A Common Energy Platform for Evaluating the Energy Efficiency of Power Generation and Desalination Plants

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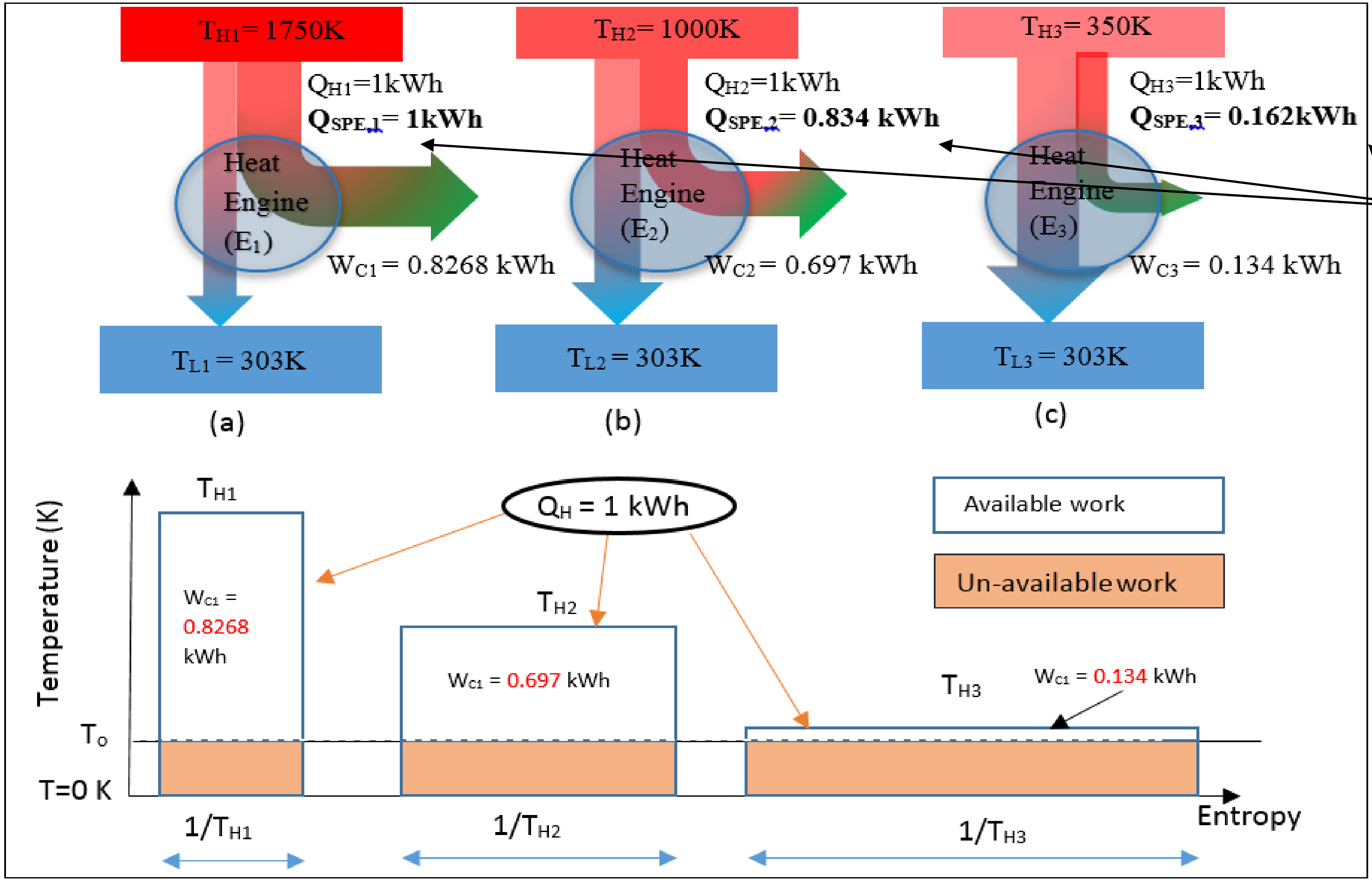
Classical thermodynamics approach:



Common energy platform could discern the energy quality:

	Case (a)	Case (b)	Case (C)
Q_H	1	1	1
W_C	0.8268	0.697	0.134
Q_{SPE}	1	0.834	0.162

Standard primary energy (SPE) platform is used.

