# Text transcript of Glycolysis Animation

Cells break down food molecules, such as glucose, through multi-step pathways. In the process of glycolysis, the breakdown of one glucose molecule into two three-carbon molecules produces a net gain of energy that is captured by the molecules ATP and NADH. In eucaryotes, the breakdown product, pyruvate, is imported into mitochondria, where it ultimately feeds into the citric acid cycle and the electron transport chain.

Glycolysis involves a sequence of 10 steps. In the first three steps, energy in the form of ATP is invested to be recouped later. In the fourth and fifth steps, this energy allows glucose to be split into two smaller molecules from which energy can be harnessed efficiently. And in the last five steps, energy is released step-wise as ATP and NADH. The elegant chemistry that evolved to catalyze these reactions ensures that energy is released in small portions that can be efficiently captured. Less controlled combustion reactions would release most of the energy as heat.

In the first step, the enzyme hexokinase uses ATP to phosphorylate glucose. This investment of energy primes glucose for energy-releasing reactions later in glycolysis.

The resulting molecule is glucose 6-phosphate. ADP is released. This first step of glycolysis is irreversible.

In the second step of glycolysis, the enzyme phosphoglucose isomerise catalyzes the opening of the ring form of glucose 6-phosphate to the open chain form.

The same enzyme then performs a reversible reaction in which the carbonyl group of glucose 6-phosphate changes position from the first carbon to the second carbon in the chain.

This reaction involves a water molecule, which donates a hydrogen ion to the carbonyl oxygen.

The hydrogen ion is then retrieved from the hydroxyl group on the second carbon, creating a new water molecule. In the process, fructose 6-phosphate is formed.

The same enzyme, phosphoglucose isomerase, catalyzes the formation of fructose 6-phosphate into its ring form.

In the third step of glycolysis, the enzyme phosphofructokinase uses ATP to phosphorylate fructose 6-phosphate. ADP is released and the molecule fructose 1,6-bisphosphate is formed.

This third step, in which the second phosphorylation event occurs, is irreversible and is a major regulatory point in the commitment to glycolysis. The phosphorylations in steps 1 and 3 represent an investment of energy that will be paid back in the later stages of the pathway.

Step 4 of glycolysis begins with the opening of the ring form of fructose 1,6-bisphosphate into its open chain form.

In this step, the enzyme aldolase cleaves fructose 1,6-bisphosphate into two molecules.

One molecule that is formed is the 3-carbon glyceraldehyde 3-phoshate. The enzyme performs additional reactions on the second 3-carbon molecule. The second molecule is dihydroxyacetone phosphate.

In step 5 of glycolysis, the enzyme triose phosphate isomerase catalyzes the isomerization of dihyroxyacetone phosphate into glyceraldehyde 3-phosphate.

The catalytic mechanism of this enzyme is very similar to that of phosphoglucose isomerase, back in step 2. The result is two molecules of glyceraldehyde 3-phosphate.

All of the subsequent steps of glycolysis will occur twice—once for each molecule of glyceraldehyde 3-phosphate. These are the energy generation steps of gylcolysis.

In step 6, the enzyme glyceraldehyde 3-phosphate dehydrogenase uses $NAD^+$ to oxidize glyceraldehyde 3-phosphate. The resulting molecule is connected to the enzyme by a high-energy thioester bond.

A molecule of inorganic phosphate displaces the high-energy thioester bond, forming a high-energy acyl-anhydride bond. The resulting molecule is 1,3-bisphosphoglycerate.

In the seventh step, the enzyme phosphoglycerate kinase dephosphorylates 1,3-bisphosphoglycerate. The high-energy phosphate is transferred to ADP, forming ATP. The 3-carbon molecule is now 3-phosphoglycerate. Because this reaction occurs twice, once for each 3-carbon molecule, a total of 2 ATPs are generated. At this point the energy investment from the first three steps has been paid back.

In the eighth step, 3-phosphoglycerate, which has a relatively low free energy of hydrolysis, is transformed by the enzyme phosphoglycerate mutase into 2-phosphoglycerate.

In the ninth step, the enzyme enolase removes a water molecule from 2-phosphoglycerate, creating phosphoenolpyruvate. The loss of water redistributes energy within the molecule, creating a phosphate group with an extremely high free-energy of hydrolysis.

In the tenth and last step of glycolysis, the enzyme pyruvate kinase transfers the high-energy phosphate group to ADP, forming ATP and pyruvate.

In the second half of glycolysis, many of the reactions release energy, captured in the form of ATP and NADH. Overall the net energy produced in glycolysis from a single molecule of glucose is two molecules of ATP and two molecules of NADH.

The chemistry of glycolysis is conserved all the way from bacteria to animal cells.

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