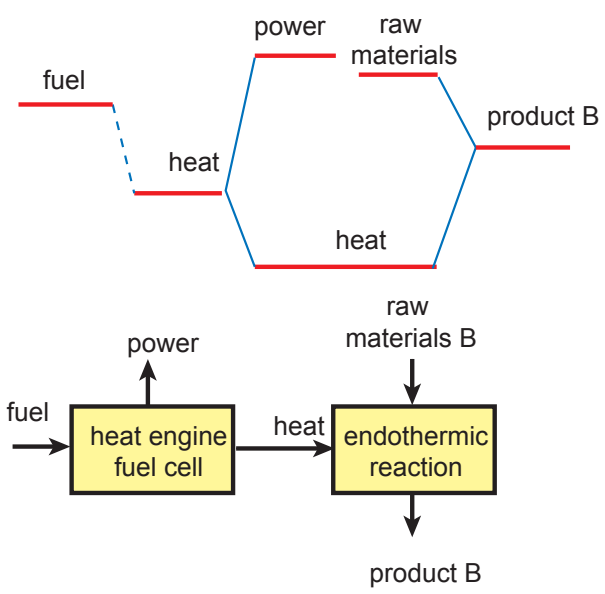


Coproduction by combination of endothermic and exothermic reactions

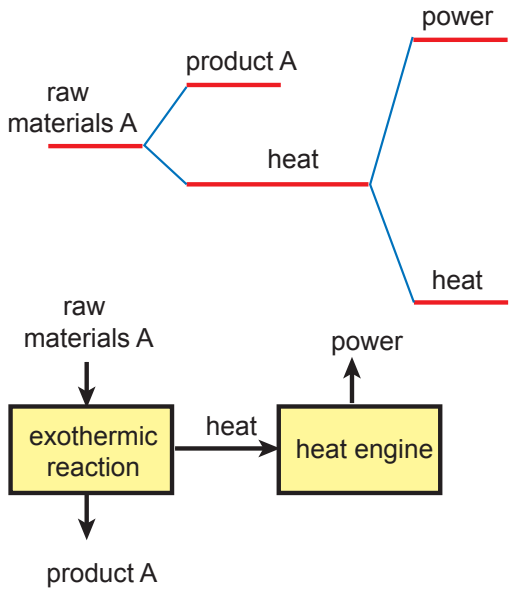
Material and Energy Co-production



(a) Integration of exothermic and endothermic reactions

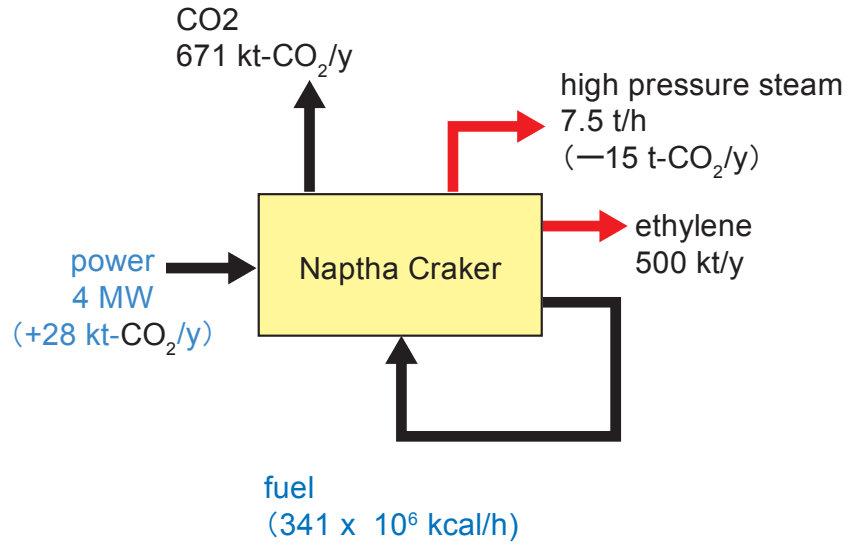


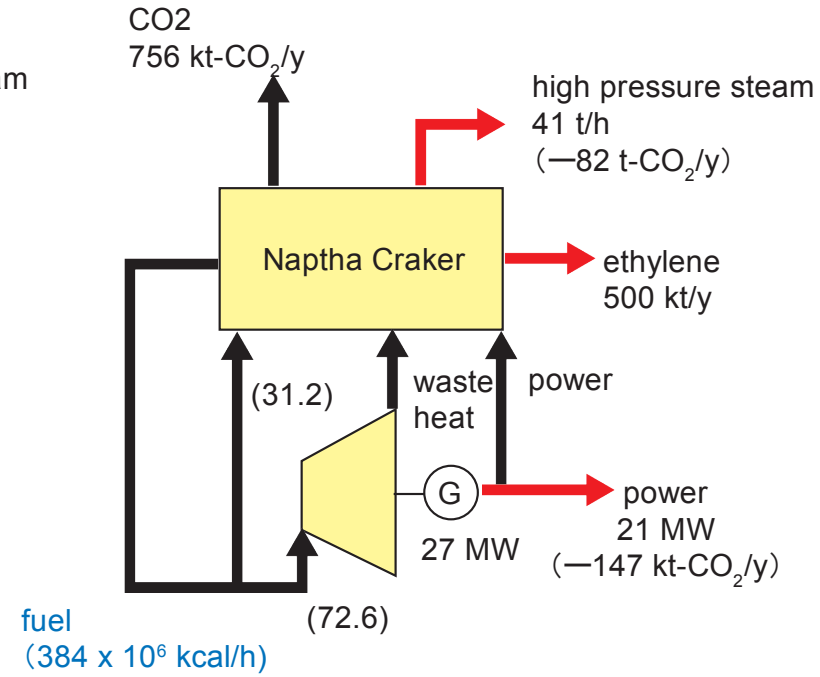
(b) Integration of endothermic reaction and heat engine/fuel cell



