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Advanced-Integrated Gasification Combined Cycle with Exergy Recuperation

Collaborative Research Center for Energy Engineering
Institute of Industrial Science
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Outlines

- Clean Coal Technology in Japan
- Integrated Coal Gasification Combined Cycle (IGCC)
- Hydrogen and Power Co-production with Exergy Recuperative Gasification
- Multi-Loop High Density Solid Circulation System

Present Energy System

Largely depends on oil

↓

Utilization of coal

- Widely available
- Abundant（R/P ratio is approx. 200 years）

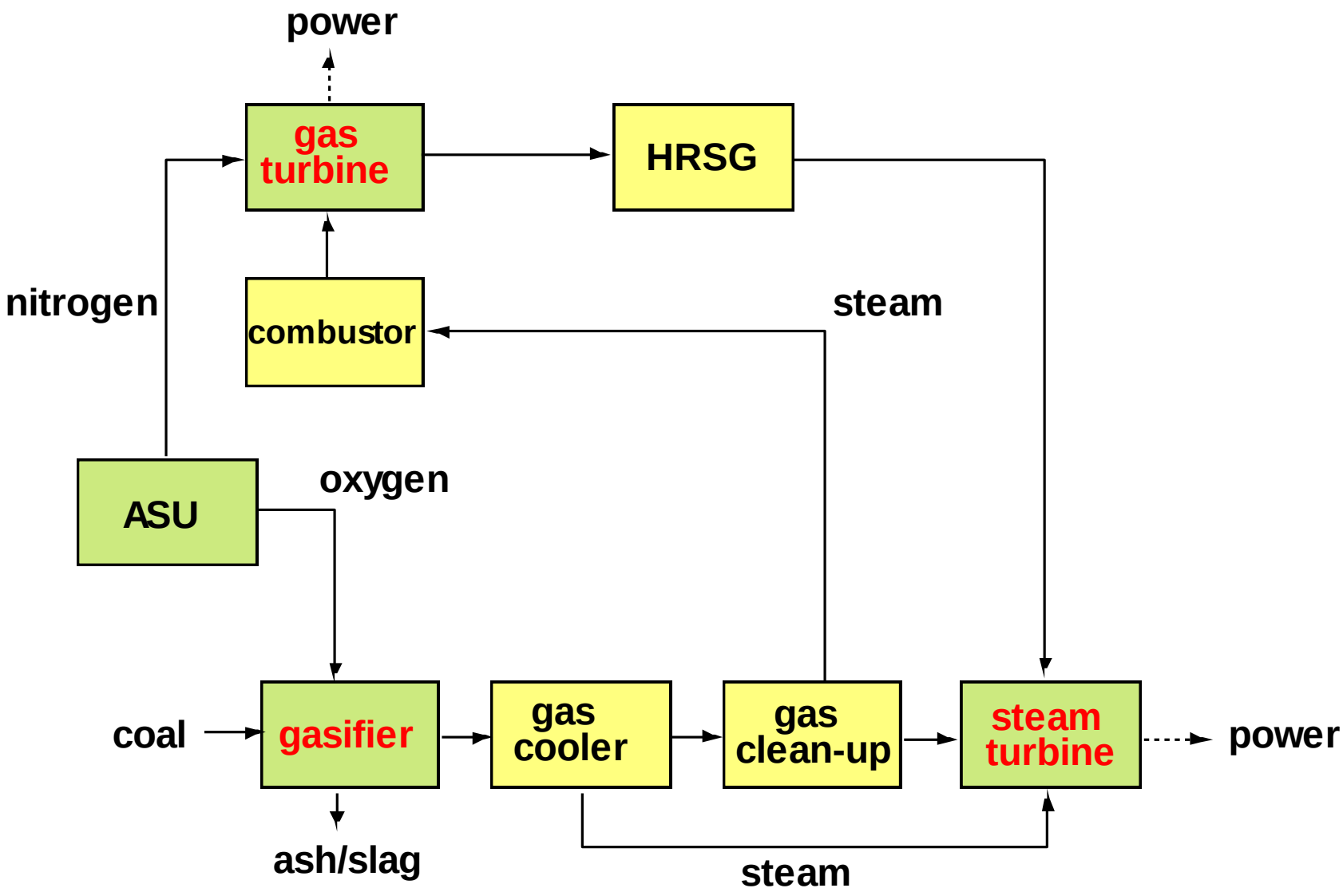
↓

Clean Coal Technology (CCT)

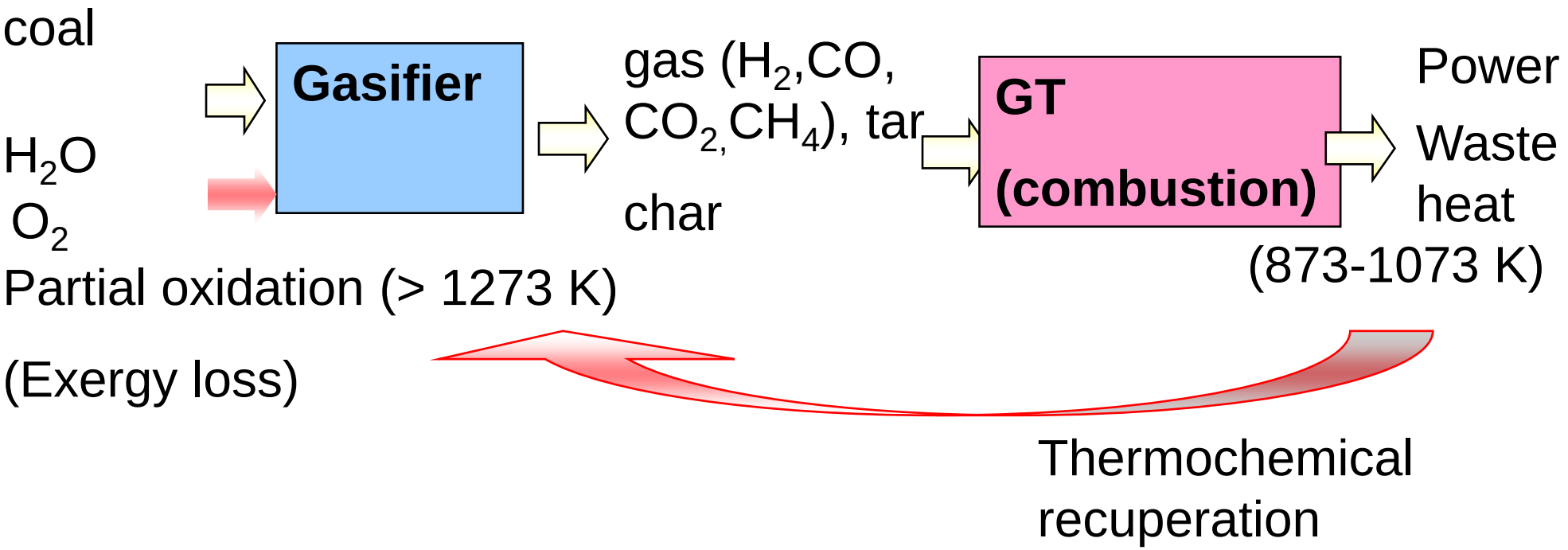
Clean Coal Technology in Japan

- **Power generation process**
  - ・Advanced pulverized coal firing boiler (PC)
  - ・Pressurized fluidized bed combustion combined cycle power generation (PFBC)
  - ・Advanced PFBC combined cycle power generation (A-PFBC)
  - ・Integrated coal gasification combined cycle power generation (IGCC)
  - ・Integrated coal gasification fuel cell combined cycle power generation (IGFC)
- **New concept**
  - ・Hyper coal (ashless coal) power generation system

Integrated Coal Gasification Combined Cycle (IGCC)



