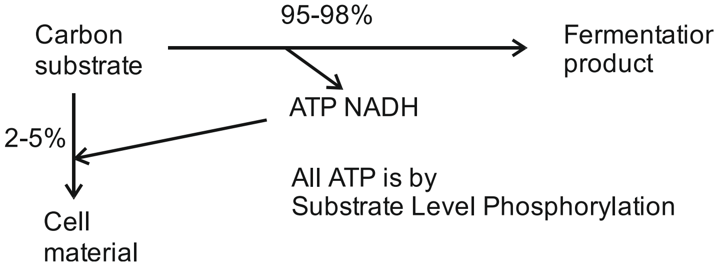
Energy from anaerobic oxidation (Fermentation

There are one or two oxidation steps that produce NADH; and the energy from this oxidation is used to drive substrate level phosphorylation reactions. There is no electron transport chain to re-oxidise the NADH so this must happen by using an oxidised product of the fermentation pathway. This results in accumulation of the reduced fermentation product. The only reason for producing the fermentation product is to regenerate the NAD so that oxidation/ATP synthesis can continue. **Note** that all NADH that is produced must be re-oxidised to NAD during this process

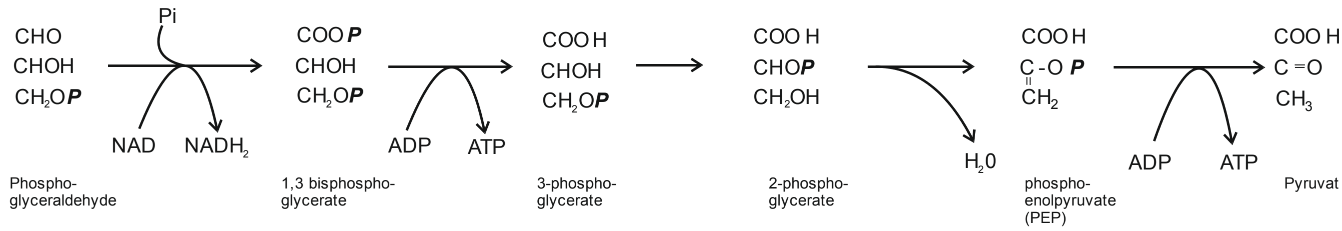


Fermentation balance: This is an equation that shows substrate conversion to fermentation product plus ATP. Growth (increase in cell mass) is proportional to the ATP produced.

Substrate Level Phosphorylation(SLP)

This is when a metabolic substrate becomes phosphorylated to produce an 'energy-rich compound'. In a subsequent reaction the phosphate is used to phosphorylate ADP to ATP. Many fermentation pathways start with conversion of glucose to pyruvate (glycolysis).

SLP: Substrate level phosphorylation reactions in glycolysis

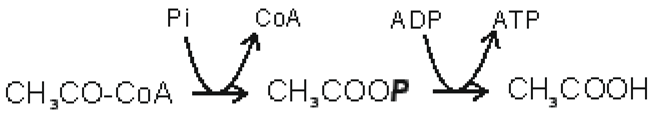


In glycolysis Glucose is metabolised to 2x phosphoglyceraldehyde in a process that uses 2 ATP.
In the 2nd part of glycolysis shown here a single phosphoglyceraldehyde yields 1 pyruvate , 1 $NADH_2$ and 2ATP

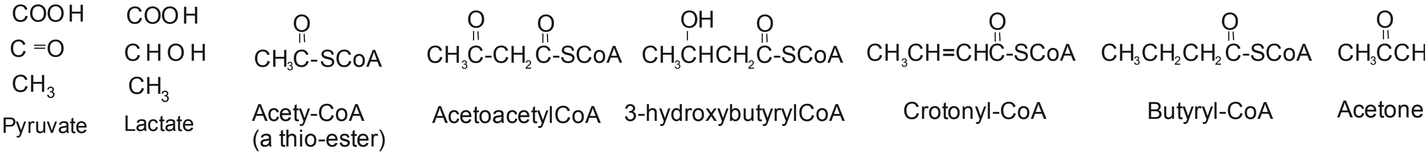
In sum: Glucose $\longrightarrow$ 2 Pyruvate + 2 $NADH_2$ + 2ATP

Substrate level phosphorylation involving acyl phosphates

Acetyl-CoenzymeA and butyryl-CoenzymeA are energy rich compounds. After they are produced in fermentation pathways they can be converted to acetyl phosphate and butyryl phosphates (also energy-rich compounds) which can provide phosphate to convert ADP to ATP.

