

Common redox reactions in the oxidation of organic matter

Photosynthesis reduces the C⁴⁺ of CO₂ and, in adding electrons to C to give the C⁰ of CH₂O, stores energy. Dead organic matter is thus a source of energy, if the C⁰ can be oxidized (if the added electrons can now be moved to an electron acceptor). In aerobic environments (those with O₂), O₂ acts as the electron acceptor. After (or where) an environment's O₂ has been used up, various positively charged atoms serve as electron acceptors.

One should appreciate that the anaerobic reactions below are almost always bacterially mediated, rather than abiotic. Bacteria as a group use the most energetically favorable reaction, and some individual species can use different reactions depending on the most energetically favorable electron acceptor available. Thus natural systems use the reactions below in a progression from 1 to 7, with methanogenesis in effect the reaction of last resort.

	Electron acceptor	Reaction by which organic matter is oxidized	Relative yield of energy	Characteristic H ₂ concentration (nM) in solution
1	O ⁰ in O ₂	CH ₂ O + O ₂ --> CO ₂ + H ₂ O	100	0
----- aerobic conditions ----- anaerobic conditions -----				
2	N ⁵⁺ in NO ₃ ⁻	5CH ₂ O + 4NO ₃ ⁻ --> 4HCO ₃ ⁻ + 2N ₂ + CO ₂ + 3H ₂ O	93	<0.1
3	N ⁵⁺ in NO ₃ ⁻	2CH ₂ O + NO ₃ ⁻ + H ₂ O --> 2HCO ₃ ⁻ + NH ₄ ⁺		
4	Mn ⁴⁺ in MnO ₂	CH ₂ O + 3CO ₂ + H ₂ O + 2MnO ₂ --> 2Mn ²⁺ + 4HCO ₃ ⁻	87	<0.1
5	Fe ³⁺ in Fe(OH) ₃	CH ₂ O + 7CO ₂ + 4Fe(OH) ₃ --> 4Fe ²⁺ + 8HCO ₃ ⁻ + 3H ₂ O	84	0-0.5
6	S ⁶⁺ in SO ₄ ²⁻	2CH ₂ O + SO ₄ ²⁻ --> H ₂ S + 2HCO ₃ ⁻	6	1-2
7	C ⁰ in CH ₂ O	2CH ₂ O --> CH ₄ + CO ₂ (Methanogenesis)	3	5-10

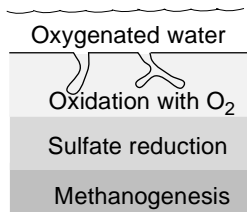
Carbonic acid (H₂CO₃)

Fe²⁺ and S²⁻ for formation of pyrite

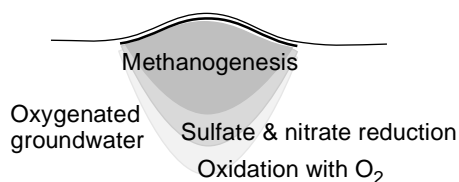
Reactions that produce bicarbonate (HCO₃⁻)

This series of reactions is relevant in any setting where organic matter is sealed away from the atmosphere:

In sediments:



Under landfills:



Note that methanogenesis uses C in two ways: of any two C atoms in CH₂O, one is oxidized as in all the other reactions above and goes from C⁰ to C⁴⁺, whereas the other C⁰ serves as the electron acceptor and goes from C⁰ to the C⁴⁻ of methane.

Sources: Reactions 1-2 and 4-7 are derived from Berner (1981, *Fortschr. Miner.*, v. 59, p. 117-135); those reactions and Reaction 3 are derived from Stumm & Morgan's *Aquatic Chemistry*; relative energy yield and hydrogen concentrations are from Lovley and Chapelle (1995, *Reviews of Geophysics*, v. 33, p. 365-381).