Manufacturing Process Homeworks 2011

1. ***Make an order of magnitude estimate of the minimum energy-primary fuels, assume all processes are electric (not asking for exergy) required per unit mass (in kJ/kg) to: 1) machine (plastically deform), 2) melt, and 3) vaporize aluminum and steel. You may use the values given in Table 1 below, as well as other information given in the class handouts.***

Table 1. Selected Approximate Material Properties

	Y (MPa)	ρ (kg/m^3)	C kJ/kg·K	T_m (K)	T_V (K)	*H_m (kJ/kg)	*H_V (kJ/kg)
Steel	2000	8000	0.5	1773	~3134	270	6259
Aluminum	330	2700	0.9	933	~2773	400	10900

2. ***Estimate actual energy usage for machining, casting and a vapor phase processes compared to these theoretical values. What do you think was left out?***

3. ***Compare these values with the values given by Ashby in Figure 6.12 on page 120 of his book.***

4. ***Compare the values you obtained in question 2, to the values given in Figure 9 in Ch 6 by Gutowski & Sekulic (class reading for manufacturing)***

5. ***Do problem 1 above for the minimum work (exergy) for aluminum.***

Ashby

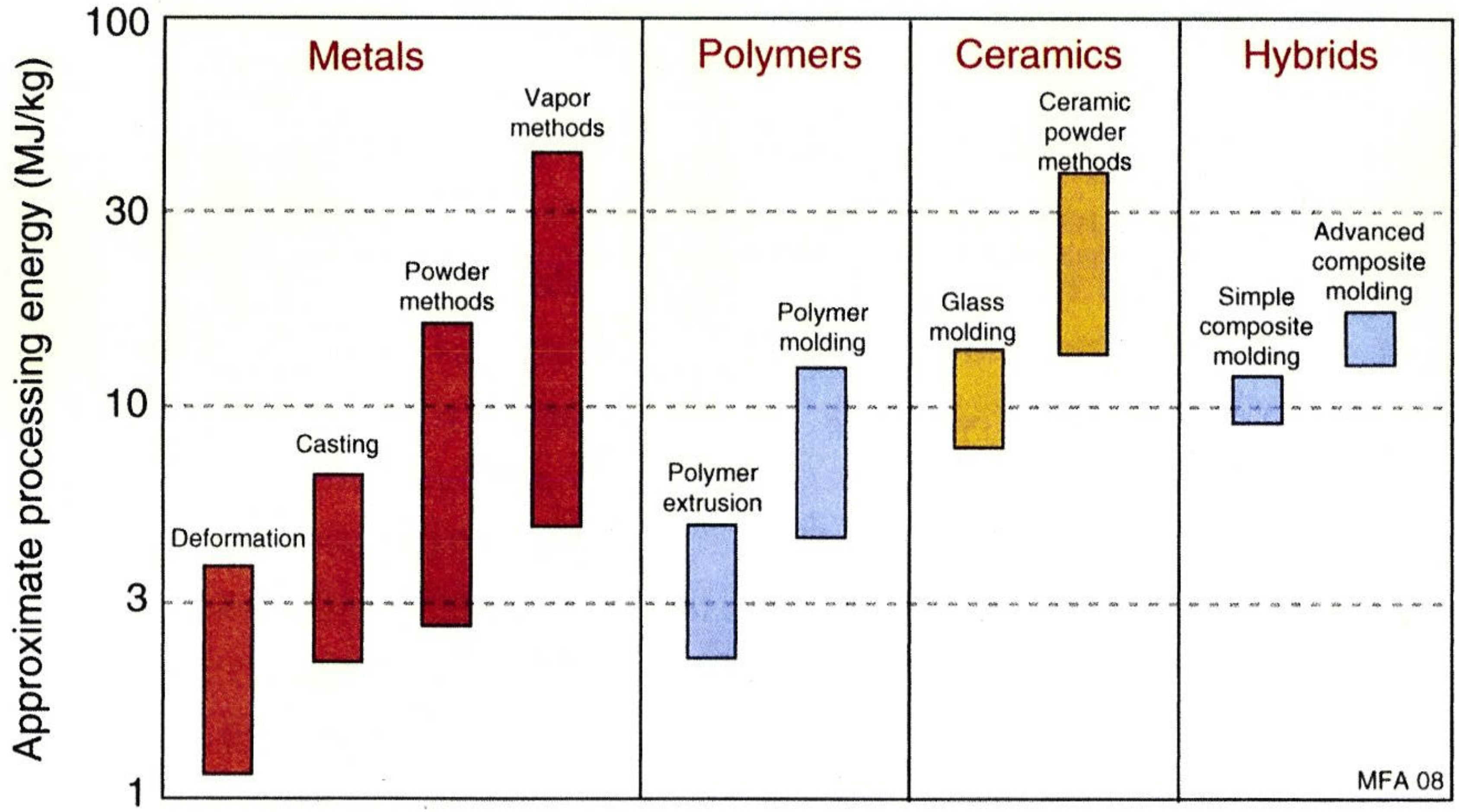
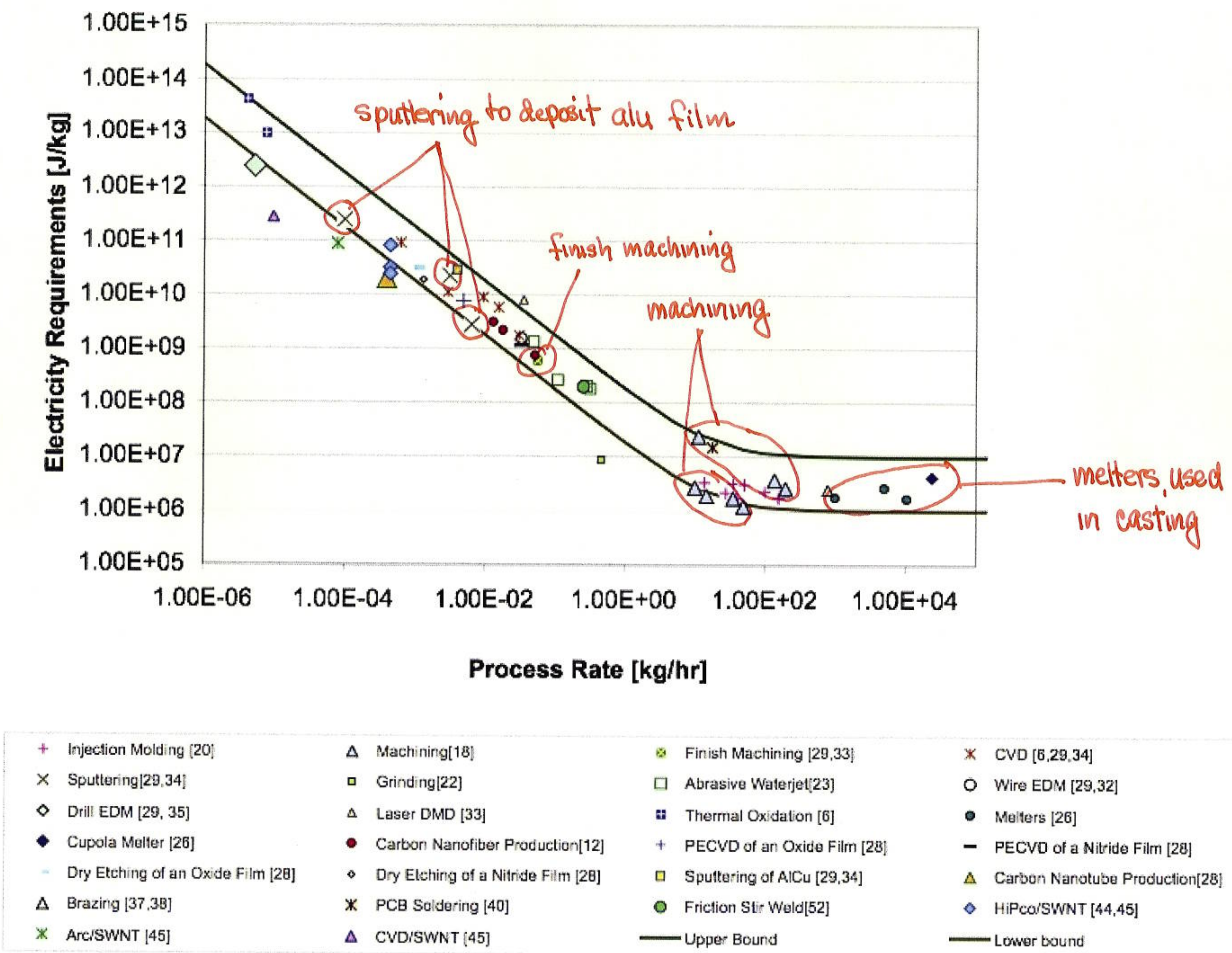