(c) Integration of exothermic reaction and heat engine

Gas Turbine integrated Ethylene Plant





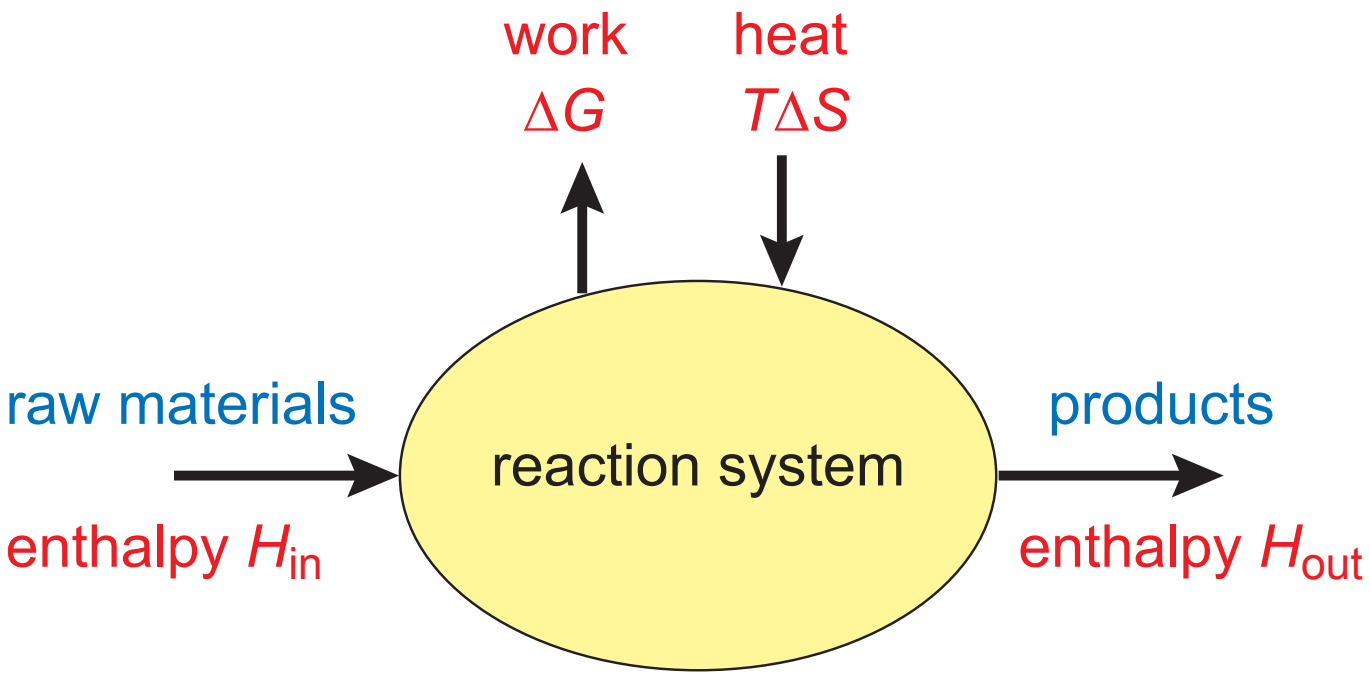
- Energy Intensity : 5922 kcal/kg-ethylene
- CO_2 emission: 684.4 kt-CO_2/y

