

## Common redox reactions in the oxidation of organic matter

Photosynthesis reduces the C<sup>4+</sup> of CO<sub>2</sub> and, in adding electrons to C to give the C<sup>0</sup> of CH<sub>2</sub>O, stores energy. Dead organic matter is thus a source of energy, if the C<sup>0</sup> can be oxidized (if the added electrons can now be moved to an electron acceptor). In aerobic environments (those with O<sub>2</sub>), O<sub>2</sub> acts as the electron acceptor. After (or where) an environment's O<sub>2</sub> has been used up, various positively charged atoms serve as electron acceptors.

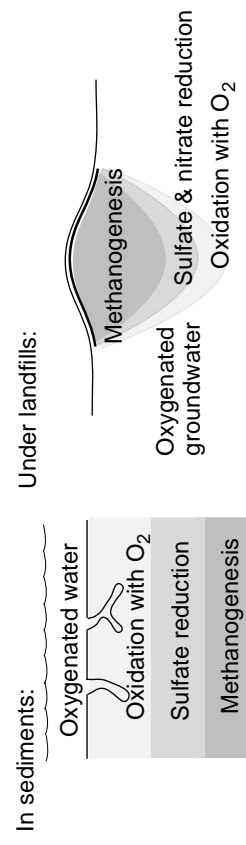
One should appreciate that the anaerobic reactions below are almost always bacterially mediated, rather than abiotic. Bacteria as a group use the most energetically favorable reaction, and some individual species can use different reactions depending on the most energetically favorable electron acceptor 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 <sub>2</sub> concentration (nM) in solution
1	O <sup>0</sup> in O <sub>2</sub>	CH <sub>2</sub> O + O <sub>2</sub> → CO <sub>2</sub> + H <sub>2</sub> O	100	0
----- Carbonic acid (H <sub>2</sub> CO <sub>3</sub> ) -----				
2	N <sup>5+</sup> in NO <sub>3</sub> <sup>-</sup>	5CH <sub>2</sub> O + 4NO <sub>3</sub> <sup>-</sup> → 4HCO <sub>3</sub> <sup>-</sup> + 2N <sub>2</sub> + CO <sub>2</sub> + 3H <sub>2</sub> O	93	<0.1
3	N <sup>5+</sup> in NO <sub>3</sub> <sup>-</sup>	2CH <sub>2</sub> O + NO <sub>3</sub> <sup>-</sup> + H <sub>2</sub> O → 2HCO <sub>3</sub> <sup>-</sup> + NH <sub>4</sub> <sup>+</sup>		
4	Mn <sup>4+</sup> in MnO <sub>2</sub>	CH <sub>2</sub> O + 3CO <sub>2</sub> + H <sub>2</sub> O + 2MnO <sub>2</sub> → 2Mn <sup>2+</sup> + 4HCO <sub>3</sub> <sup>-</sup>	87	<0.1
5	Fe <sup>3+</sup> in Fe(OH) <sub>3</sub>	CH <sub>2</sub> O + 7CO <sub>2</sub> + 4Fe(OH) <sub>3</sub> → 4Fe <sup>2+</sup> + 8HCO <sub>3</sub> <sup>-</sup> + 3H <sub>2</sub> O	84	0-0.5
6	S <sup>6+</sup> in SO <sub>4</sub> <sup>2-</sup>	2CH <sub>2</sub> O + SO <sub>4</sub> <sup>2-</sup> → H <sub>2</sub> S + 2HCO <sub>3</sub> <sup>-</sup>	6	1-2
7	C <sup>0</sup> in CH <sub>2</sub> O	2CH <sub>2</sub> O → CH <sub>4</sub> + CO <sub>2</sub> (Methanogenesis)	3	5-10

Reactions that produce bicarbonate (HCO<sub>3</sub><sup>-</sup>)

Fe<sup>2+</sup> and S<sup>2-</sup> for formation of pyrite

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



Note that methanogenesis uses C in two ways: of any two C atoms in CH<sub>2</sub>O, one is oxidized as in all the other reactions above and goes from C<sup>0</sup> to C<sup>4+</sup>, whereas the other C<sup>0</sup> serves as the electron acceptor and goes from C<sup>0</sup> to the C<sup>-4</sup> 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).