Thermochemical Recuperative Steam Gasification



Process	Reaction	ΔH [kJ mol^{-1}]	Reaction rate
Steam-carbon reaction	$C + H_2O \rightarrow CO + H_2$	131	Moderate
Shift reaction	$CO + H_2O \rightarrow CO_2 + H_2$	-41	Moderate
Partial oxidation	$2C + O_2 \rightarrow 2CO$	-111	Rapid
Combustion	$C + O_2 \rightarrow CO_2$	-393	Rapid
Boudoard reaction	$C + CO_2 \rightarrow 2CO$	172	Slow

Exergy (available energy)

$$E = H - H_0 - T_0(S - S_0)$$

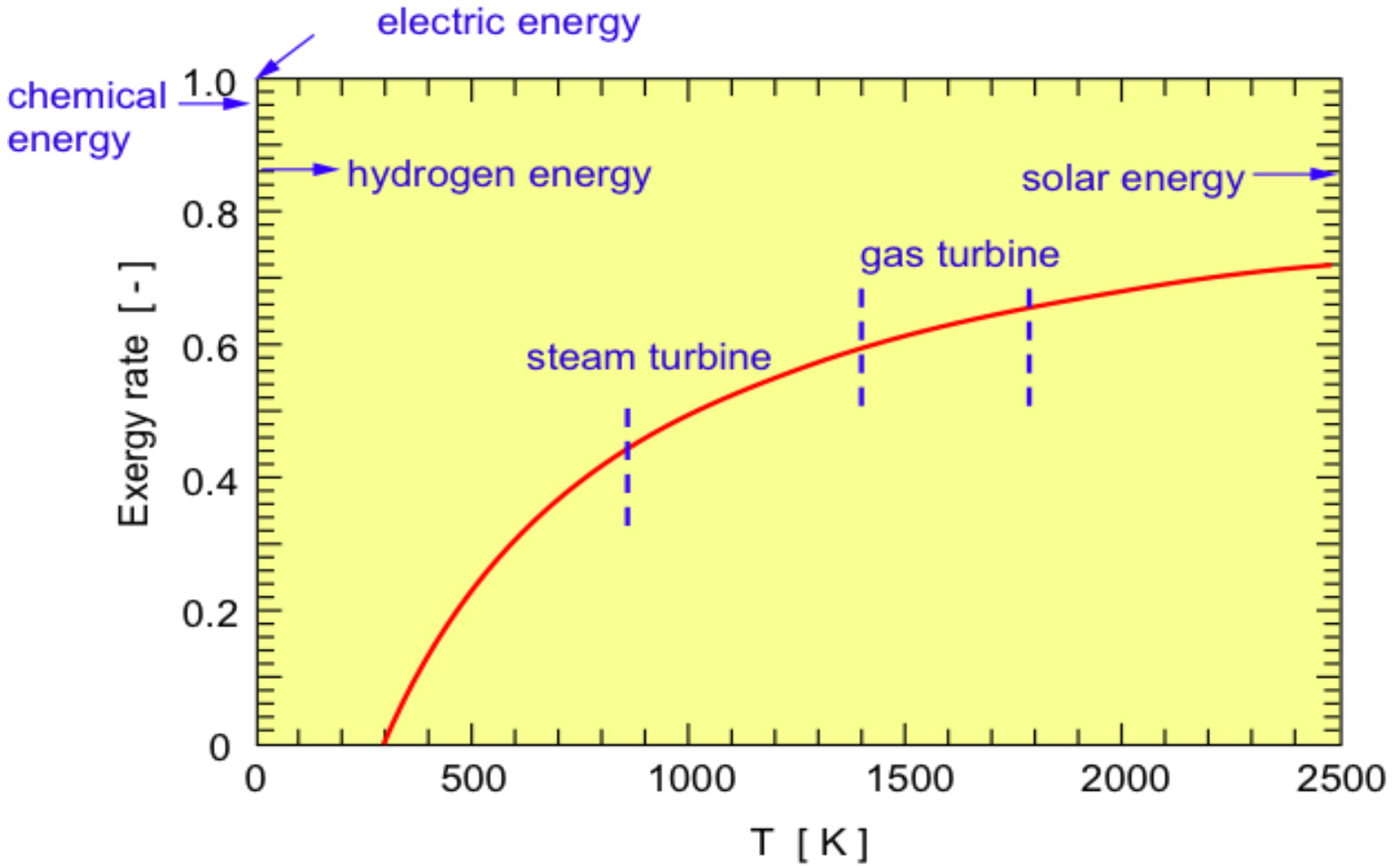
H : enthalpy
H_0: enthalpy at T_0 (298 K)
S : entropy
S_0: entropy at T_0 (298 K)

Exergy rate (exergy/enthalpy ratio)

$$\varepsilon \text{ (exergy rate)} = 1 - T_0 (S - S_0)/(H - H_0)$$

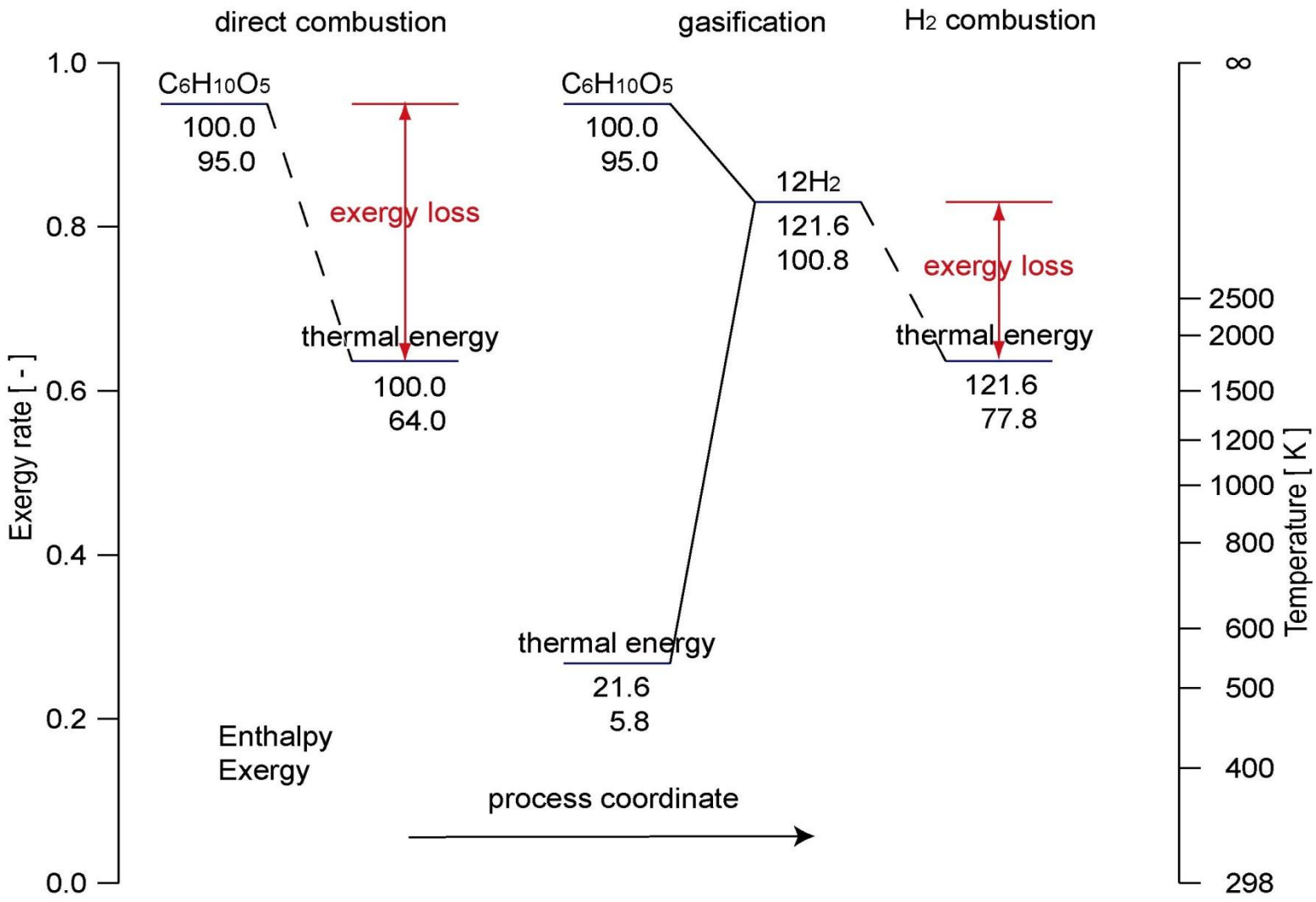
$$(= 1 - T_0 \ln(T/T_0)/(T - T_0) \text{ for thermal energy})$$

