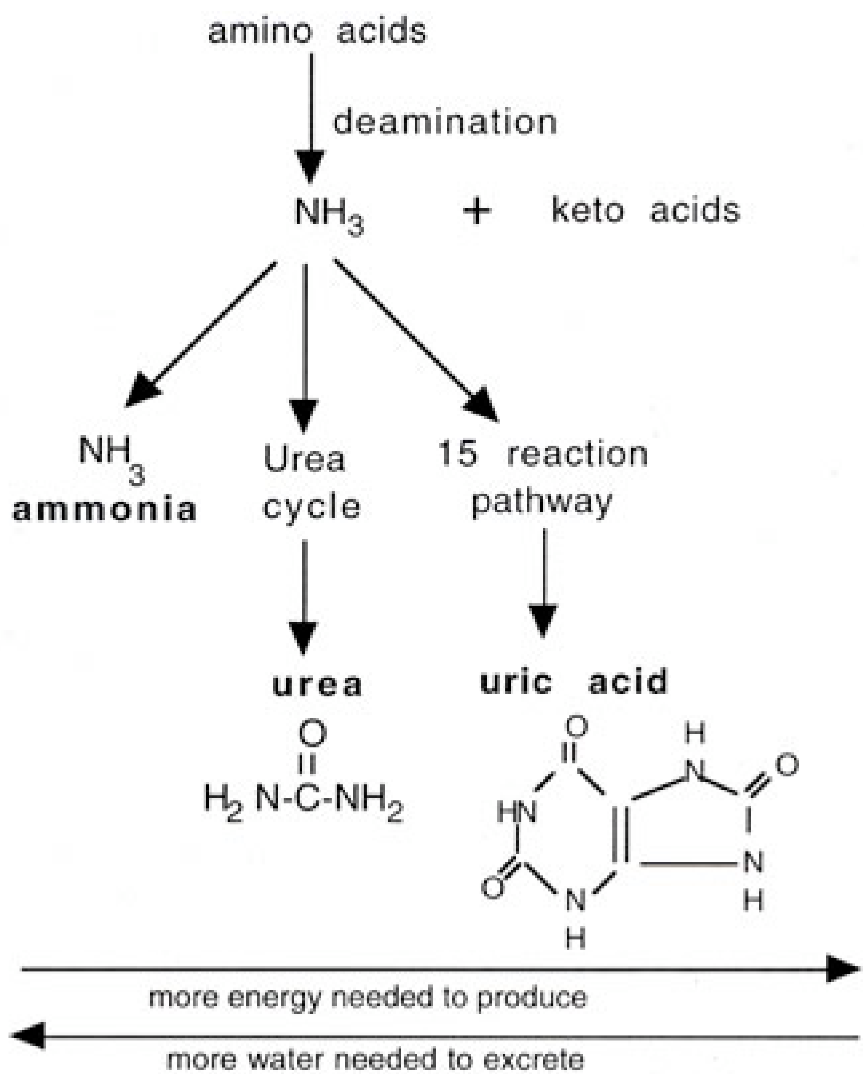
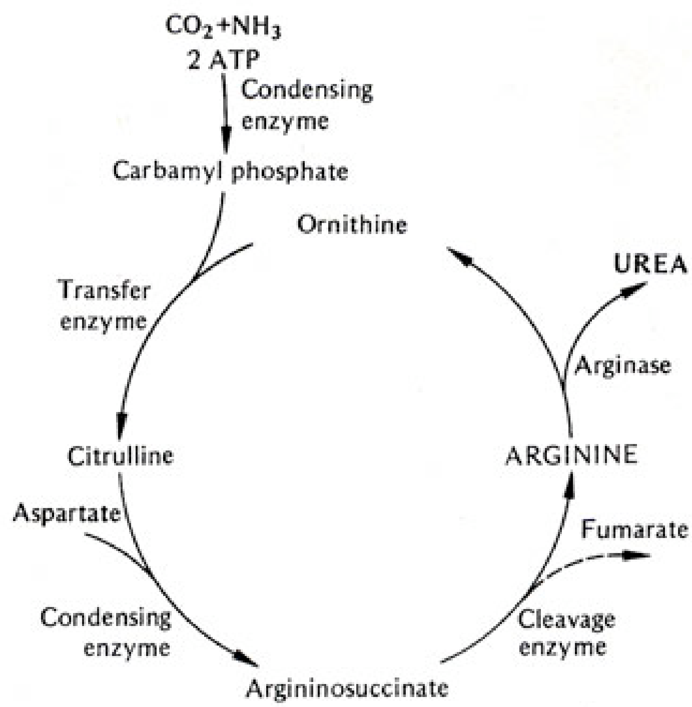
A Comparison Of Nitrogenous Waste Products

When amino acids are metabolized, the amino group (-NH2) is removed by the process of **deamination** and forms **ammonia** (NH3). The ammonia is excreted unchanged by many animals, particularly aquatic invertebrates, but by some animals it is synthesized into **urea** and by others, into **uric acid**, before being excreted.



Ammonia is toxic in anything but the most dilute solution. Aquatic organisms avoid ammonia poisoning by dissolving it in large quantities of water from their environment and excreting this dilute solution. Thus, ammonia diffuses across the gill epithelium, skin, or other permeable membrane bathed by water. And, since ammonia is the first breakdown product in the metabolism of amino acids, it requires very little energy to produce. However, in terrestrial vertebrates, water is often scarce and water conservation may be a problem. And, because terrestrial vertebrates have lost their gills, the gill epithelium is no longer a major route for ammonia excretion. Given these constraints, ammonia is converted into urea or uric acid, both being less toxic forms that address the immediate problem of ammonia poisoning. In addition, less water is required to excrete urea or uric acid, so water is conserved as well.

Urea is soluble in water and is moderately toxic. Because urea is less toxic than ammonia, it can accumulate in higher levels in the tissues without damage and can be excreted in a more concentrated form. The synthesis of urea from ammonia occurs in the urea cycle shown below. This biochemical process required energy, but for an animal needing to conserve water, it is worth the investment of energy.



Urea is synthesized from ammonia and carbon dioxide by condensation with the amino acid ornithine. Through several more steps arginine is formed, which, with the aid of the enzyme arginase, splits off urea, forming ornithine, which can reenter the cycle.

Uric acid, which is almost insoluble in water, is excreted by the kidney and is transported by the ureters into the **cloaca** (a common chamber into which the digestive, urinary, and reproductive systems empty their contents). In the cloaca, uric acid joins with ions and precipitates out. The water not used is reabsorbed through the walls of the cloaca into the blood. A concentrated, nearly solid uric acid "sludge" forms, allowing nitrogen elimination with little loss of water. Uric acid excretion is correlated with egg-laying on land. Because uric acid precipitates out of solution, it is nontoxic and does not exert osmotic pressure on the embryo. It can, therefore, be safely sequestered within the egg without requiring large amounts of water. Uric acid production has its energetic cost however; its synthesis requires a series of about 15 reactions, each catalyzed by an enzyme. A great deal of energy is required to drive these reactions.

There is no clear correlation between the phylogenetic relationship of vertebrates and their major excretory products. Most bony fish excrete ammonia; most mammals, amphibians, and sharks, urea; and most birds and reptiles, uric acid. But, there are many exceptions. For example, frog tadpoles excrete ammonia while adult frogs use urea, and crocodiles excrete mainly ammonia. Many turtles excrete uric acid, but some excrete urea or even ammonia, while some frogs excrete uric acid. Birds and mammals however, seem to have no exceptions; mammals excrete primarily urea and birds uric acid.