oxidised to sulphate or even hydrogen gas can be an electron source, provided that there is a redox potential between them.

A few examples – bacteria can have complex I and succinate dehydrogenase, the alternative NADH dehydrogenase, but it also has various other enzymes that can utilise formate, glucose, hydrogen and a myriad of electron donors. Almost always these enzymes donate to a quinone and even the quinone can be varied in bacteria; some of them use ubiquinone and some use menaquinone, which has a lower redox potential and then the quinone pool can donate to a whole load of things, such as cytochrome bo or bd, nitrate or nitrite reductase, fumarate reductase, e.t.c.

Many bacteria have a complex III and can reduce cytochrome c. for example, methanol can be oxidised by some bacteria by an enzyme that reduces cytochrome c, which then goes to cytochrome oxidase. (summarised in biophysics article). Some bacteria actually use crude metals, ferric ion or manganese for example which act as an electron sink.

In many cases, bacteria are able to flip their respiratory metabolism depending on their environment as they have to deal with much more extreme environments than out own mitochondria. For example, with Paraccocus denitrificans, which is a soil bacterium, one of the closest to mitochondria actually, if it is in an aerobic environment, it has a completely normal respiratory chain identical to our own. If however, that environment goes anaerobic, it switches complex III and IV off and switches on a nitrate reductase instead, so using complex I and II to ubiquinol is normal, but now because there is no oxygen around, it utilises nitrate from the soil and reducing it to nitrite instead. This is part of soil nitrification.

Nitrate reduction – nitrate reductase takes electrons from the respiratory chain and reduced nitrate to nitrite, but actually that reaction there chemically can go all the way through form nitrite to NO, NO to N2O and N2O can be reduced to nitrogen and in total, this complete reduction of nitrate utilises 8 electrons and there are 4 different enzymes that can do this and some organsims have all 4 of these enzymes, so they are able to fix nitrogen back into the air. One example is paracoccus denitrificans.

Denitrification – this process is carefully regulated as some of the products od the reduction of nitrate to nitrogen gas are toxic. The enzymes are spatially arranged in the plasma membranes. NADH by complex I reduced quinone to quinol, quinol is oxidised by a nitrate reductase which is plugged into the same membrane to make nitrite, nitrite is pumped out into the periplasm and nitrate in (an antiporter system), the nitrite is reduced by nitrite reductase with electrons from cytochrome c in the periplasm to make NO gas, the NO gas is trapped by NO reductase to make N2O and finally, N2O is reduced to nitrogen by a different periplasmic enzyme. in different bacteria, these enzymes are in different places, some are insdie the cell and some are out and they don't necessarily use cytochrome c, some use other electron sources.

Remarkably, sequence comparisons show that N2O reductase and NOreductase have homology with, respectively, subunits II and I of cytochrome c oxidase. Hence, it is possible that cytochrome ocidase evolved from pre-exisitign enzymes for nitrogen metabolism, probably after oxygenic photosynthesis has increases the atmospheric oxygen concentration.

Sulphate reduction – the reduction of sulphate is a strictly anaerobic process – all of the microbes that are capable of carrying it out only grow in environments completely devoid of oxygen. The reduction of sulphate is also a final sink for some bacteria and many bacteria, strictly in anaerobic environmetns because the sulphate utlilising enzymes are oxygen sensitive and their often at the bottom of lakes and these lakes become black becayse they reduce sulphate to sulphide, which then reacts with iron and makes ferrous sulphide. This is what makes anaerobic lakes stink.

Suplahte can be reduce to sulphide in the form of hydrogen sulphide which requires 8 electrons. The reducing substrates used by sulphate reducers are very variable, they can use hydrogen gas if that is around (some organsims can make hydrogen gas) or various organic material, such as acetate or lactate as these things tend to be present in anaerobic environments. They use these as an electron source and the sulphate acts as the final sink for the respiratory chain to make a proton motive force and therfroe ATP.

And again because bacteria are so diverse, you can get not only sulphate reduction, but you can also get sulphur oxidation. Some bacteria use sulphur as the electron source instead and converts it to sulphite and then sulphide.

Carbon reduction – Co2 is a very common anion in nature in the form of carbonate, so several groups of mcirobes are capable of using carbon dioxide as a terminal electron acceptor. Howver, Co2 has a low redox potential and the enrrgy yields are low, so you need something more reducing in order to be able to reduce Co2. The most common group of microbes that take advantage of co2 are the methanogens, which produce methane. Cattle, for example, have methanogenic bacteria in their guts and hydrogen producing bacteria and basically, co2 in the form of bicarbanote is reduced to methan with hydrogen gas and they are using this as an electron transfer chain to make a proton motive force. In mnay cases, it is actually molecular hydrogen that is used and this comes from other bacteria that are using protons as the electron sink; they are putting electrons onto a proton with a hydrogenase and generating hydrogen. It has been found that there are a lot of hydrogen generating micorbes in our gut flora.

Hydrogenases – there are two different strucutres of hydrogenases, one has a nickel-iron centre and one has just an iron centre that forms the active sites. The metals are ligated by cysteine residues and have carbon monoxides and cyanide ligands attached. Some types can reduce ubiquinone.

Metal eating bacteria – ferrous has a high redox potential so at normal pHs, you can't use oxygen to oxidise Fe^{2+} to Fe^{3+} as they are too close in potential, there is not much energy difference between them, but at very low pH, the oxygen potential is pH dependent and rises 60mV per pH unit and so acidophilic bacteria are able to use ferrous iron oxidation by molecular oxygen.

Acidithiobacillus ferroxidans – they have a blue copper protein which grabs electrons from the ferrous iron and that donates electrons to a cytochrome oxidase which pumps protons across the membrane and then allows ATP to be formed. Interestingly these ones, in order to get NADH which they cannot generate, they actually utilise complex I backwards and forces protons to move backwards causing NAD to form NADH. So it generates both ATP and NADH for catabolic processes.