Exergy rate (Exergy/Enthalpy ratio)



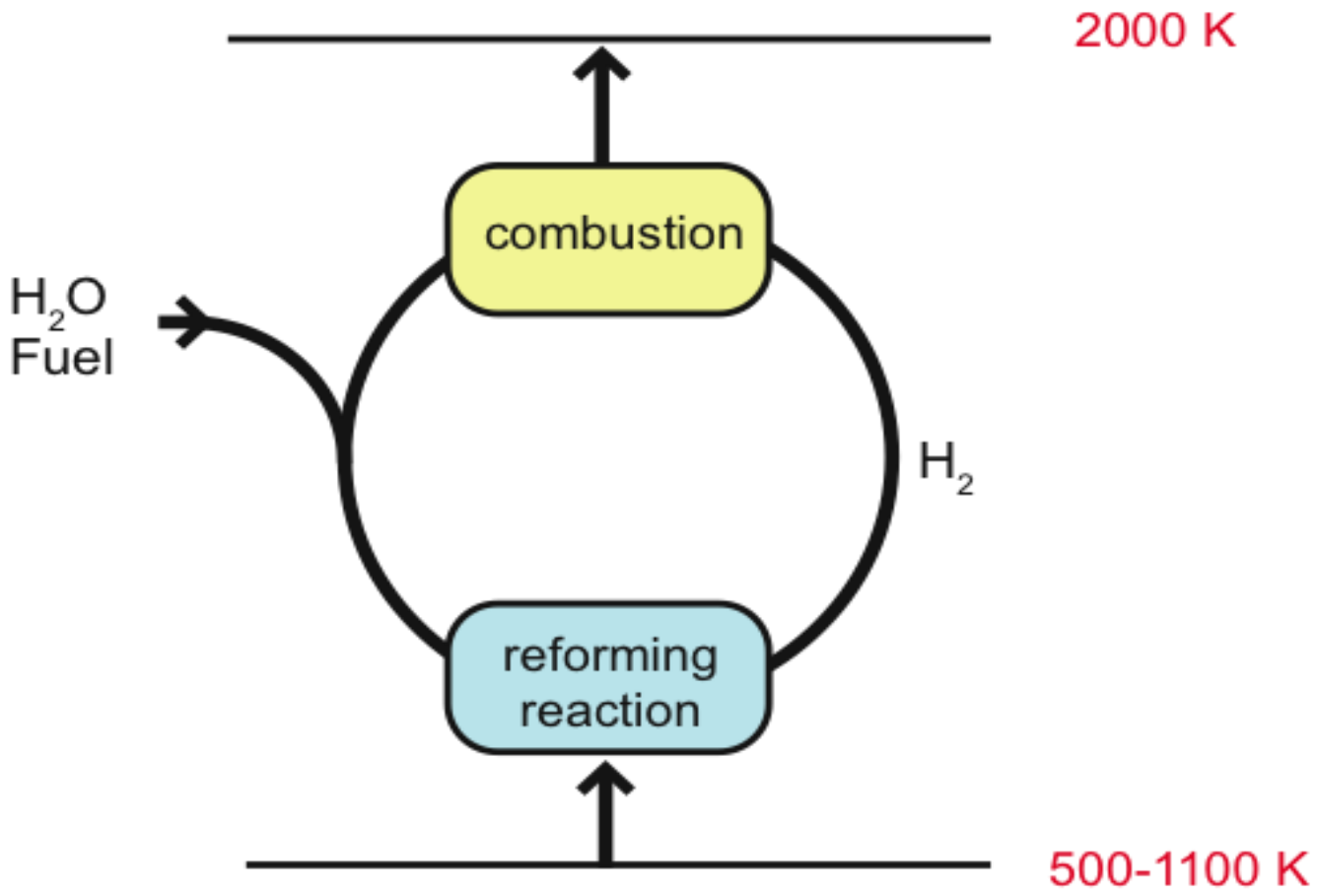
Exergy rate of air at 1 atm

Exergy Loss in Combustion Process



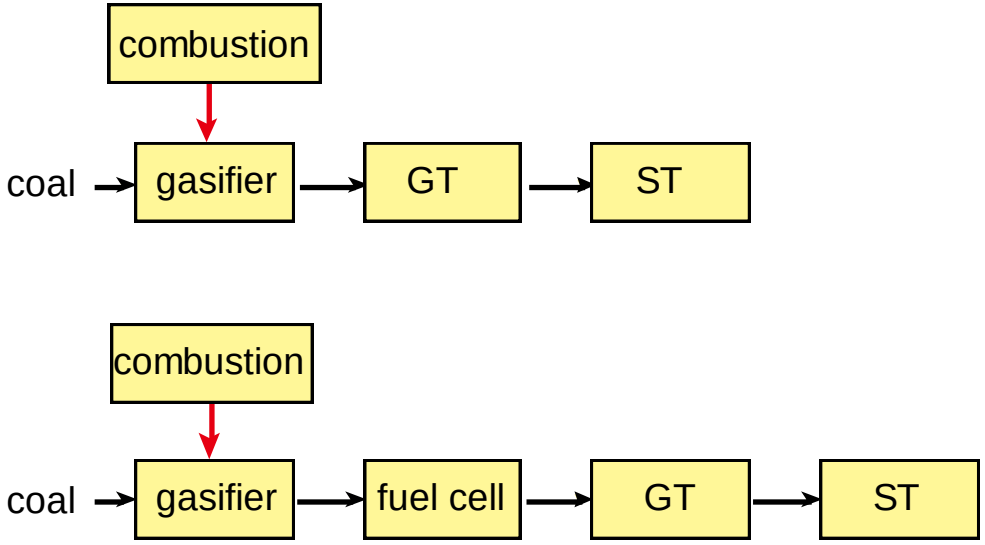
Reduction in exergy loss by gasification and H_2 combustion