Conventional Ethylene Plant

- Energy Intensity : 5093 kcal/kg-ethylene
- CO_2 emission: 526.9 kt-CO_2/y

GT-integrated Ethylene Plant

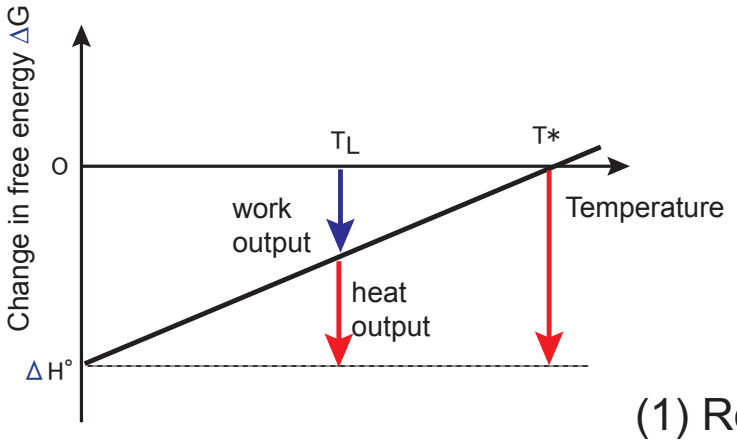
Energy balance of reaction system

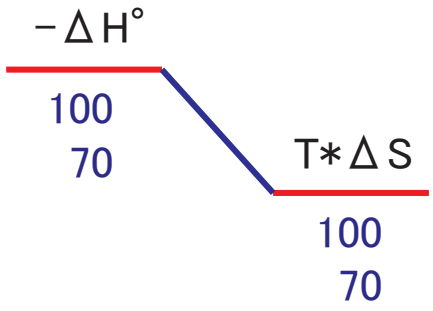


$$-\Delta H = H_{in} - H_{out} = -\Delta G - T\Delta S$$

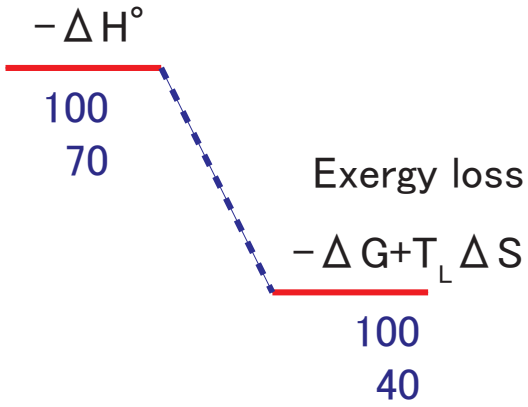
total energy work heat

Exergy loss in exothermic reaction

