Supporting Information Cover Sheet

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Manuscript Title:

Thermodynamic Analysis of Resources Used in Manufacturing Processes

Summary: Additional information to accompany Figure 4 in the paper.

Figures: none

Tables: 2

SI Pages : This page plus 2

Table SI 1
Supporting
Information
for Figure 4
in the
manuscript.

	Estimates					
Process Name	Power Required	Process Rate	Electricity Required	Note	Reference in Paper	Additional References
	kW	kg/hr	J/kg			
Sputtering of AlCu	32.07	4.00E-03	2.89E+10	a	[28]	
Dry Etching of Silicon Nitride	6.96	1.31E-03	1.91E+10	a		
Dry Etching of Silicon Dioxide	8.74	1.01E-03	3.11E+10	a		
PECVD of Silicon Nitride	10.71	3.29E-02	1.17E+09	a		
PECVD of Silicon Dioxide	10.59	4.97E-03	7.67E+09	a		
Carbon Nanofiber Production	11.30	1.30E-02	3.13E+09	a	[12]	
	11.09	1.80E-02	2.22E+09	a		
	10.99	5.20E-02	7.61E+08	a		
Cupola Melter	28333.3	2.40E+04	4.25E+06	a	[26]	
CVD Growth of Carbon	0.28	1.98E-05	5.05E+10	a	[28]	
	2.17	3.96E-04	1.97E+10	a		
Electric Induction Melting	5000.0	1.05E+04	1.72E+06	----	[26]	
	500.0	9.98E+02	1.80E+06	----		
	3750.0	4.99E+03	2.71E+06	----		
Injection Molding	10.76	1.36E+01	3.39E+06	----	[20]	
	26.10	3.54E+01	3.19E+06	----		
	71.40	1.83E+02	1.94E+06	----		
	35.76	5.08E+01	3.07E+06	----		
	47.46	9.80E+01	2.28E+06	----		
	65.34	1.63E+02	1.98E+06	----		
	12.73	2.77E+01	2.19E+06	----		
	13.17	3.95E+01	1.74E+06	----		
Machining	51.41	1.54E+02	1.74E+06	----	[18]	
	194.80	1.94E+02	5.26E+06	----		
	194.80	1.35E+02	7.50E+06	----		
	10.65	4.86E+01	1.30E+06	----		
	10.65	3.46E+01	1.88E+06	----		
	2.80	1.46E+01	1.81E+06	----		
Finish Machining	2.80	1.01E+01	2.63E+06	----	[29, 33]	[SI.1]
	75.16	1.13E+01	2.40E+07	a		
	9.59	5.75E-02	6.00E+08	a		
CVD	16.00	6.36E-04	9.05E+10	----	[6]	
	6.75	2.96E-03	1.10E+10	b	[29]	[SI.2]
	15.00	3.09E-02	1.75E+09	b	[34]	
	14.78	9.48E-03	8.89E+09	b	[29]	[SI.3]
	25.00	1.57E-02	5.72E+09	d	[29]	[SI.4]
Sputtering	6.75	1.02E-04	2.39E+11	b	[34]	
	19.50	3.16E-03	2.22E+10	b		
	5.04	6.51E-03	2.79E+09	----		
Grinding	10.00	4.70E-01	8.79E+06	----	[22]	
Waterjet	16.00	2.93E-01	2.03E+08	----	[23]	
	0.00	3.27E-01	1.82E+08	----		
	8.16	1.11E-01	2.65E+08	a		
	8.16	5.01E-02	1.36E+09	a		
Wire EDM	14.25	3.34E-02	1.54E+09	----	[29, 32]	[SI.6]
Drill EDM	2.63	5.29E-06	2.38E+12	b	[29, 35]	[SI.7]
Laser DMD	80.00	3.60E-02	8.00E+09	b	[33]	
Oxidation	21.00	7.80E-06	9.69E+12	d	[6]	
	48.00	4.16E-06	4.15E+13	d		
Notes/Assumptions:						
a = Required power is back-calculated from SEC (in MJ/kg or J/cm ³) and throughput						
b = Power required is assumed to be 75% of rated power.						
c = Power required is equal to rated power since the machine is operating at maximum						
d = If both idle and run power are provided, the machine is assumed to run 100% of the						

Additional notes on the materials and equipment types used for the data given in Table SI 1 starting at the seventh entry “Cupola Melter” and moving down. More details can be obtained by going to the original references.

Process	Equipment Variations	Materials Processed
1. Cupola Melter	Coke fuel with afterburner	Iron, steel,
2. CVD Growth of Carbon	Thermal, room pressure	carbon
3. Electric Induction Melting	Batch and Heel	Iron and steel
4. Injection Molding	Hybrid and electric machines	Plastics – PE, PP, PS, PVC
5. Machining	Milling	Steel, aluminium, and tool steel
6. Finish Machining	Milling	Tool steel
7. CVD	With and with out plasma enhancement, low pressure	Silicon Dioxide, Silicon Nitride
8. Sputtering	DC & RF	Aluminium
9. Grinding	Surface	Aluminium, Steel & Nylon
10. Waterjet	Garnet abrasive	Steel, aluminium, glass
11. Wire EDM	Wire	Tool steel
12. Drill EDM	Drill	Ni based alloy
13. Laser DMD		Tool Steel
14. Oxidation	Batch and individual furnaces	SiO ₂

Table SI 2 Additional Information on Processes

Additional References for the Supporting Information

[SI.1] Polgar, K.C., 1996, Simplified Time Estimation Booklet for Basic Machining Operations. Massachusetts Institute of Technology, M.S. Thesis, Department of Mechanical Engineering, Cambridge, MA, USA.

[SI.2] Griffin, Ryan, Experiment performed August 11th 2005 at the Microsystems Technology Laboratory, at the Massachusetts Institute of Technology

[SI.3] Novellus Concept One - 200 mm Dielectric System, 1992, Users Guide to 200mm PECVD Processing, Novellus Systems Inc., San Jose, CA, USA.

[SI.4] Krishnan, N., Earth Institute Research Fellow and Instructor at Columbia University. Personal communication. 8 Jul. 2005.

[SI.5] Holland, H., Technician at AJA International, Inc. Telephone interview. 9 June 2005.

[SI.6] Product literature, Sodick Co Ltd, CNC Wire-cut EDM, Model Selection Guide, Japan.

[SI.7] Product literature, "NC Drill EDM Machines" King Edm Ltd. Visited: 12 Dec. 2005
<<http://www.manufacturers.com.tw/showroom-6464-4-5-0000009919-0.php>>.