Thermochemical cycle for hydrogen production as a thermochemical heat pump



Integration Technology: Energy Cascading & Exergy Recuperation

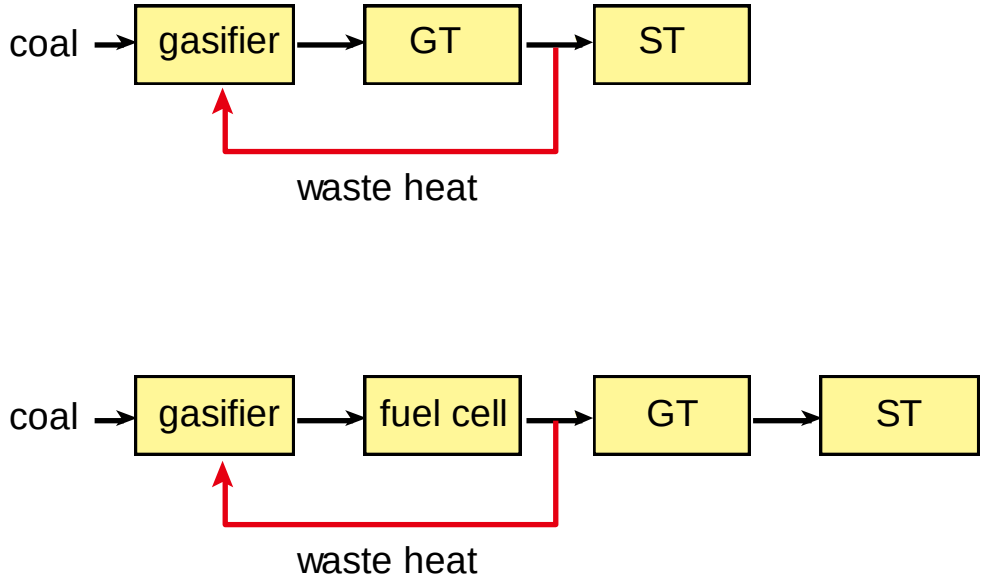
Cascade utilization IGCC



Partial oxidation

Low cold gas efficiency

Exergy recuperative IGCC/IGFC



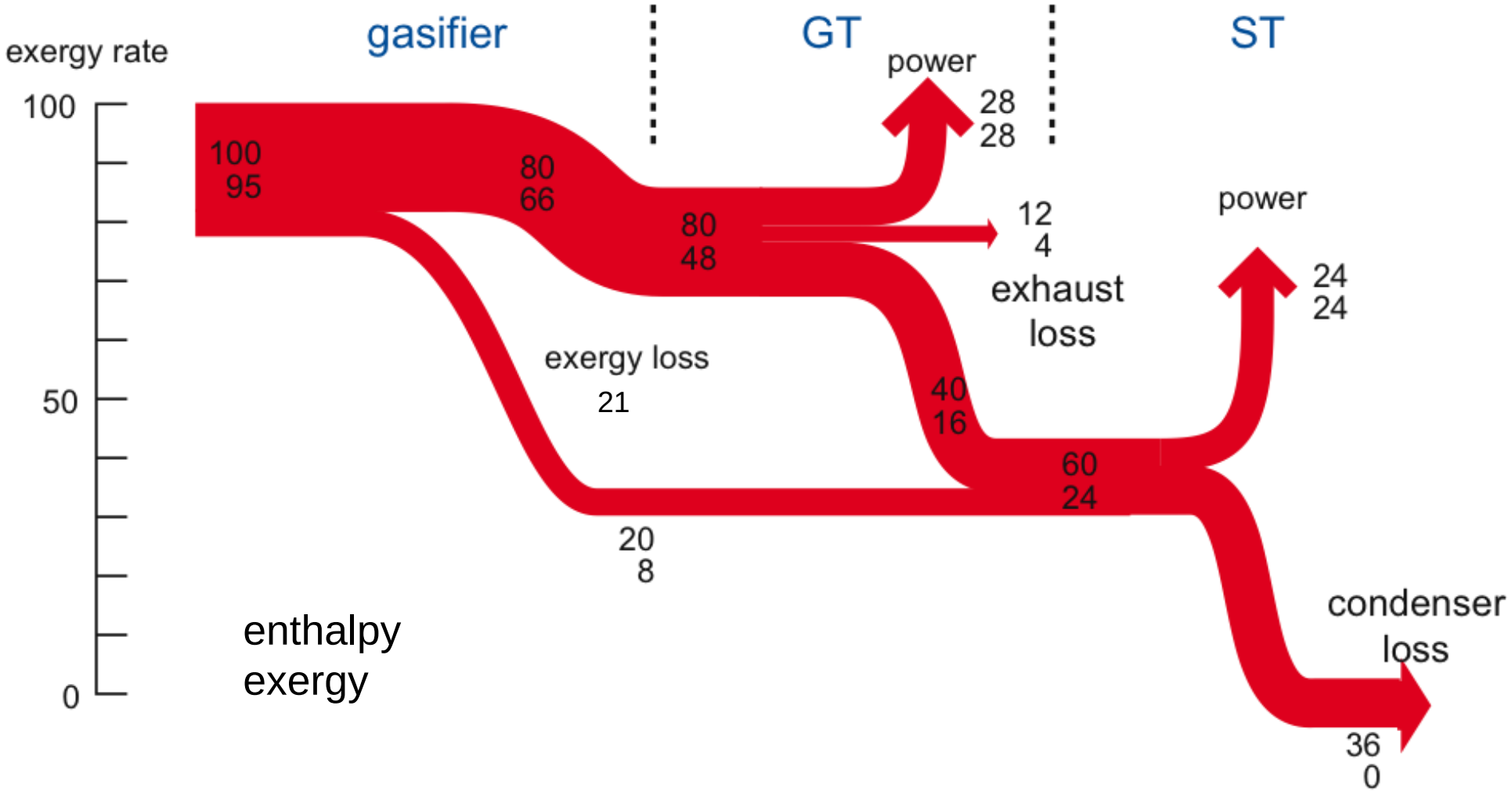
Recycle of waste heat from GT/FC

Large cold gas efficiency
Reduction of exergy loss