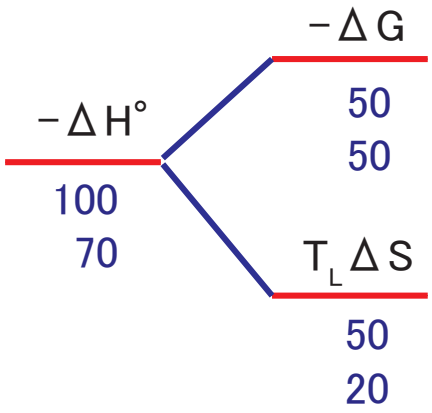




(1) Reaction at turning temperature T*

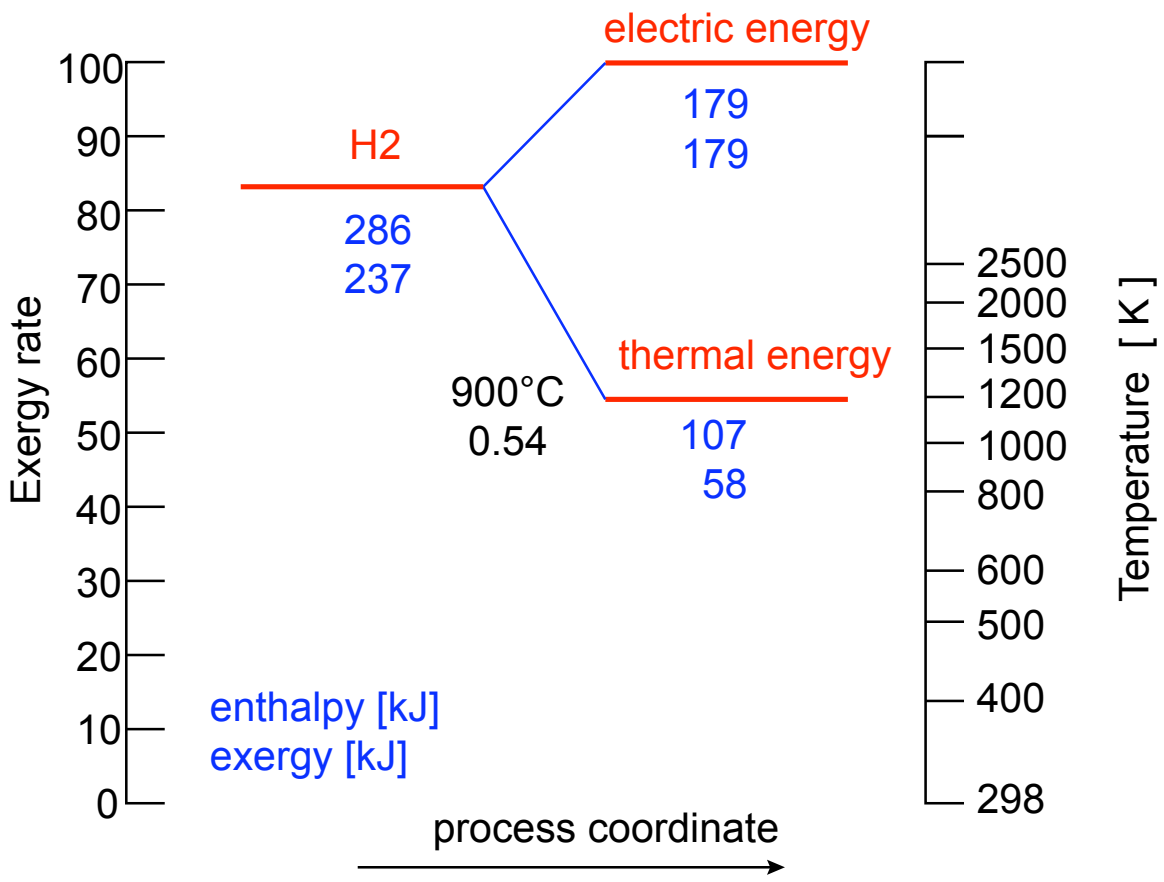


Exothermic reaction
at low temperature

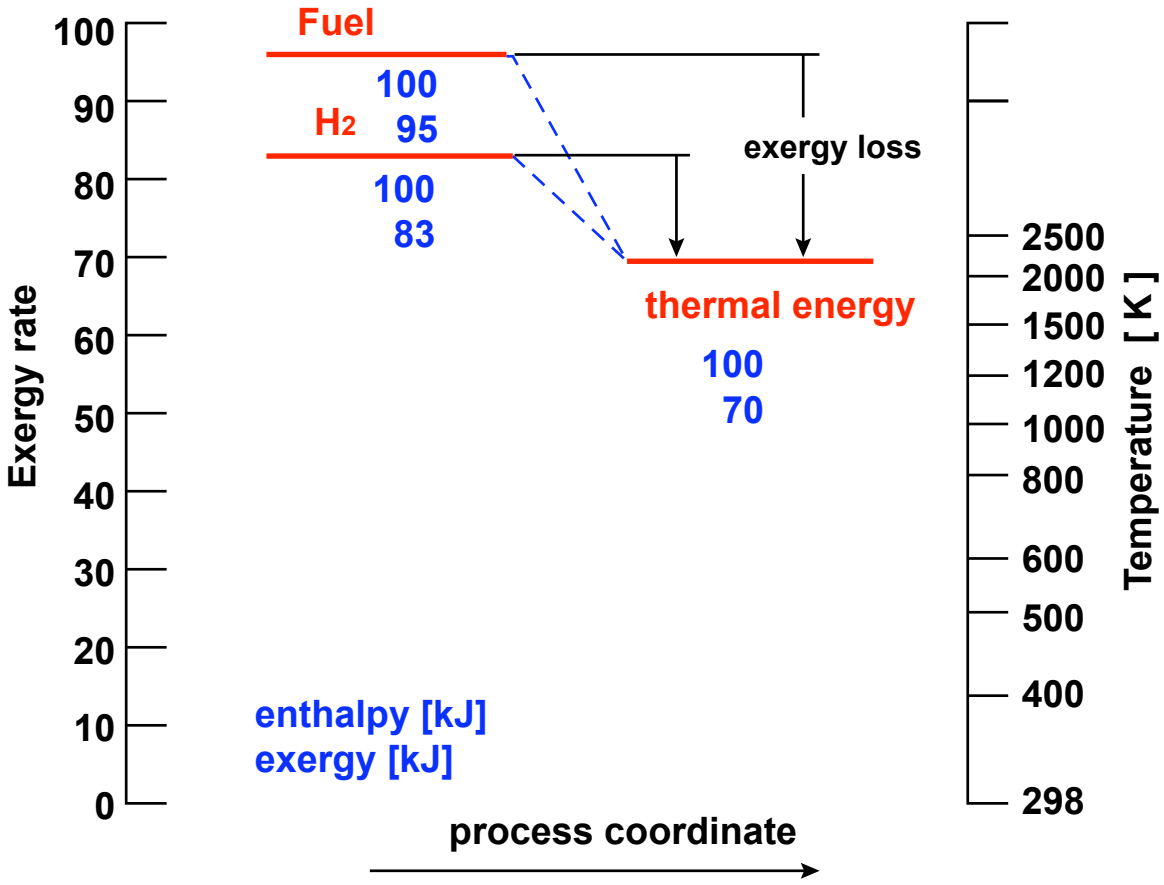


(2) -ΔG is produced as work

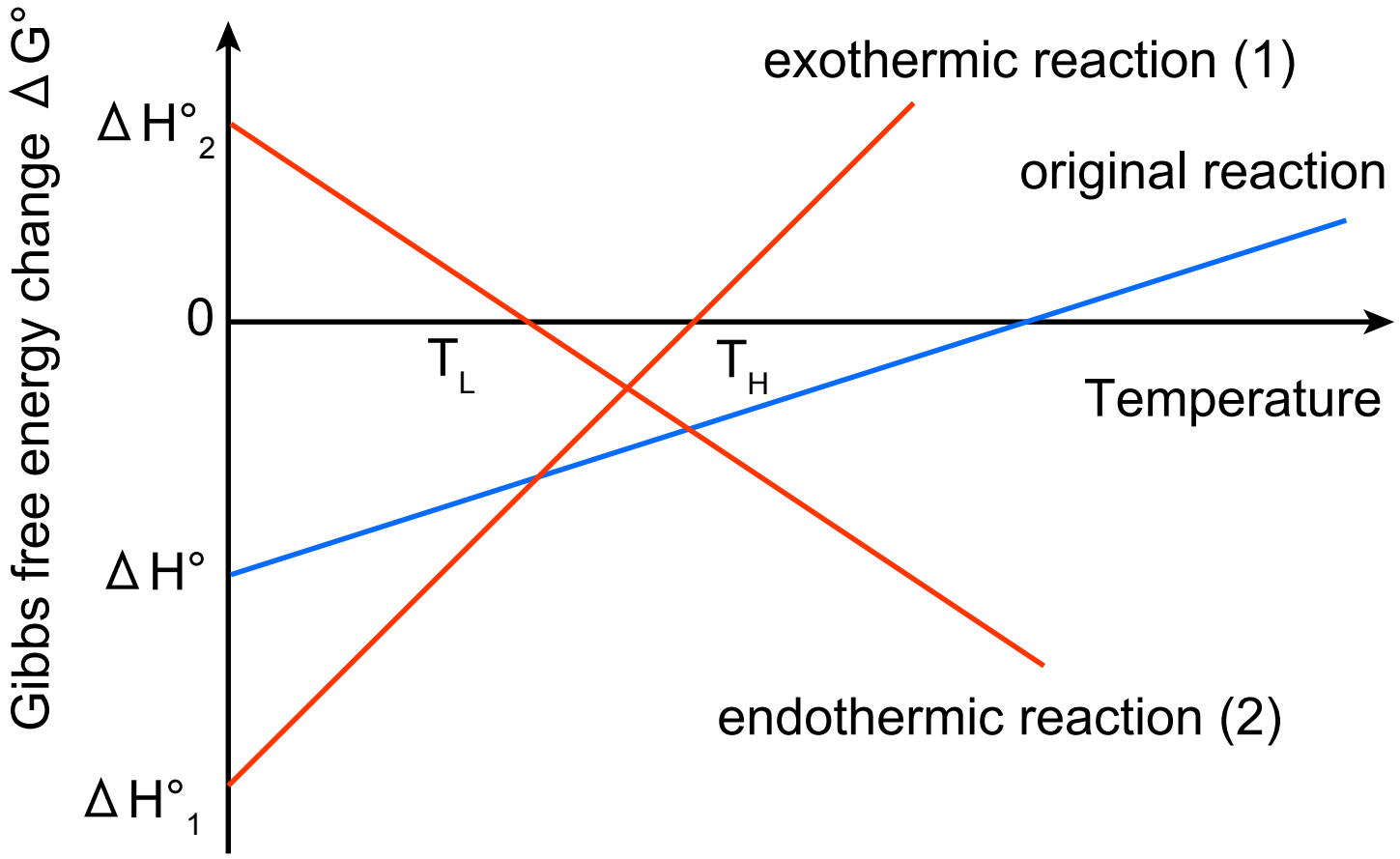
Energy conversion diagram of ideal SOFC



Exergy Loss in Combustion Process



The principal of reaction splitting



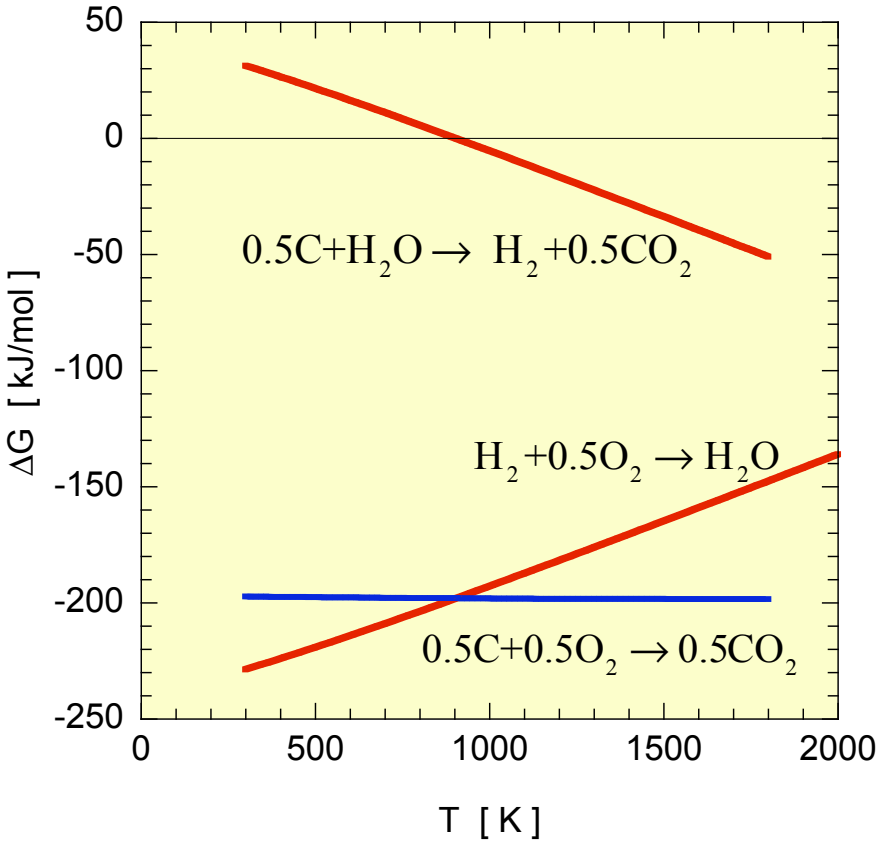