FIGURE 6.12 *Approximate processing energies for materials.*

2

Ch6 Gutowski & Sekulic



ANS

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<u>Answer</u> for aluminum

1. Machining, use the "specific energy" values given in class (slide 21) for aluminum alloys (pure aluminum will be on the softer side).

range for alu: U_s = 0.4 W·s/mm³ = <u>148kJ/kg</u> (plastic work & friction)
U_s = 1.1 = 407 kJ/kg

2. Melting

$U_M = 0.9(933 - 293) + 400 =$ <u>976kJ/kg</u>

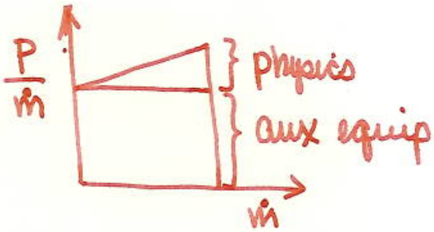
3. Vaporization

$U_v = U_M + \int C\,dT + 10{,}900$

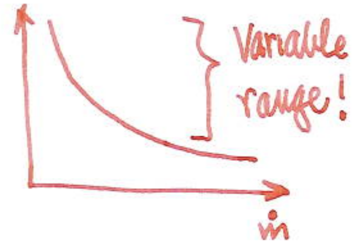
If we assume C (specific heat of the liquid) ~ C (solid), then U_V ~ <u>13,500kJ/kg</u>.

So the minimum energy increases by about an order of magnitude each time when we go from machining, to melting, to vaporization.

$P = P_{aux} + k\dot{m}$



$\Rightarrow \frac{P}{\dot{m}} = \frac{E}{m}$



2. **Estimate actual energy usage for machining, casting and a vapor phase processes compared to these theoretical values. What do you think was left out?**

Look for inefficiencies in the physics, method of delivery, aux equip, utilities

3. **Compare these values with the values given by Ashby in Figure 6.12 on page 120 of his book.**

on the low side

4. **Compare the values you obtained in question 2, to the values given in Figure 9 in Ch 6 by Gutowski & Sekulic (class reading for manufacturing)**

these are measurements of electricity

5. **Do problem 1 above for the minimum work (exergy) for aluminum.**

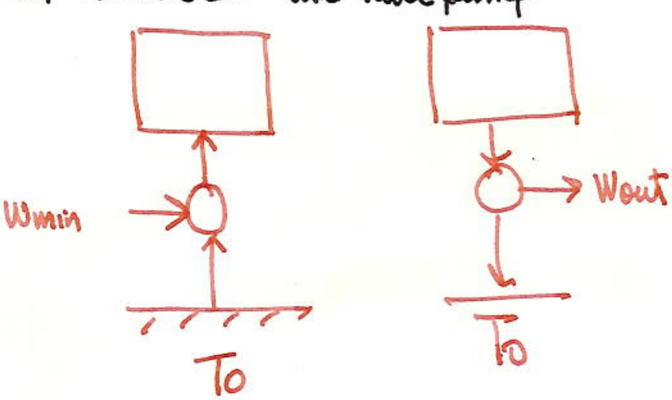
compare 1st law analysis w/ 2nd law (exergy)

ex. energy to raise temp of block

1st law: $\delta Q = dU$, $dU = c\,dT$ $\Rightarrow$ $Q_{min} = c\Delta T = 976 \frac{kJ}{kg}$ (c: ave)

exergy (see Ch 6): $W_{min} = c\Delta T - T_o c \ln\frac{T}{T_o} = 545 \frac{kJ}{kg}$

explanation: use heat pump



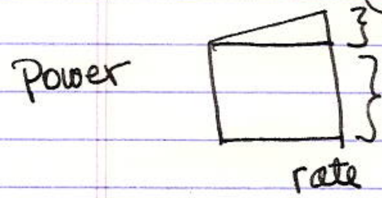
$T_o \neq$ zero Kelvin

∴ environment has heat (thermal energy - atomic motion) (but no exergy)

min work (heat pump) = reversible work (heat engine)