Energy flow in the cascade utilization IGCC system

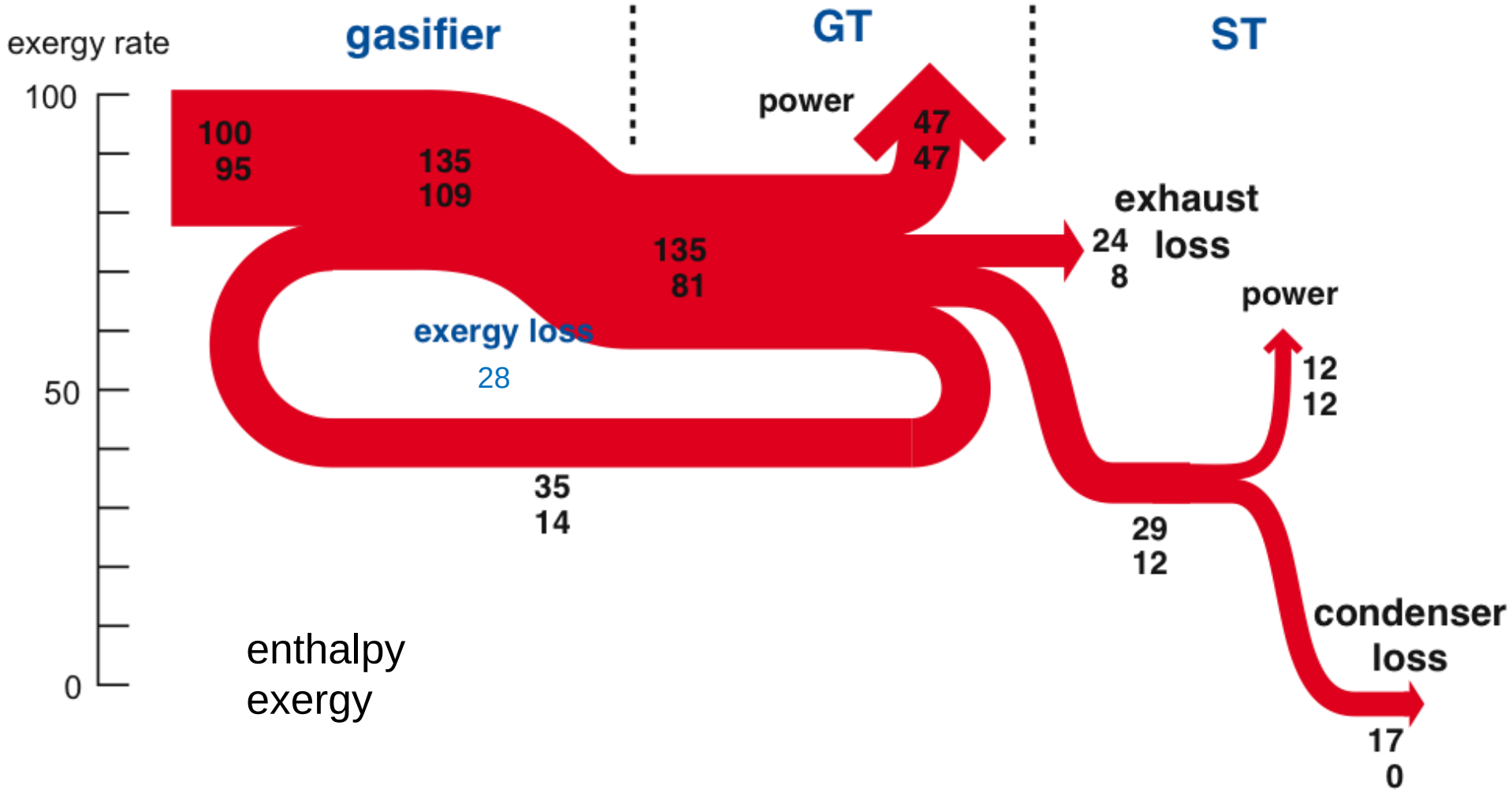
Cold gas efficiency 80%

$$\eta = \frac{28 + 24}{100} = 52\% \ (48\%)$$



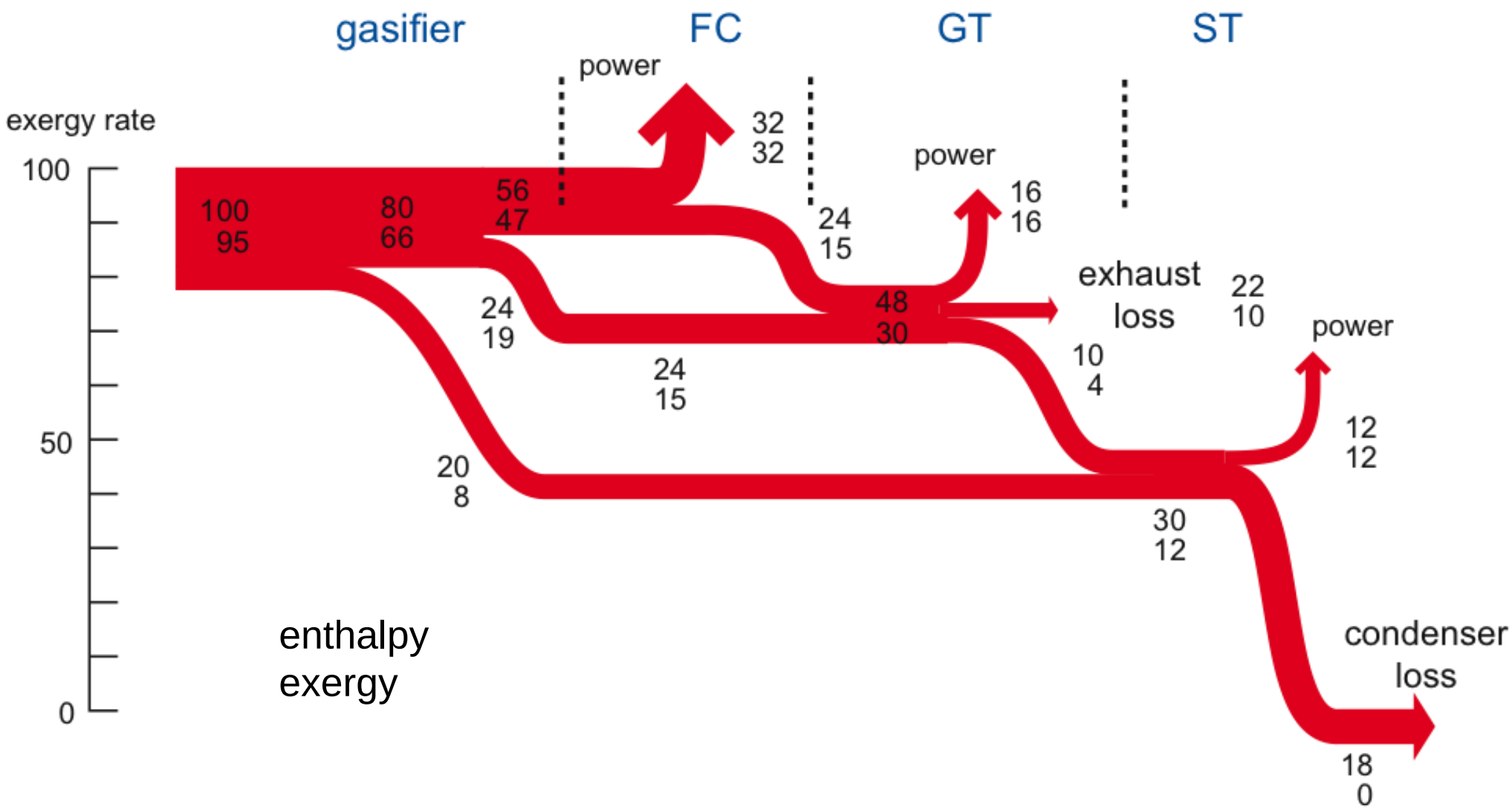
Energy flow in the exergy recuperation IGCC system

$$\eta = \frac{47 + 12}{100} = 59\% \ (57\%)$$



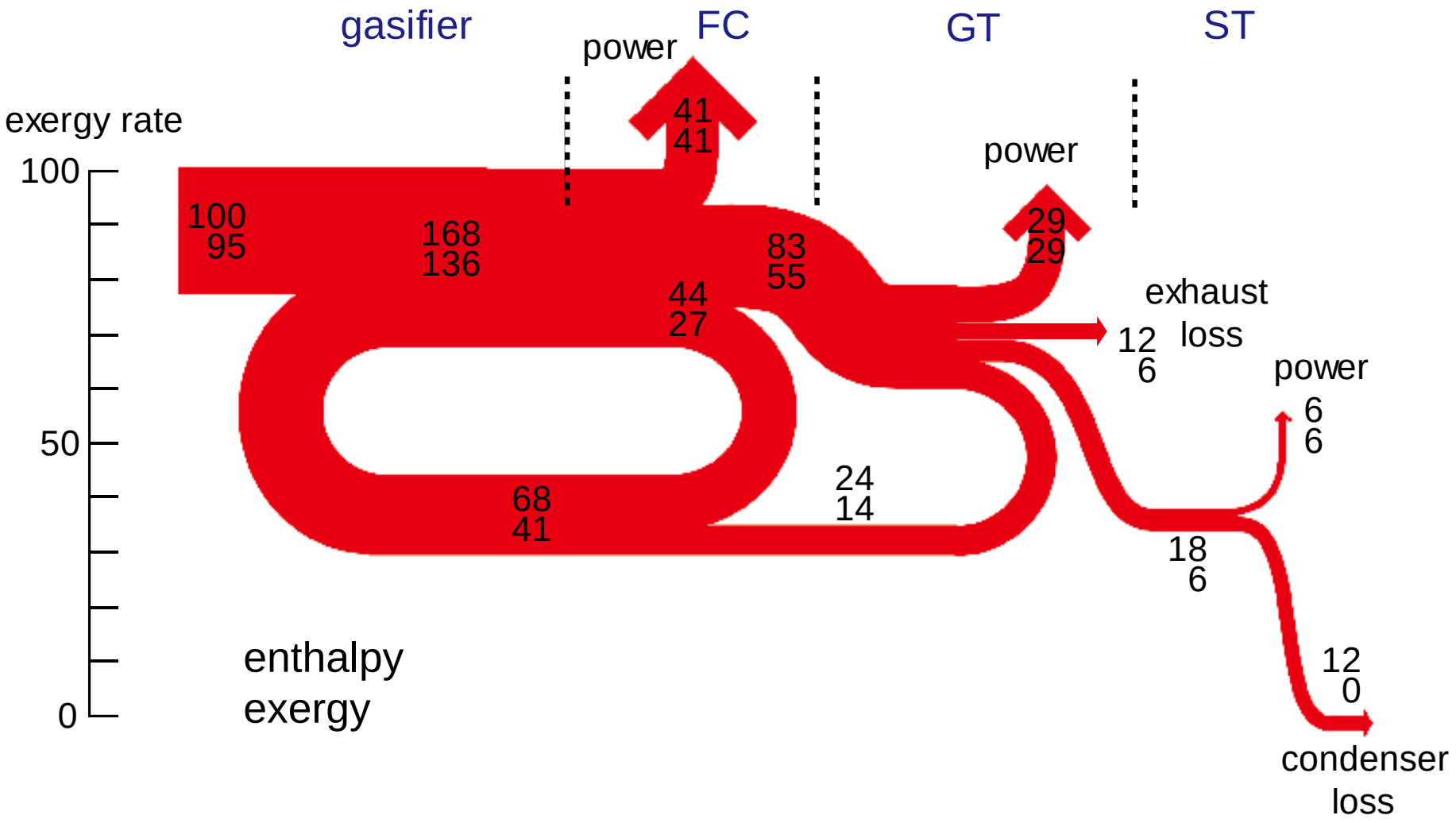
Energy flow in the cascade utilization IGFC system

