TABLE 13. *Dehydrogenations: electron-donating, formally hydrogen-forming reactions of energy metabolism*[a]

Equation no.	Substrates[b]	Products[b]	$\Delta G^{0'}$ kcal/reaction	$\Delta G^{0'}$ kJ/reaction	Route[c]
	Carboxylic acids				
1	$Formate^- + H_2O$	$HCO_3^- + H_2$	+0.3	+1.3	
2	$Acetate^- + 4H_2O$	$2\ HCO_3^- + 4H_2 + H^+$	+25.0	+104.6	CC
3	$2\ Acetate^- + 2H_2O$	$1\ HCO_3^- + pyruvate^- + 3H_2$	+36.3	+151.7	GC
4	$Acetate^- + H_2O$	$1\ HCO_3^- + CH_4$	−7.4	−31.0	
5	$Propionate^- + 3H_2O$	$1\ HCO_3^- + acetate^- + H^+ + 3H_2$	+18.2	+76.1	
6	$Propionate^- + 7H_2O$	$3\ HCO_3^- + 2H^+ + 7H_2$	+43.3	+181.1	CC/OD
7	$Butyrate^- + 10H_2O$	$4\ HCO_3^- + 3H^+ + 10H_2$	+61.5	+257.3	CC
8	$Succinate^{2-} + 8H_2O$	$4\ HCO_3^- + 2H^+ + 7H_2$	+38.3	+160.2	CC/OD
9	$Butyrate^- + 2H_2O$	$2\ Acetate^- + H^+ + 2H_2$	+11.5	+48.1	BO
10	$Caproate^- + 4H_2O$	$3\ Acetate^- + 2H^+ + 4H_2$	+23.0	+96.2	BO
	α-Keto acids				
11	$Pyruvate^- + 2H_2O$	$Acetate^- + HCO_3^- + H^+ + H_2$	−11.3[d]	−47.3	OD
12	$Pyruvate^- + 6H_2O$	$3\ HCO_3^- + 2H^+ + 5H_2$	+13.7	+57.3	OD/CC
13	$Glyoxylate^- + 2H_2O$	$Formate^- + HCO_3^- + H^+ + H_2$	−8.3	−34.7	OD
14	$Glyoxylate^- + 3H_2O$	$2\ HCO_3^- + H^+ + 2H_2$	−8.0	−33.5	OD/GC
15	$\alpha\text{-Ketobutyrate}^- + 2H_2O$	$Propionate^- + HCO_3^- + H^+ + H_2$	−11.3	−47.3	OD
16	$\alpha\text{-Ketoglutarate}^{2-} + 2H_2O$	$Succinate^{2-} + HCO_3^- + H^+ + H_2$	−10.8	−45.2	OD
17	$Oxalacetate^{2-} + 3H_2O$	$Acetate^- + 2HCO_3^- + H^+ + H_2$	−17.8	−74.5	OD
	α,β-Unsaturated acids, hydroxy acids				
18	$Lactate^- + 2H_2O$	$Acetate^- + HCO_3^- + H^+ + 2H_2$	−1.0	−4.2	OD
19	$Malate^{2-} + 3H_2O$	$Acetate^- + 2HCO_3^- + H^+ + 2H_2$	−6.3	−26.4	OD
20	$Citrate^{3-} + 3H_2O$	$Succinate^{2-} + 2HCO_3^- + H^+ + 2H_2$	−5.7	−23.8	CC
21	$Isocitrate^{3-} + 3H_2O$	$Succinate^{2-} + 2HCO_3^- + H^+ + 2H_2$	−7.3	−30.5	CC
22	$\beta\text{-Hydroxybutyrate}^- + H_2O$	$2\ Acetate^- + H^+ + H_2$	−8.4	−35.1	BO
23	$Crotonate^- + 2H_2O$	$2\ Acetate^- + H^+ + H_2$	−6.4	−26.9	BO
24	$Acrylate^- + 3H_2O$	$Acetate^- + HCO_3^- + H^+ + 2H_2$	+0.4	+1.7	OD
25	$Fumarate^{2-} + 4H_2O$	$Acetate^- + 2HCO_3^- + H^+ + 2H_2$	−7.2	−30.1	CC/OD
26	$Glycollate^- + 2H_2O$	$Formate^- + HCO_3^- + H^+ + 2H_2$	+6.6	+27.6	OD
	Aldehydes (aldoses, ketoses)				
27	$Formaldehyde + H_2O$	$Formate^- + H^+ + H_2$	−5.6	−23.4	
28	$Acetaldehyde + H_2O$	$Acetate^- + H^+ + H_2$	−7.7	−32.2	
29	$Glyceraldehyde + H_2O$	$Glycerate^- + H^+ + H_2$	−5.4	−22.6	EM
30	Glyceraldehyde	$Pyruvate^- + H^+ + H_2$	−18.4	−76.4	EM
31	$Glyceraldehyde + 2H_2O$	$Acetate^- + HCO_3^- + 2H^+ + 2H_2$	−29.5	−123.6	EM/OD