The Principle of Reaction Splitting

Hydrogen combustion $2H_2+O_2 \rightarrow 2H_2O$

Water gas reaction $C+2H_2O \rightarrow 2H_2+CO_2$

Carbon combustion $C+O_2 \rightarrow CO_2$

Carbon reforming combustion

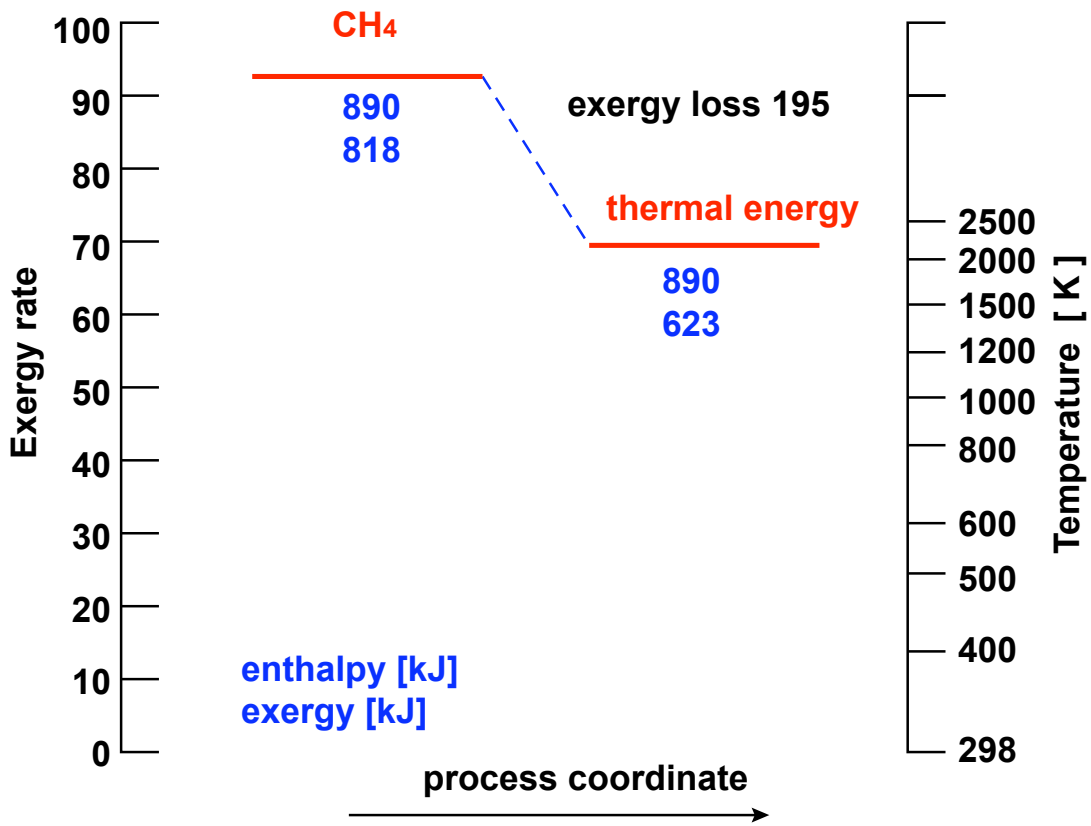


Hydrogen combustion $2H_2+O_2 \rightarrow 2H_2O$

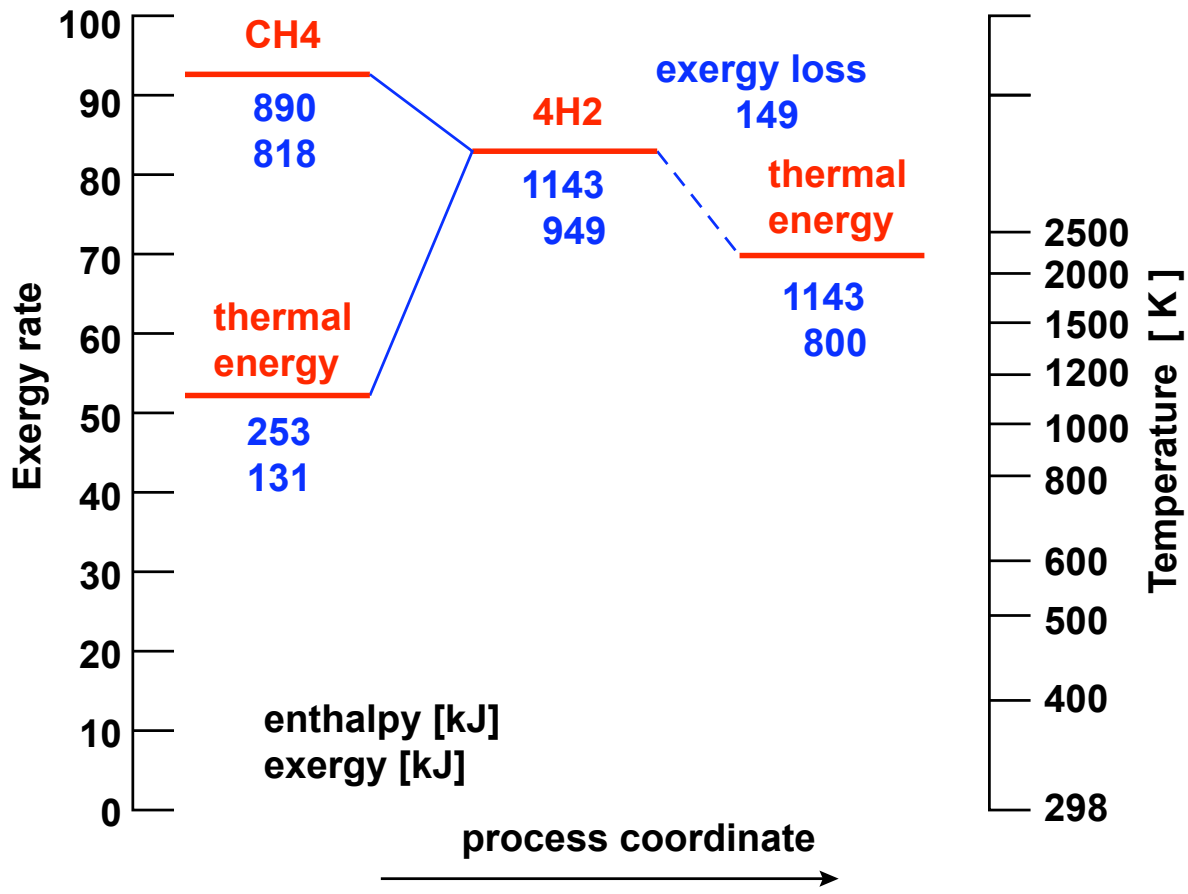
Water gas reaction $C+2H_2O \rightarrow 2H_2+CO_2$