$$\eta = \frac{32 + 16 + 12}{100} = 60\% \ (55\%)$$



Energy flow in the exergy recuperation IGFC system

$$\eta = \frac{41 + 29 + 6}{100} = 76\% \ (70\%)$$



Targeted Advanced Coal Gasification Power Generation

(1) More Efficient Utilization of Coal:

- **exergy recuperation technology**
- **partial oxidation gasification at high temperature**
  -> steam gasification at low temperature

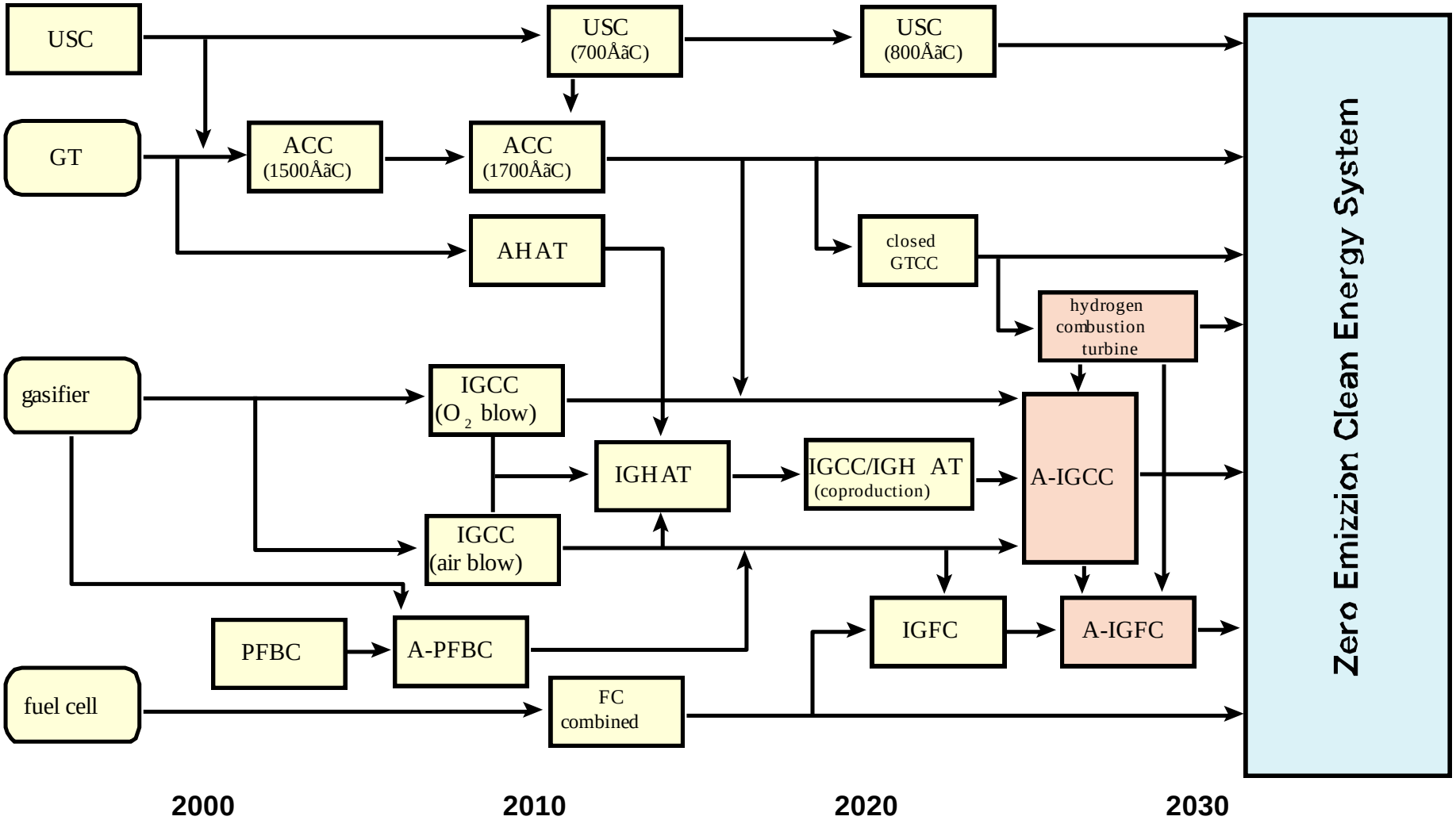
(2) Hybrid Gasification: Diversification of energy resources