#2

Machining Processes (2011)



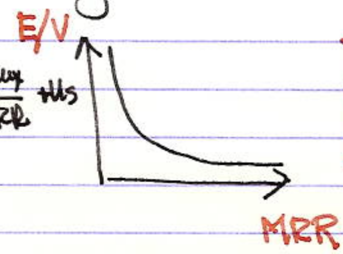
} physical work + friction = U_s (slide #15 Mfg)

} depends upon machine (slide #16 Mfg)

for machining Power = $P_{aux} + U_s$ MRR

MRR = $\dot{V}$ (prefer $\dot{m}$)

$$\frac{Power}{MRR} = \frac{E}{V} = \frac{P_{aux}}{MRR} + U_s$$



} lots of variation! depends upon MRR

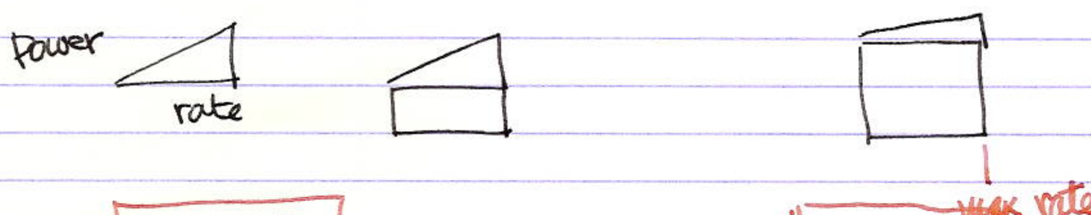
Physical Part: Alu $U_s = 0.4$ to $1.1 \ \frac{J}{mm^3} \times \left(\frac{10\,mm}{cm}\right)^3 \times \frac{1}{2.7\ g}\ cm^3$ (slide #15 Mfg lecture)

$= 0.15$ to $0.41 \ \frac{MJ}{kg}$

utilities x3 $= \boxed{0.45}$ to $\boxed{1.2 \ \frac{MJ}{kg}}$

Aux Equip: Power ratio physical : aux

manual	CNC	production
1:0	1:2	1:10



Range: $\boxed{0.45 \ \frac{MJ}{kg}}$ —— $1.2 + 12.0 = \boxed{13.2 \ \frac{MJ}{kg}}$

soft alu, manual machine

hard alu alloy, production machine, near max MRR

#2

Casting Processes

from #1 $U_m \cong 1 \frac{MJ}{kg}$ (both alu and iron)

need to include: 1. Runners, risers & scrap (depends on part and technology, ball park number ~ 2X)

2. Furnace efficiency (depends on technology and operating conditions ball park number ~ 2X)

3. For electric furnaces loses at utility 3X

4. All other activities at the foundary, pouring, shake out, mold making, finishing ... "Balance of the foundry" 2X

This results in a range from $8 \text{ to } 24 \frac{MJ}{kg}$

Vapor Phase Processes

ex. PVD- sputtering

process is inefficient because it coats the inside of the chamber as well as the target ∴ depends on geometry. a crude low ball est. for alu

$$13.5 \times 2 \times 2 \times 3 = 160 \text{ MJ/kg}$$

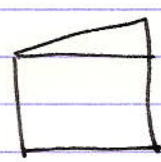
3 & 4

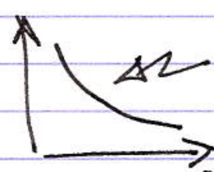
Also in LCA lecture
ref from N. Duque Ciceri