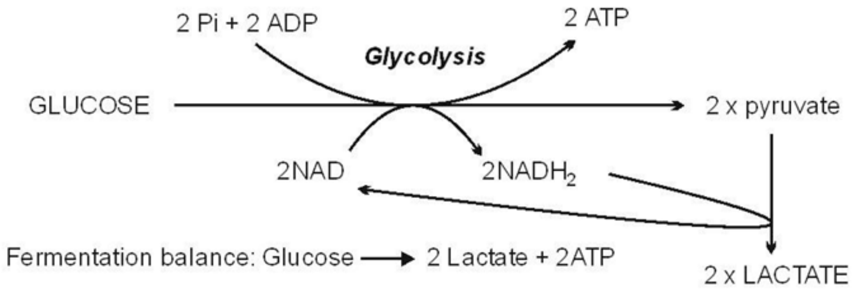


Some formulae you will need to understand fermentation pathways



Fermentation pathways

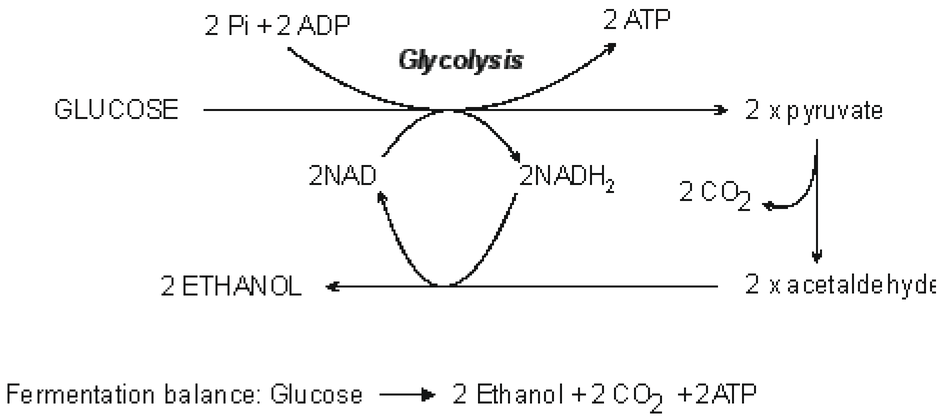
1. Lactic acid fermentation. In *Lactobacillus sp*. Glucose is the fermentation substrate; it is oxidised by glycolysis to pyruvate (described above) and the NADH is regenerated by reducing the pyruvate to lactate:



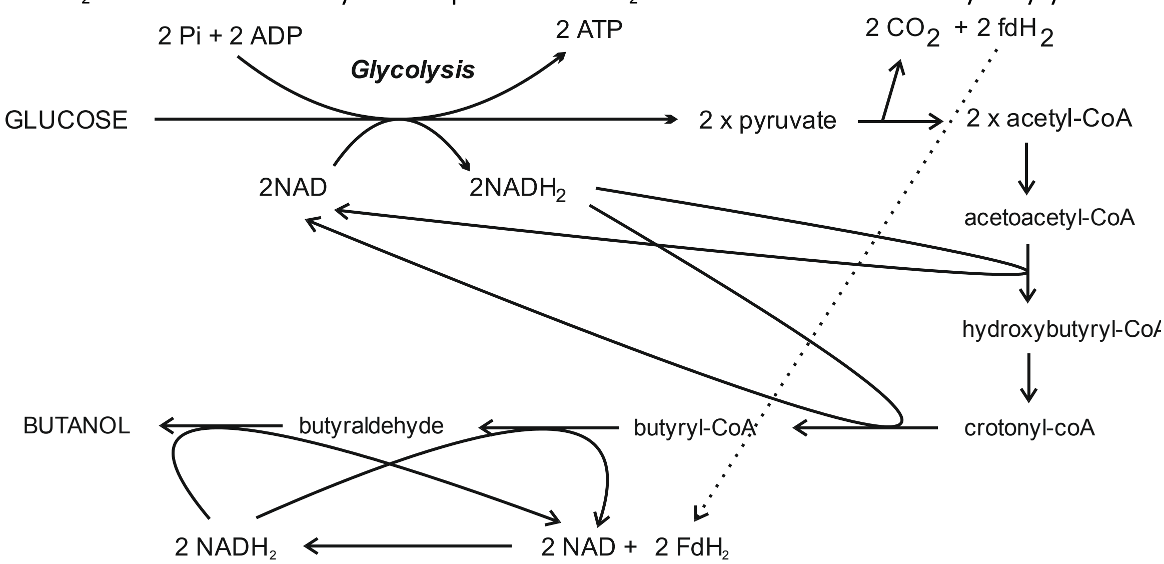
Glucose → 2 pyruvate + $2NADH_2$ + 2ATP Then 2 pyruvate + 2 $NADH_2$ → 2 Lactate