- **biomass, waste, plastics, heavy oil, etc.**
- **low rank coal**

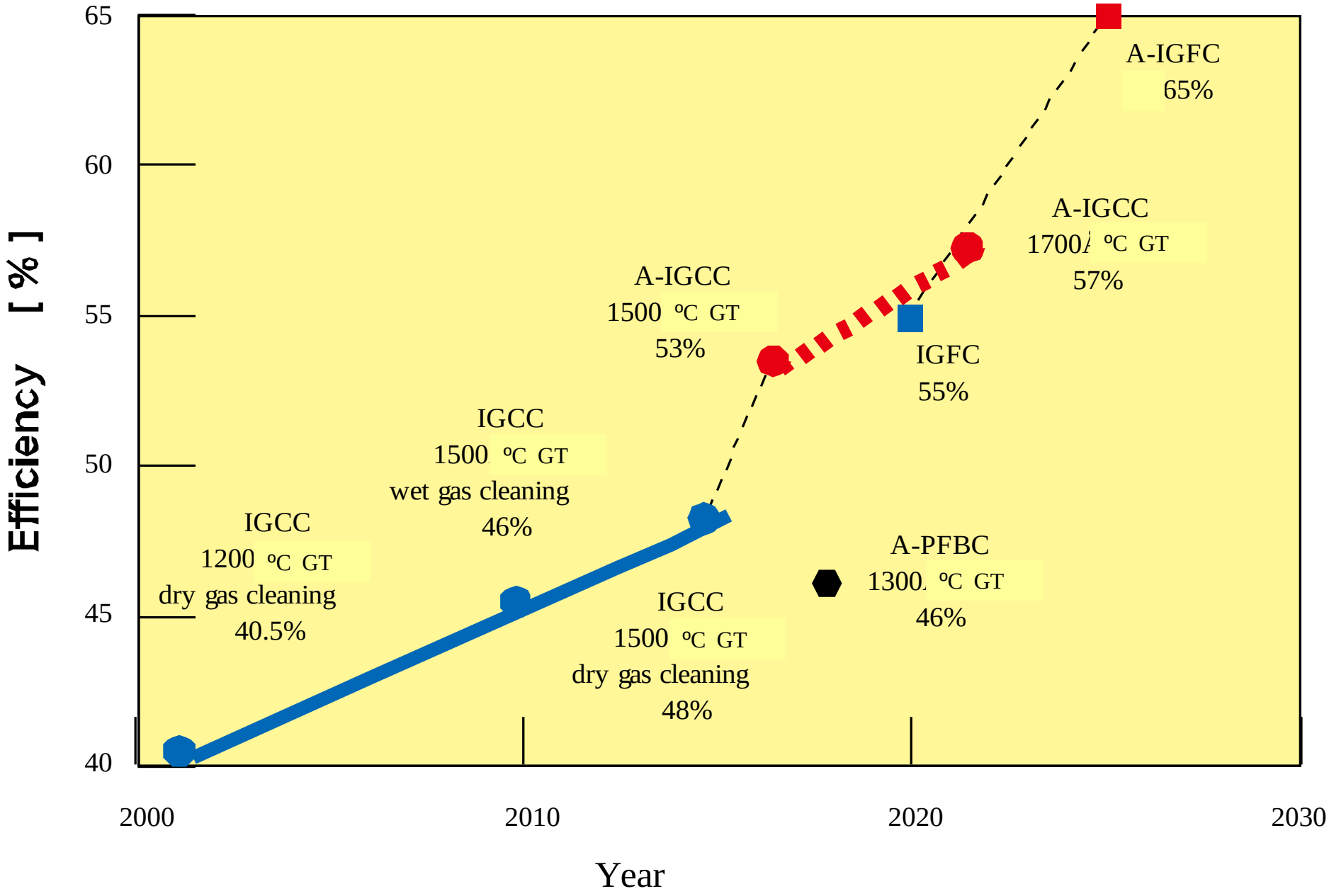
(3) Zero-Emission:

- **SOx, NOx, PM, heavy metals**
- **CO_2 sequestration ready**
- **hydrogen co-production**

Load map for advanced power generation technology



Load Map of IGCC



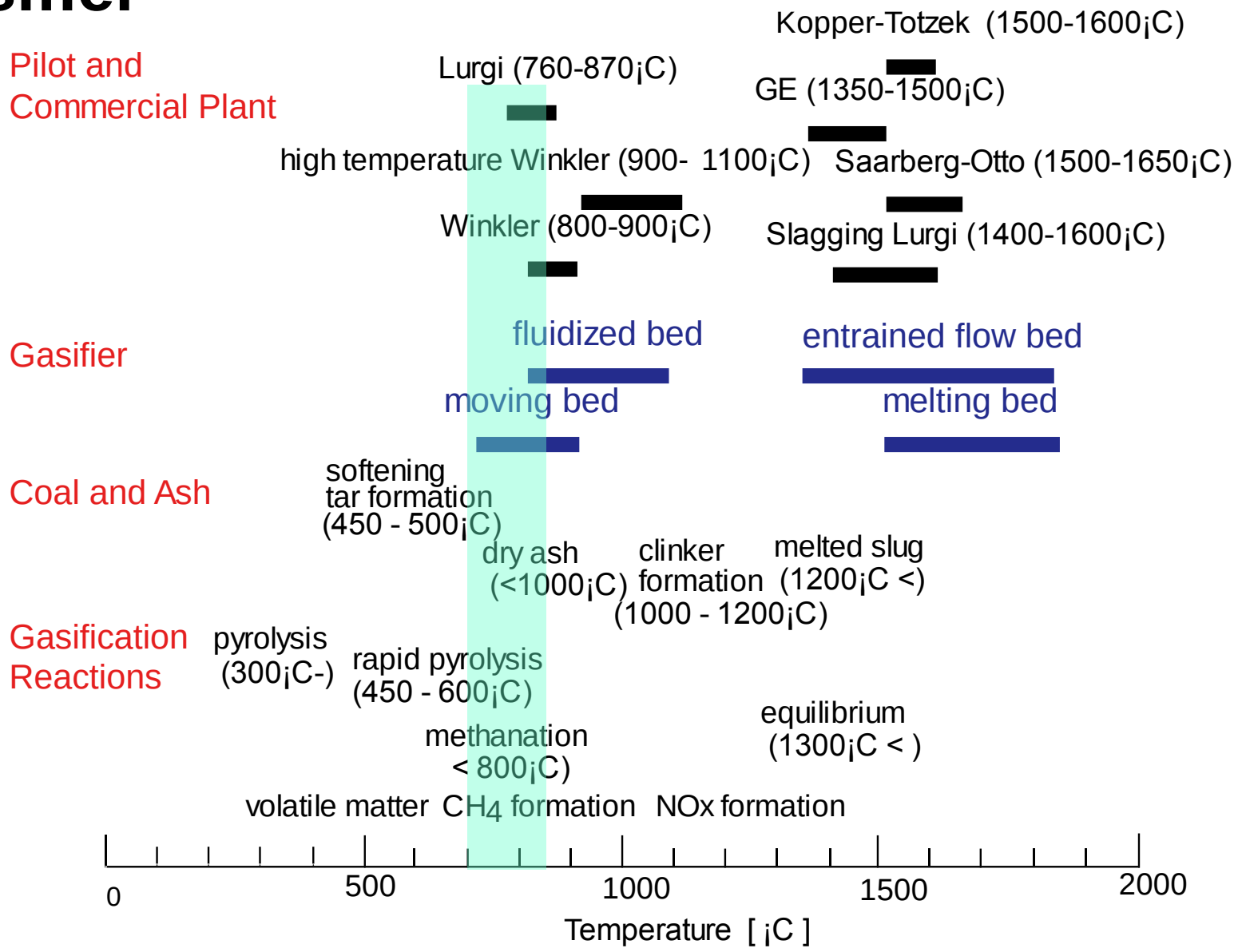
Comparison between conventional and advanced IGCC/IGFC

	Conventional IGCC/IGFC	A-IGCC/IGFC
integration	**cascade utilization**	**exergy recuperation**
gasification	**partial oxidation high temperature (1100-1500 °C)**	**steam gasification low temperature (700-1000 °C)**
gasifier	**Entrained flow bed**	**multi-loop high density solid circulation system**
efficiency	**46-48% (55%)**	**53-57% (65%)**

Key technologies

- 1700ºC GT, SOFC, MCFC,
- Efficient Hot gas cleaning, Effective gasification catalyst
- Multi-loop high density solid circulation system

Gasifier


Pilot and
Commercial Plant
Kopper-Totzek (1500-1600¡C)
Lurgi (760-870¡C)
GE (1350-1500¡C)
high temperature Winkler (900- 1100¡C)
Saarberg-Otto (1500-1650¡C)
Winkler (800-900¡C)
Slagging Lurgi (1400-1600¡C)
Gasifier
fluidized bed
entrained flow bed
moving bed
melting bed
Coal and Ash
softening
tar formation
(450 - 500¡C)
dry ash
(<1000¡C)
clinker
formation
(1000 - 1200¡C)
melted slug
(1200¡C <)
Gasification
Reactions
pyrolysis
(300¡C-)
rapid pyrolysis
(450 - 600¡C)
methanation
< 800¡C)
equilibrium
(1300¡C <)
volatile matter
CH4 formation
NOx formation
0
500
1000
1500
2000
Temperature [¡C]