Carbon combustion $C+O_2 \rightarrow CO_2$

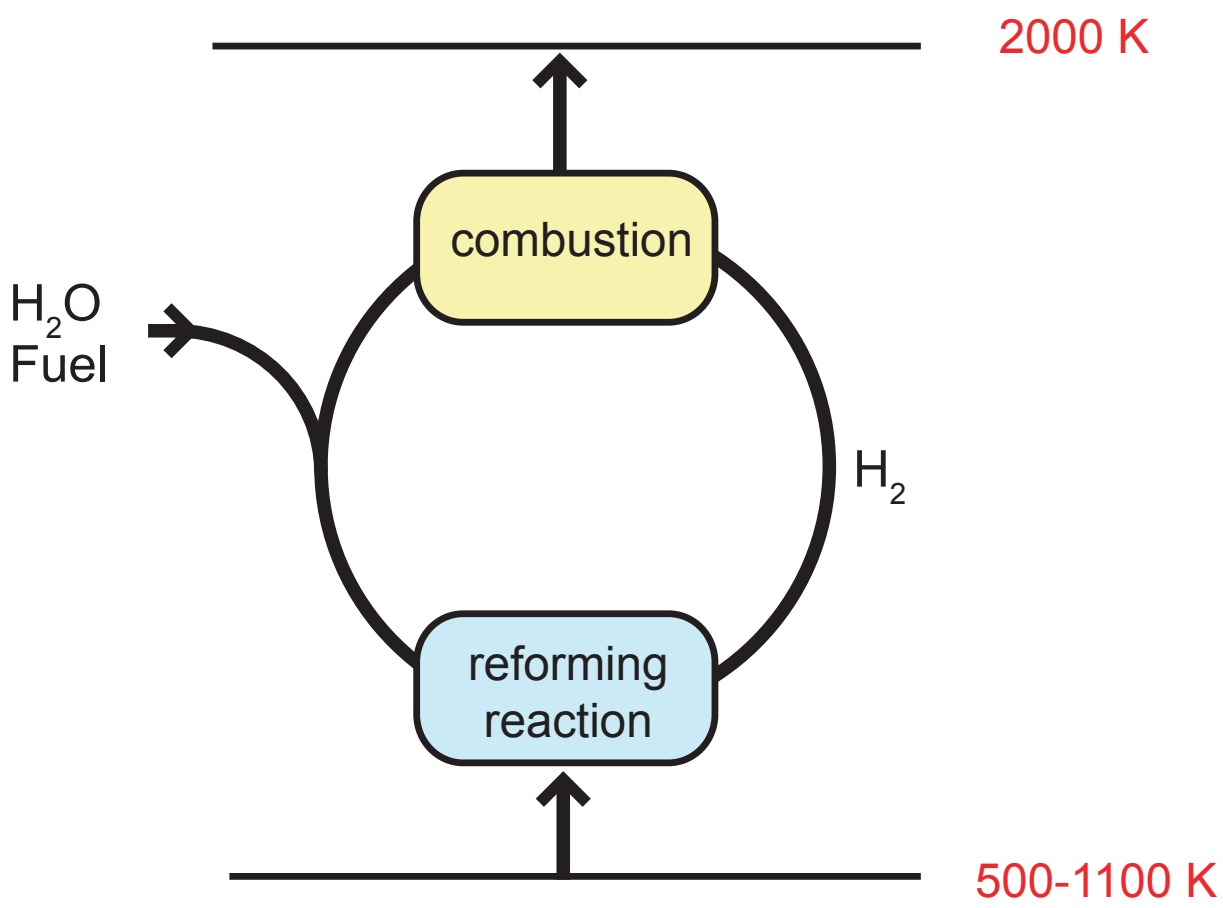
Energy conversion diagram of methane combustion