TABLE 13—*Continued*

Equation no.	Substrates[b]	Products[b]	$\Delta G^{0\prime}$ kcal/reaction	$\Delta G^{0\prime}$ kJ/reaction	Route[c]
32	Glyceraldehyde + $6H_2O$	$3HCO_3^- + 3H^+ + 6H_2$	−4.7	−19.7	EM/CC
33	3 Ribose	5 Pyruvate$^-$ + $5H^+ + 5H_2$	−71.9	−300.8	TT/EM
34	Ribose	Acetate$^-$ + pyruvate$^-$ + $2H^+ + H_2$	−39.8	−166.5	PK
35	Glucose	2 Pyruvate$^-$ + $2H^+ + 2H_2$	−26.8	−112.1	EM
36	Glucose + $4H_2O$	2 Acetate$^-$ + $2HCO_3^-$ + $4H^+ + 4H_2$	−49.3	−206.3	EM/OD
37	Glucose + $2H_2O$	Acetate$^-$ + pyruvate$^-$ + HCO_3^- + $3H^+ + 3H_2$	−38.0	−159.0	PK/EM
38	Glucose + $12H_2O$	6 HCO_3^- + $6H^+ + 12H_2$	+0.8	+3.2	EM/CC
39	3 Heptose	7 Pyruvate$^-$ + $7H^+ + 7H_2$	−88.6	−370.7	TT/EM
40	Gluconate$^-$ + H_2O	Acetate$^-$ + pyruvate$^-$ + HCO_3^- + $2H^+ + 2H_2$	−34.6	−144.9	PK/EM
41	Gluconate$^-$	2 Pyruvate$^-$ + $H^+ + H_2 + H_2O$	−24.1	−100.8	ED
42	3 Gluconate$^-$ + $3H_2O$	5 Pyruvate$^-$ + $3HCO_3^-$ + $5H^+$ + $8H_2$	−56.3	−235.7	TT/EM
43	6 Gluconate$^-$	11 Pyruvate$^-$ + $3HCO_3^-$ + $8H^+$ + $11H_2$	−126.4	−528.9	
	Alcohols				
44	Methanol + H_2O	Formate$^-$ + $H^+ + 2H_2$	+5.2	+21.8	
45	Methanol + $2H_2O$	HCO_3^- + $H^+ + 3H_2$	+5.5	+23.5	
46	Ethanol + H_2O	Acetate$^-$ + $H^+ + 2H_2$	+2.3	+9.6	
47	Ethylene glycol	Acetate$^-$ + $H^+ + H_2$	−18.8	−78.7	
48	Glycerol	Pyruvate$^-$ + $H^+ + 2H_2$	−6.2	−25.9	EM
49	Glycerol + $2H_2O$	Acetate$^-$ + HCO_3^- + $2H^+ + 3H_2$	−17.5	−73.2	EM/OD
	Amino acids				
50	2 Glycine + $4H_2O$	Acetate$^-$ + $2HCO_3^-$ + H^+ + $2NH_4^+$ + $2H_2$	−12.3	−51.5	OD
51	Glutamate$^-$ + $3H_2O$	2 Acetate$^-$ + HCO_3^- + H^+ + NH_4^+ + H_2	−8.1	−33.9	OD
52	Alanine + $3H_2O$	Acetate$^-$ + HCO_3^- + H^+ + NH_4^+ + $2H_2$	+1.8	+7.5	St
53	Leucine + $3H_2O$	Isovalerate$^-$ + HCO_3^- + H^+ + NH_4^+ + $2H_2$	+1.0	+4.2	St
54	Choline$^+$ + H_2O	Acetate$^-$ + H^+ + $(CH_3)_3NH^+$ + H_2			
	Sulfonium compounds				
55	Propiothetine + $3H_2O$	Acetate$^-$ + HCO_3^- + $2H^+$ + $(CH_3)_2S$ + $2H_2$ (618)	−10.1	−42.3	OD
	Inorganic electron donors				
56	2 NH_4^+	$N_2 + 2H^+ + 3H_2$	+18.8	+78.7	
57	$NH_4^+ + 2H_2O$	$NO_2^- + 2H^+ + 3H_2$	+104.3	+436.4	
58	$NH_4^+ + 3H_2O$	$NO_3^- + 2H^+ + 4H_2$	+143.3	+599.6	
59	$NO_2^- + H_2O$	$NO_3^- + H_2$	+39	+163.2	
60	$HS^- + H^+$	$S + H_2$	+6.7	+28.8	
61	$HS^- + 4H_2O$	$SO_4^{2-} + H^+ + 4H_2$	+36.4	+152.2	
62	$S + 4H_2O$	$SO_4^{2-} + 2H^+ + 3H_2$	+29.7	+124.3	
63	$S_2O_3^{2-} + 5H_2O$	2 SO_4^{2-} + $5H_2$	+50.2	+210.0	
64	$S_2O_3^{2-} + 3H_2O$	2 SO_3^{2-} + $3H_2$	+60.2	+251.9	
65	2 $Fe^{2-} + 2H^+$	2 $Fe^{3+} + H_2$	+54.6	+228.5	

[a] According to Decker et al. (129). The free energy data have been recalculated using the free energies of formation from the elements listed in Table 15, and are given to the first decimal place, which is, however, not significant in most of the values. The data do not include formation or consumption of ATP.

[b] H_2, N_2, CH_4, and C_2H_6 in the gaseous state; all other substances in aqueous solution at 1 mol/kg activity.

[c] Abbreviations: EM, Embden-Meyerhof pathway; OD, oxidative decarboxylation; CC, citric acid cycle; GC, glyoxylate cycle; BO, β-oxidation of fatty acids; ED, Entner-Doudoroff pathway; PK, phosphoketolase pathway; TT, transaldolase-transketolase pathway; St, Stickland reaction.

[d] In analogy with equation II.