Transport Reactor

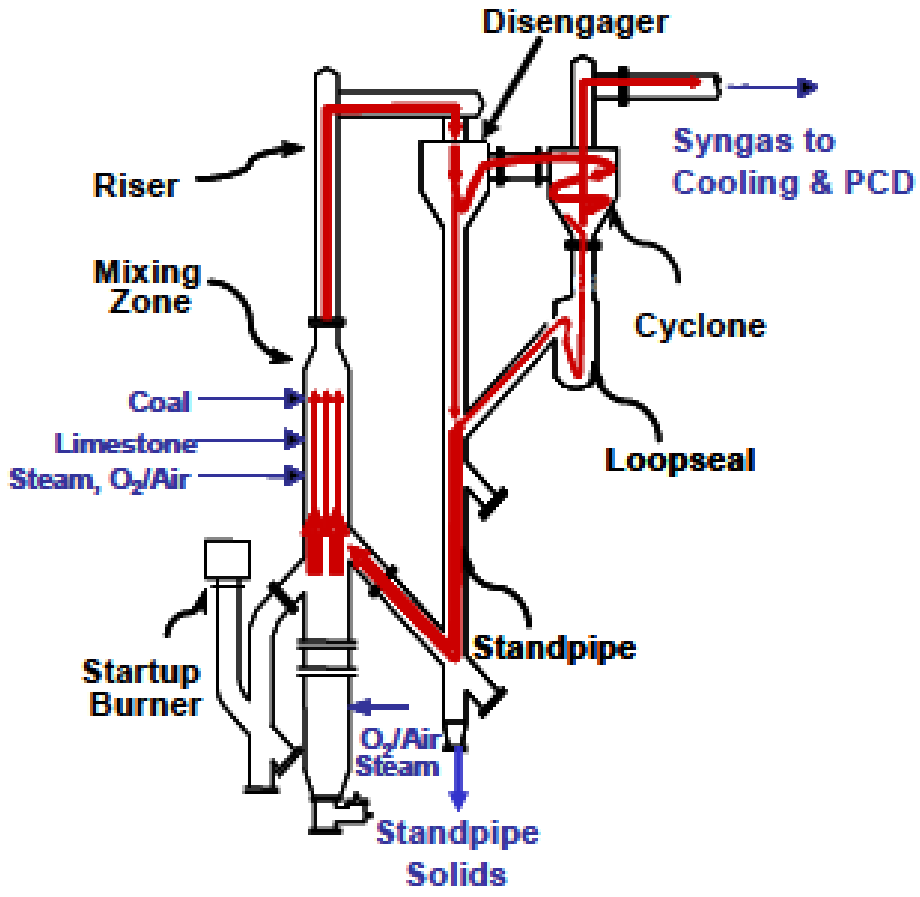
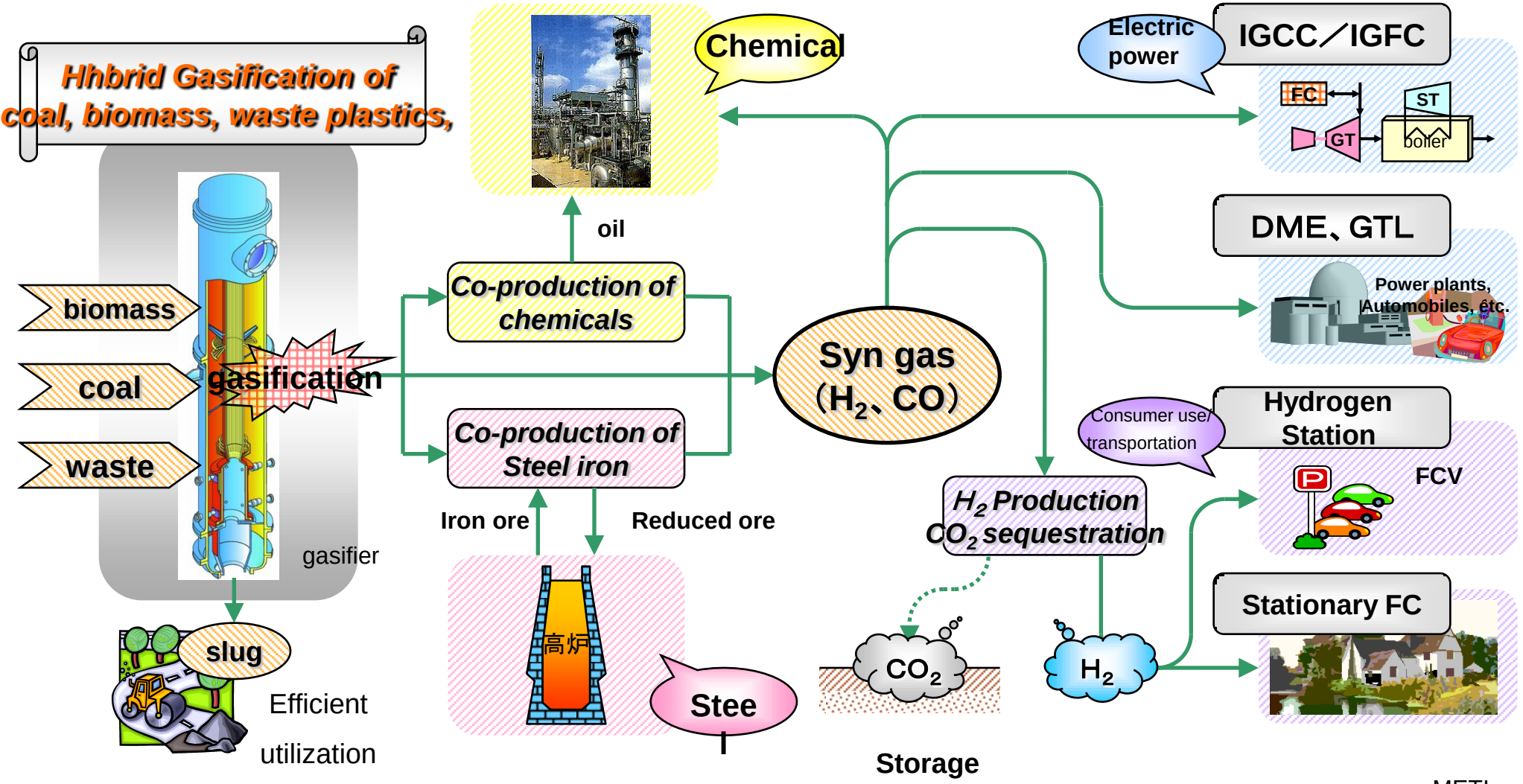


Figure 1 - Transport Gasifier

J. Matthew Nelson et al. Proc. of 18th Low-Rank Fuels Symposium, Session 2B - Gasification June 24-26, 2003, Billings, Montana

Japan's New Coal Policy
C3 Initiative towards the establishment of the Clean Coal Cycle

Demonstration of diversified CCT models, with coal gasification as the core technology



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Summary

- The hydrogen and power co-production by using the exergy recuperation gasification technology could considerably increase the energy utilization efficiency.
- In the advanced IGCC/IGFC for hydrogen and power co-production, a multi-loop high density solid circulation system is required to be developed as a gasifier.
- 1700ºC GT, SOFC, MCFC, and efficient hot gas cleaning are also important key technologies for A-IGCC, IGFC
- It is necessary to facilitate gasification at low temperature (700-1000 ºC) by using effective catalyst.

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The End

Thank you very much!