Energy conversion diagram of methane reforming combustion



Thermochemical cycle for hydrogen production as a thermochemical heat pump



Exergy Recuperation Technology for Combustion

- **Thermochemical Recuperation**

  Thermal energy can be recuperated into chemical energy by endothermic reaction

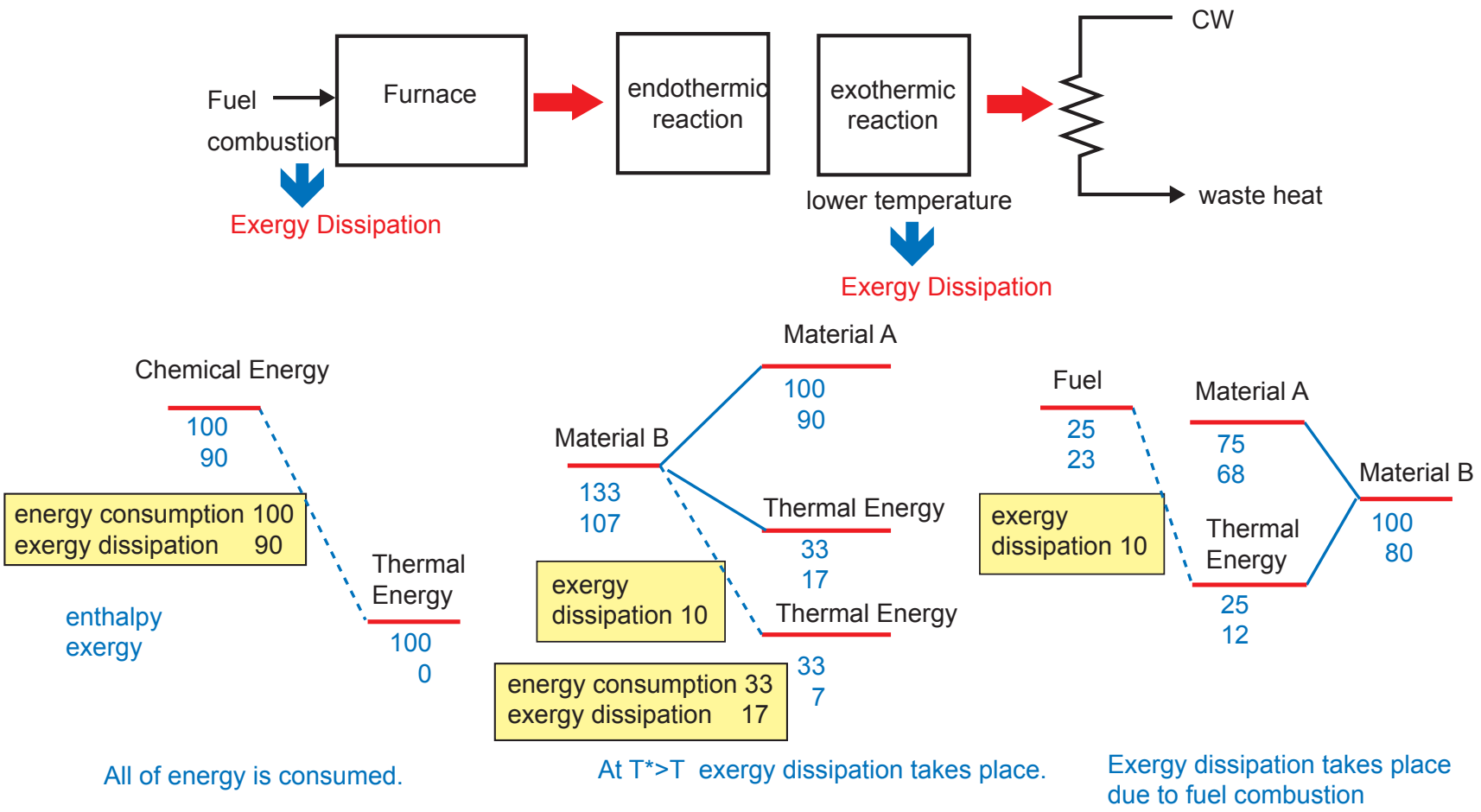
- **Heat Recuperation**

  The equilibrium of combustion reaction can be shifted to reactant side by fuel preheating using waste heat, leading to the reduction of exergy loss during combustion

- **Steam/CO2 recuperation**

  The equilibrium of combustion reaction can be shifted to reactant side by recycling the combustion products(steam and CO2).

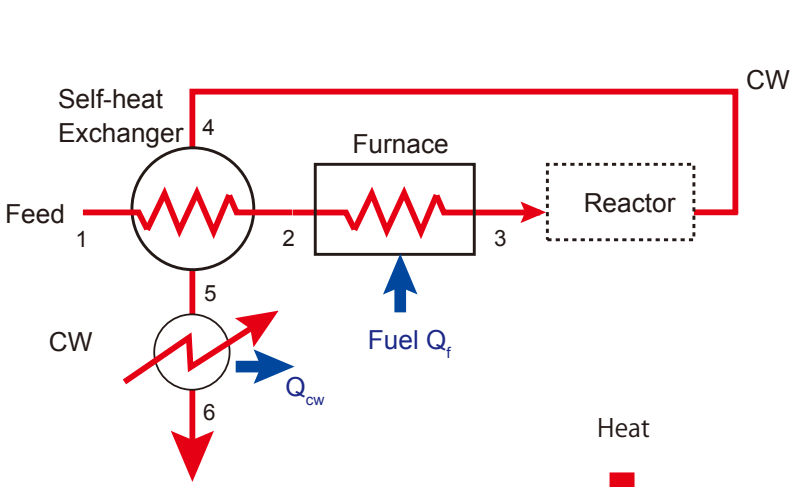
Energy Consumption & Exergy Dissipation in Chemical Process

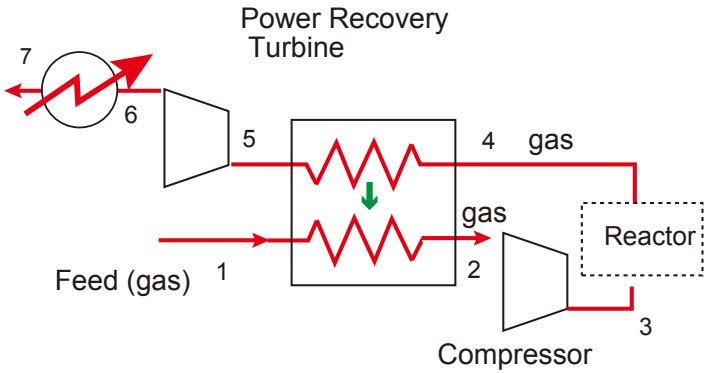


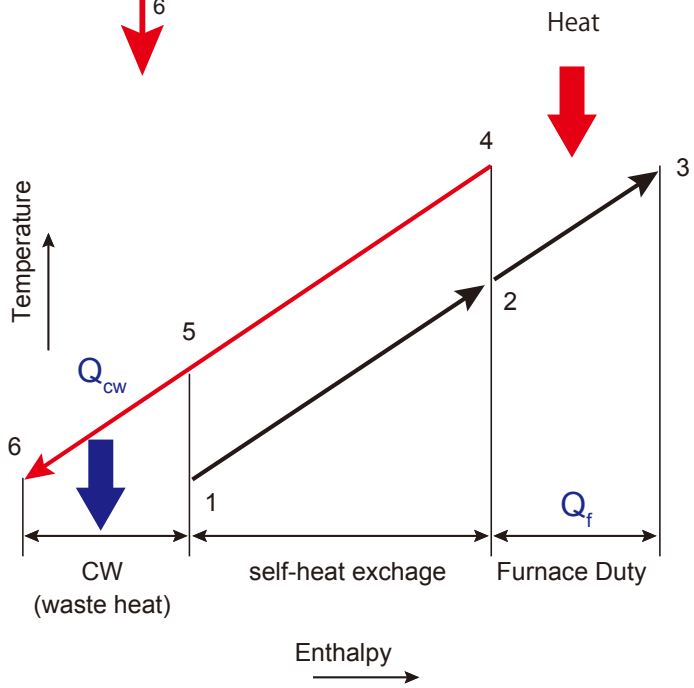
（1）Preheat

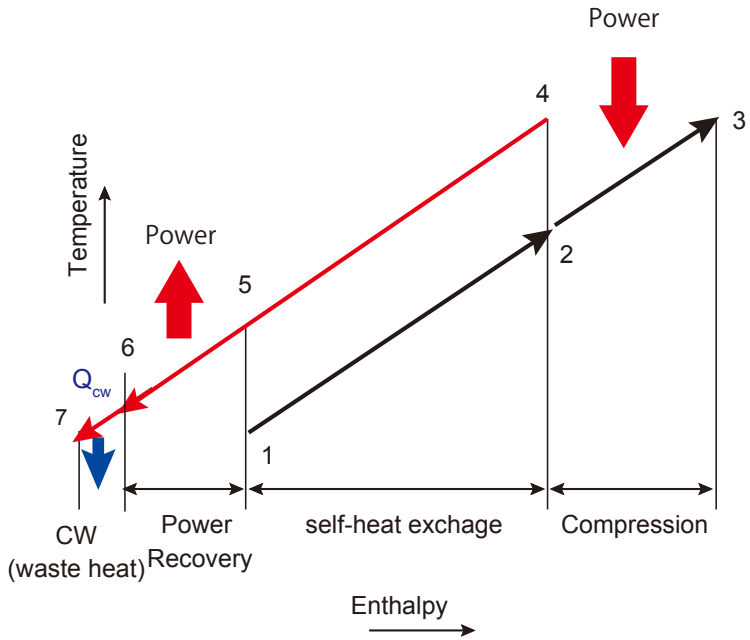
（2）Heat of Exothermic Reaction （3）Heat supply to endothermic reaction