Co-generation of derived energy (electricity & heat) from CCGT plants

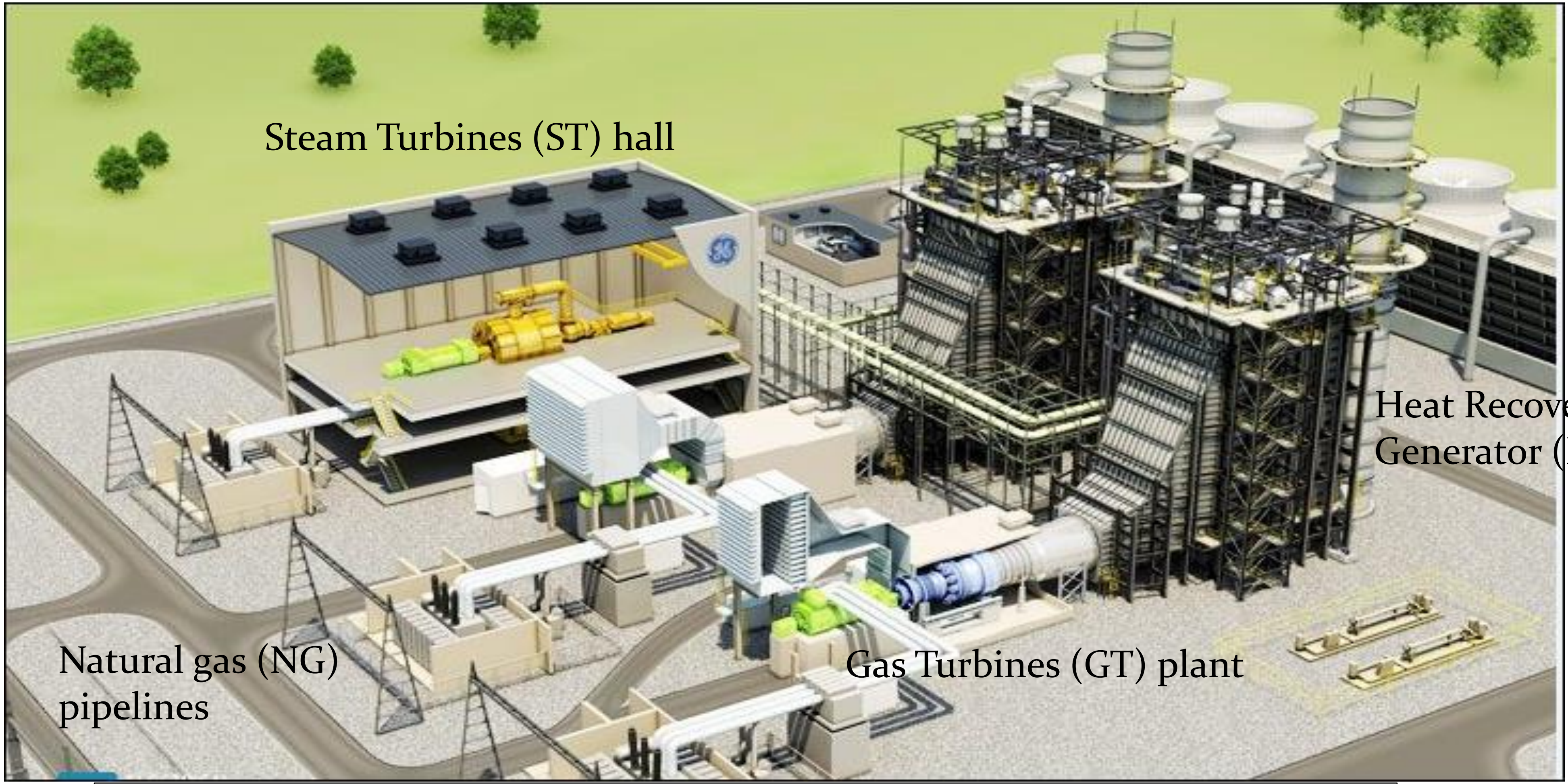
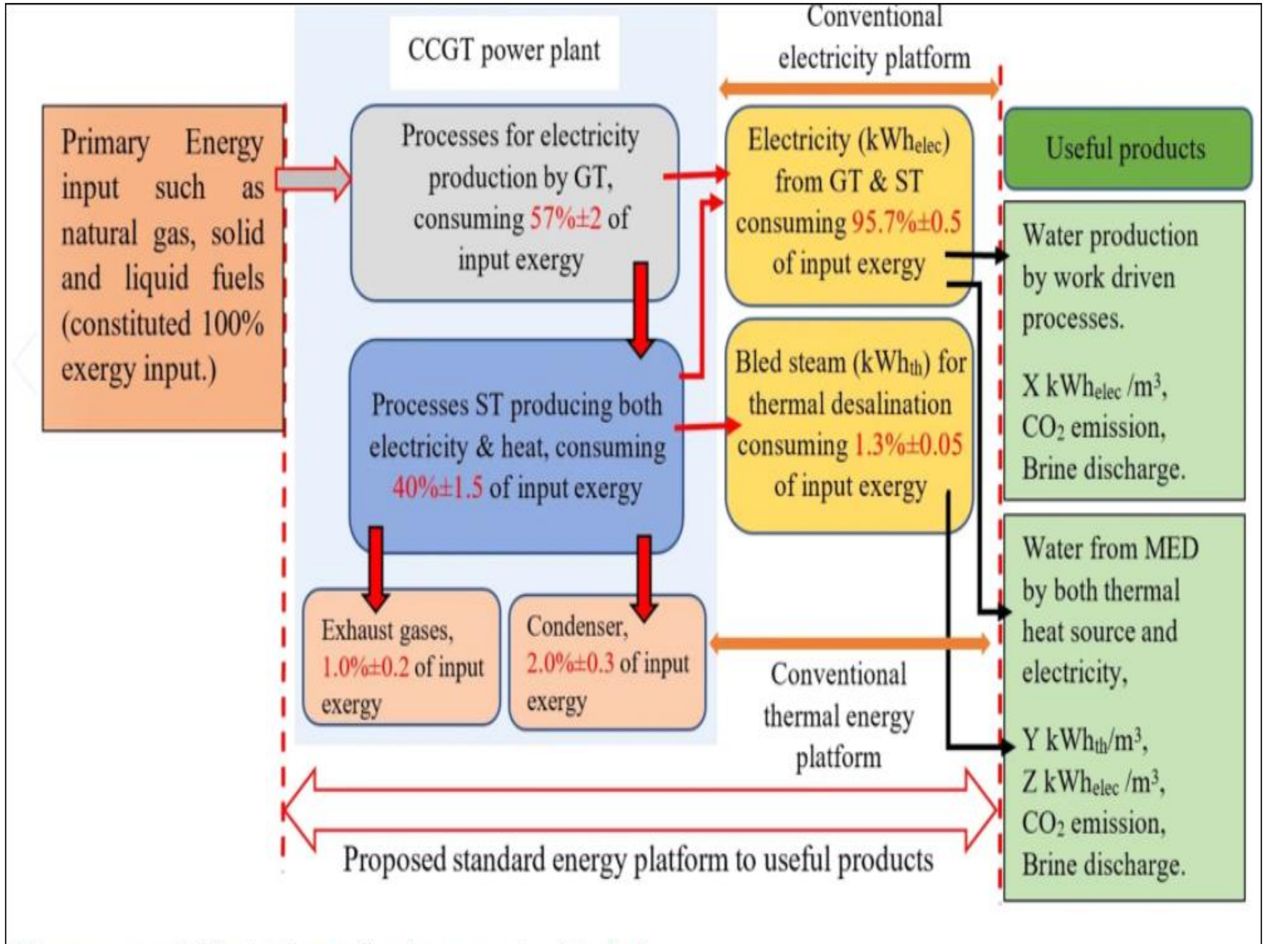