	Gutowski & Sekulic (Ch 6)	Ashby p120 (all appear on low side)
machining	1 - 10 MJ/kg electricity **3 - 30 MJ/kg** primary energy 1.3 - 8.8 (machining, milling, grinding)	**1 - 4 MJ/kg** (not clear but I presume primary energy)
casting	only give melters electric melters ~ 1 - 3 MJ/kg (elect) x3 ⇒ 3 - 9 MJ/kg (pri) double for foundary **6 - 18 MJ/kg** Note SIC code for this activity national averages are known above range agrees well. 11.6 - 29* (sand casting, iron casting*, die casting) * ← cupola melter, Neenah Foundry	**2 - 7 MJ/kg** (again not clear what was included ...)
vapor phase	sputtering 2 to 200 GJ/kg electricity midpoint say ~ 20 GJ/kg (electricity) X3 ⇒ **60 GJ/kg** (primary) or 6,000 to 600,000 MJ/kg !	note: sputtering preferred to evaporation - cleaner, more uniform deposition **5 - 40 MJ/kg**

recall

$P = P_{aux} + k\dot{V}$ (or $\dot{m}$)





(good thing mfg is usually small contributor to Energy!)

Manufacturing Process Estimates
Summary from various sources

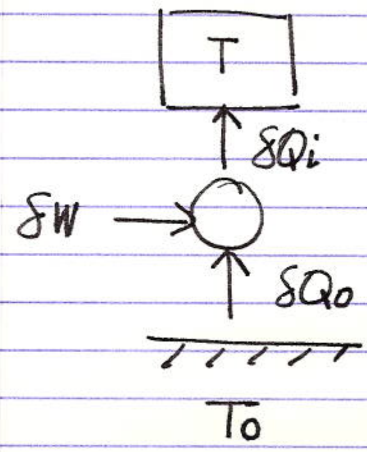
All values given in
MJ(primary energy)/kg (processed)

	Machining	**Casting**	**Vapor**
Minimum energy (#1 see attached)	0.5 (soft alu)	1 (alu & iron, does not include heating above Tm)	14 (alu)
Physical reasoning (#2 see attached)	0.5 – 13.0	8 – 24	160
Ch. 6 by Gutowski & Sekulic Mostly from measurements (#4 see attached)	3 – 30	6 – 18	6,000 – 600,000 (sputtering)
LCA slide # From paper by N. Duque Ciceri Mostly based on the literature	1 – 9	12 – 29	
Ashby's book Fig 6.12 page 120 (#3 see attached)	1 – 4	2 – 7	5 - 40
Range	**0.5 – 30**	**2 – 29**	**Too much variation to list**

These process energy intensity values vary by about 2 orders of magnitude or more. This variation is due to variation in operating conditions, in particular process rate, alternative process configurations and technologies, and equipment size among other factors.

#5

Heat Pump



$T_o \neq$ zero kelvin

∴ it has thermal energy
(but zero exergy)

1st law applied to heat pump

$$\delta Q_o + \delta W = \delta Q_i$$

or $\delta W = \delta Q_1 - \delta Q_o$

recall (here we sneak in the 2nd law) reversible process)

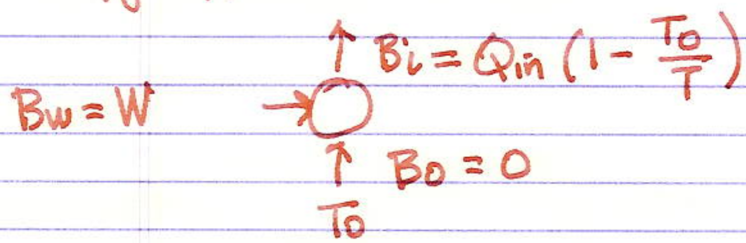
$$\frac{\delta Q_o}{\delta Q_i} = \frac{T_o}{T_1}$$

$$\delta W = \delta Q_i \left(1 - \frac{T_o}{T}\right)$$

now $\delta Q_i = C\,dT$
(applied to block)

$$\boxed{dW_{min} = \left(1 - \frac{T_o}{T}\right) C\,dT}$$

exergy approach is easier



Balance

$$dW = \delta Q_{in}\left(1 - \frac{T_o}{T}\right) + dB_{lost}$$

$$dW_{min} = C\left(1 - \frac{T_o}{T}\right) dT$$