Self-heat Recuperation Technology



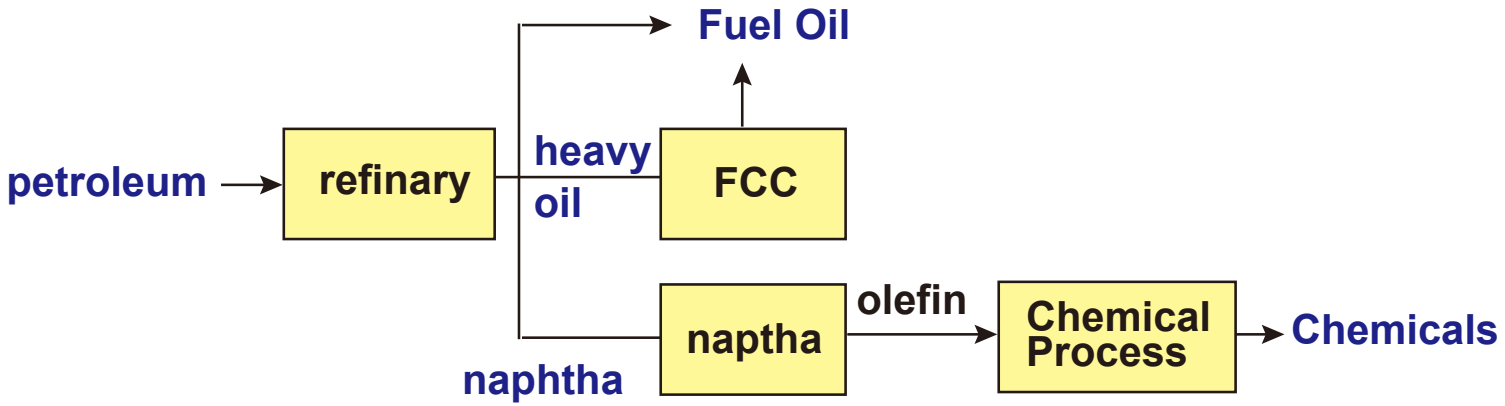






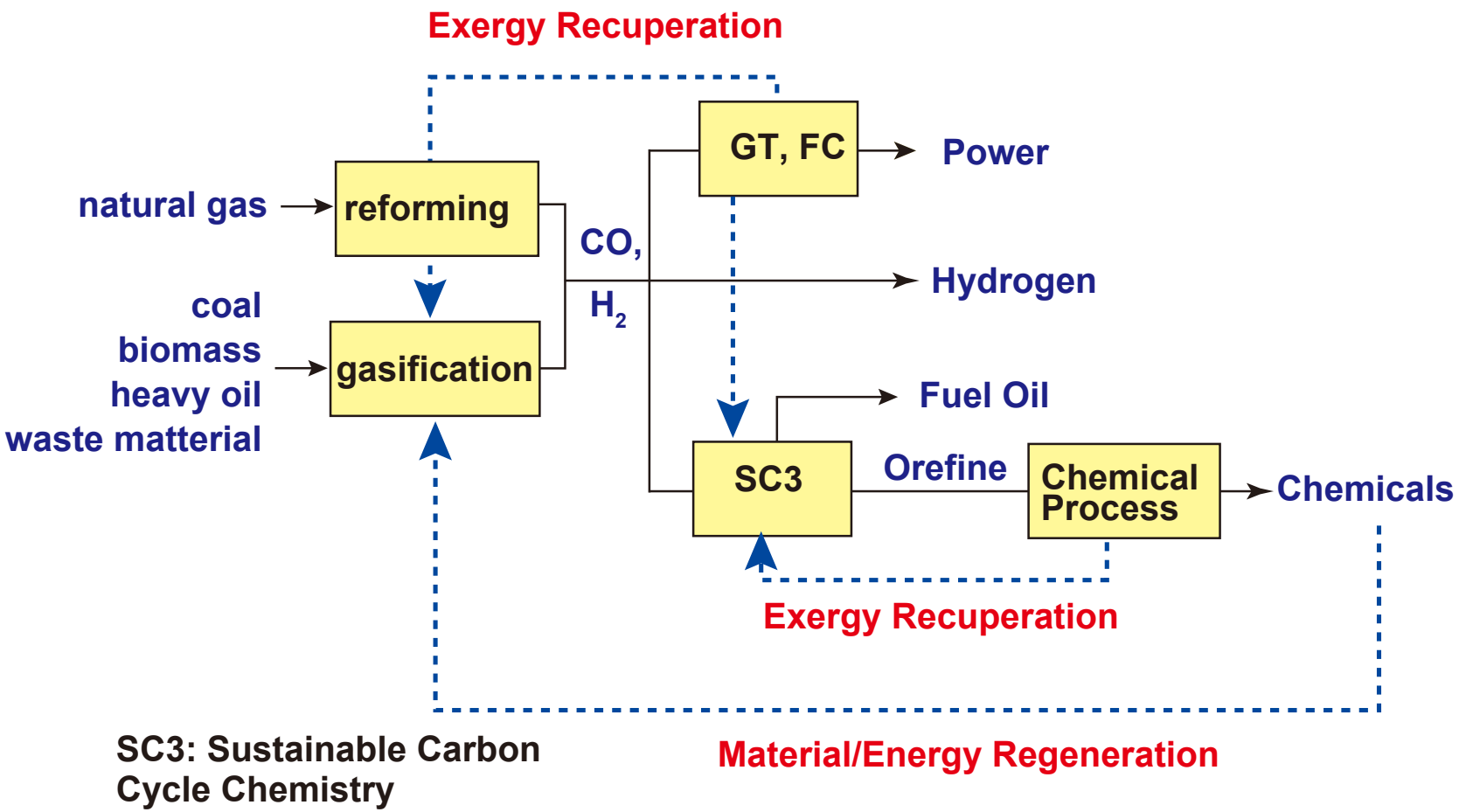
Current Energy and Material Production System

Current Power Generation



Current Oil Refinary/Petrochemical Industry

Future Energy and Material Coproduction System



SC3: Sustainable Carbon Cycle Chemistry

The End