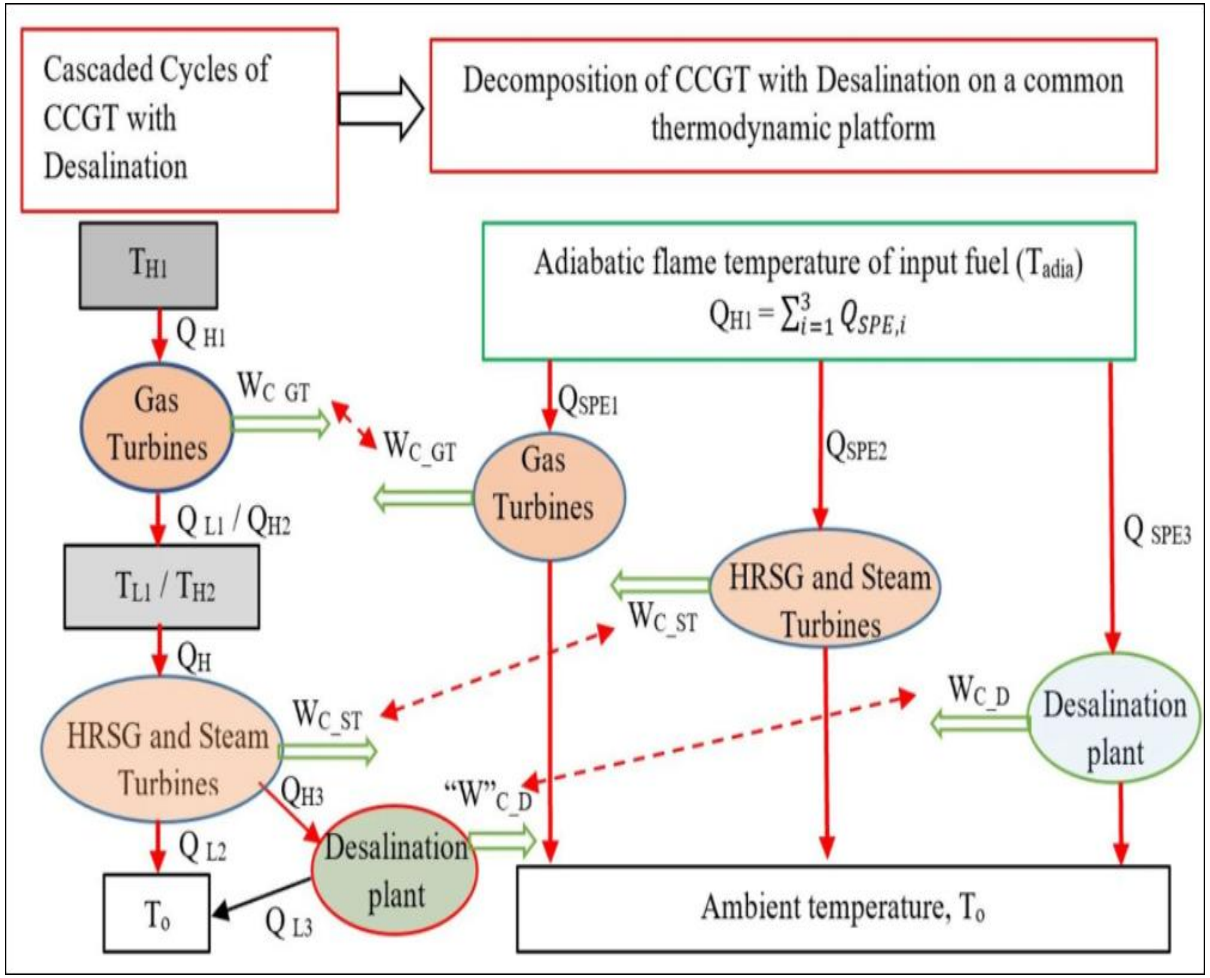
Fig.1(a). A pictorial view of a typical CCGT power plant.
(Courtesy of Busineesswire.com.)

Methodology and Causal Relations

- Underlying the processes for derived energy production y



Primary energy distribution in combined power and water plant.



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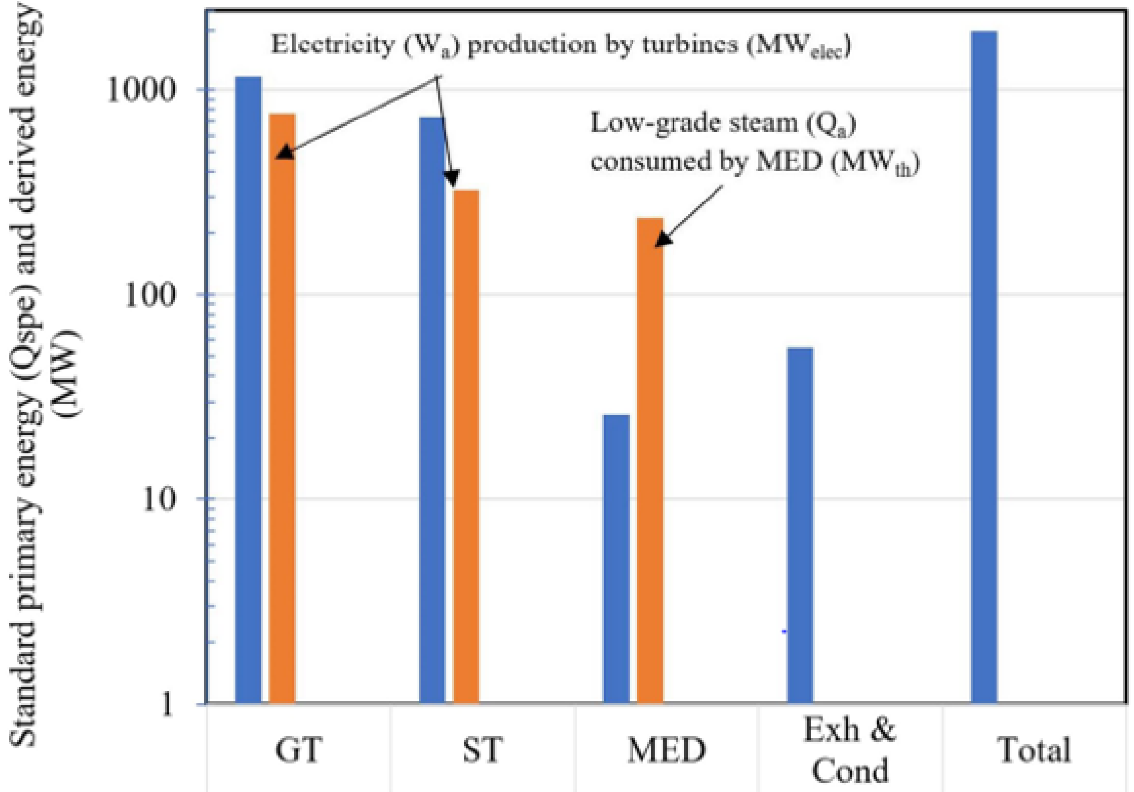
Corollary of Second Law of Thermodynamics

$$\frac{W_C}{(T_H - T_L)} = \frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

Types of engines	Carnot work	Common energy platform (e.g., Standard Primary energy (Q_{SPE}))	Causal Relations (with 2nd Law, $W_C = \frac{W_a}{\eta''}$)
Work driven engine (Q_H), e.g., electricity production, W_a	$W_C = QH\left(1 - \frac{T_{L,i}}{T_{H,i}}\right)$	$\left(\frac{W_a}{\eta''_{elec}}\right) = W_C = QSPE\left(1 - \frac{T_o}{T_{adia}}\right)$	$\left(\frac{Q_{SPE}}{W_a}\right) = \frac{1}{\eta''_{elec}\left(1 - \frac{T_o}{T_{adia}}\right)}$
Heat driven engine (Q_a), e.g., MED, with heat input of MED, Q_a	"W_C" $= Q_H\left(1 - \frac{T_{L2}}{T_{H2}}\right)$	$Q_a\eta''\left(1 - \frac{T_{L2}}{T_{H2}}\right) = Q_{SPE}\left(1 - \frac{T_o}{T_{adia}}\right)$	$\left(\frac{Q_{SPE}}{Q_a}\right) = \frac{\eta''\left(1-\frac{T_{L2}}{T_{H2}}\right)}{\left(1-\frac{T_o}{T_{adia}}\right)}$

W_a and Q_a are what is measured or consumed in a process

Alternative method of assessing causal relations



	GT	ST	MED	Exh & Cond	Total
Q_spe (MW)	1159.64	736.65	25.88	54.93	1977.10
Derived energy (MW)	768.87	325.50	237.54	0.00	
Conversion factor (CF)	1.5082	2.2632	0.1089		
Weighted CF_(GT+ST)	1.7328				

Fig. 4 The consumption of standard primary energy by different processes. The consumption of standard primary energy by different processes.

Parameters at SPE:

T_o = 303 K, T_{adia} = 1750 K

Cf_{elec} = 1.7328, CF_{ther} =0.1089

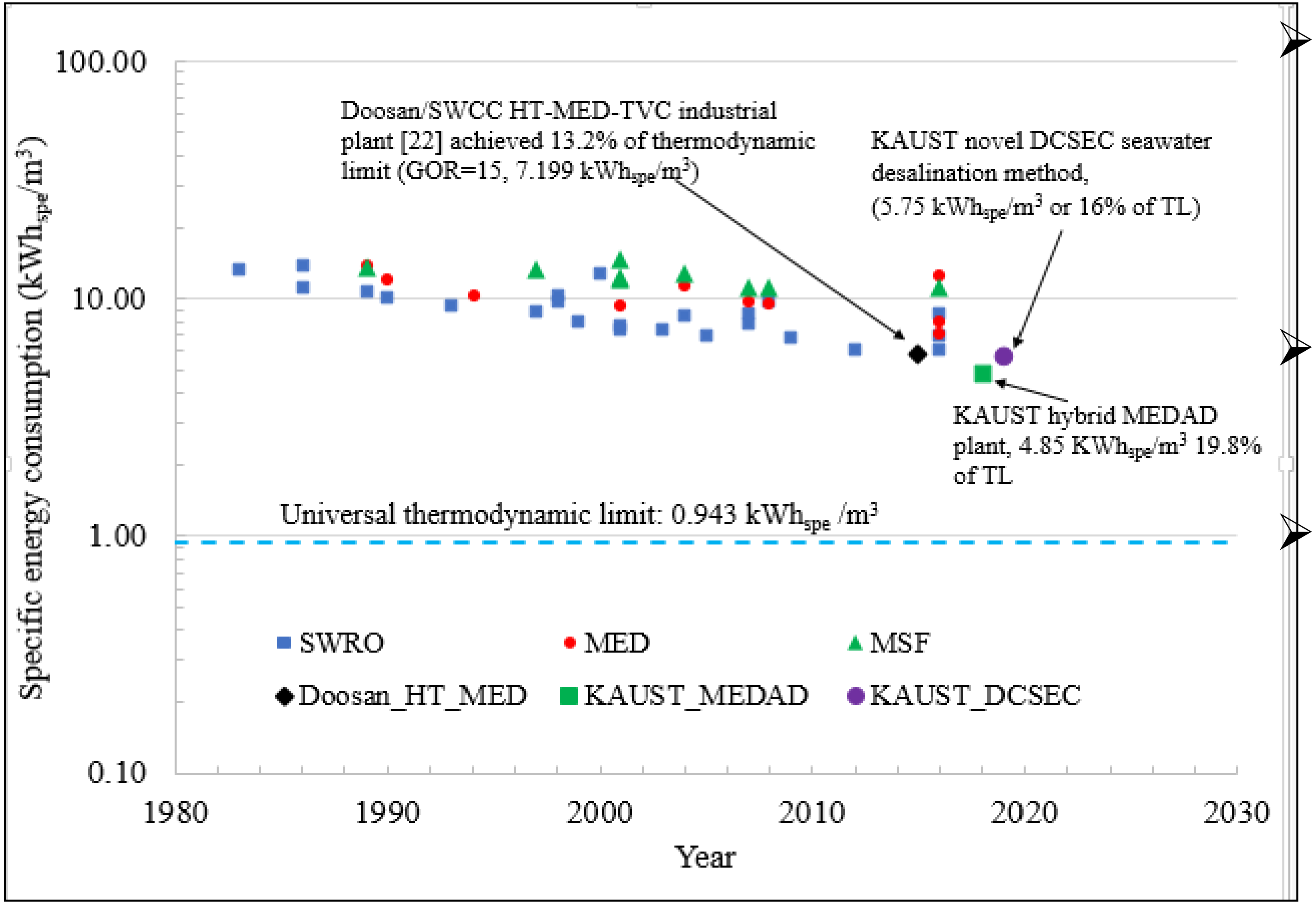
Cf_{elec} / CF_{ther},= 1.7328/0.1089

=15.9 times

Also, the weighted 2nd Law efficiency $(W_a / W^C)_{GT, ST}$ for electricity generation (GT & ST) = 0.697 or 69.7%.

And the 1st Law efiiency of CCGT plant is 57.7 %.

Comparison of EE of desalination methods



- At thermodynamic limit (TL), the Gibbs exergy or minimum work =0.78 kWh $_{\_work,TL}$). The $Q_{SPE,TL}$ /m³ is =0.78/0.8265 = 0.943.
- All present desalination methods consumed 6 to 12 time of TL,
- Plausible EE improvement, dropping the Q_{SPE} consumption from 5 → 3.5 times of Thermodynamic Limit.

Conclusion

- Using a common primary energy platform, the absolute value of derived energy (electricity and heat transfer) are capture accurately. FOM of desalination plants of assorted types., the $kWh_{\_SPE}/m^3$ of water are evaluated at this common energy platform. Pedagogically, the long-held fallacy is resolved with this approach.
- The best practical desalination process consumed > 5 $kWh_{\_SPE}/m^3$ whilst the thermodynamic limit is around 0.95 $kWh_{\_SPE}/m^3$.
- With better thermodynamic synergy amongst processes, a plausible target of < 3.5 $kWh_{\_SPE}/m^3$ can be reached in near future. Target can be attained by better hybrid membranes or thermally-driven cycles