Fermentation balance: Glucose → 2 Lactate + 2 ATP

2. Ethanol fermentation. In yeast (*Saccharomyces*) Glucose is oxidised by glycolysis to pyruvate which is then decarboxylated to CO_2 and acetaldehyde which is reduced to ethanol order to regenerate the NAD that was reduced during glycolysis.



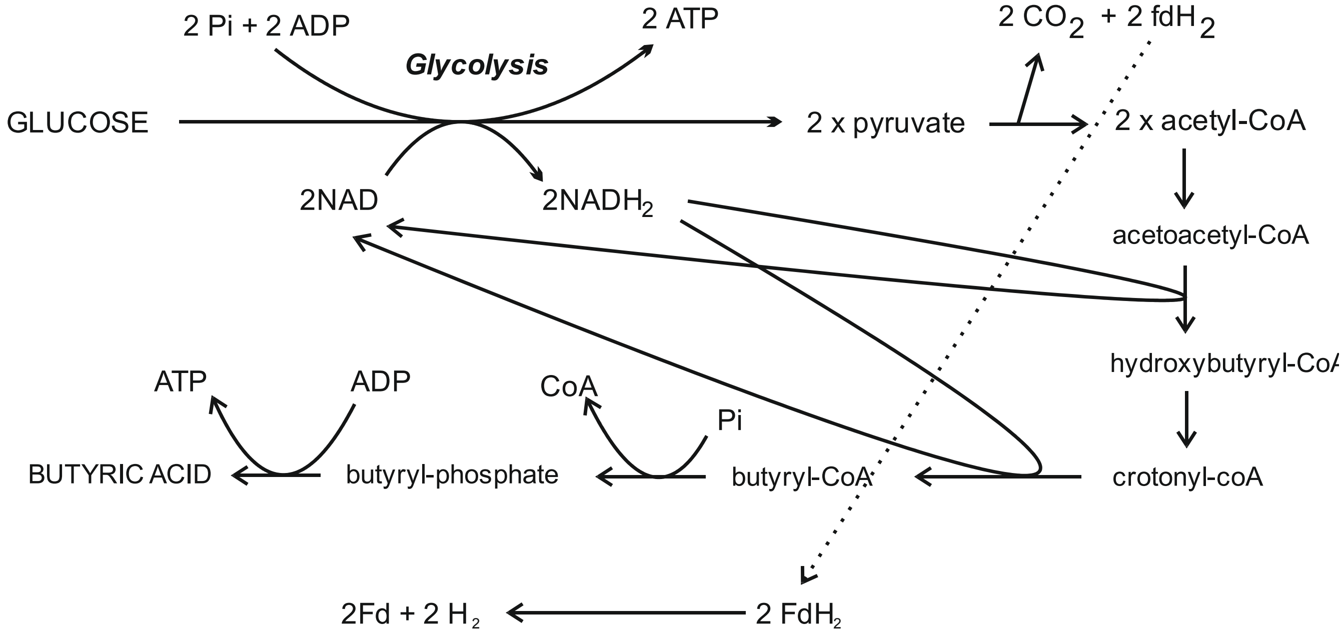
3. Butanol fermentation. *Clostridium sp*. ferments glucose to butanol. In this pathway pyruvate is oxidatively decarboxylated to acetyl-Coenzyme A. This process uses the iron-sulphur protein Ferredoxin as electron acceptor. It accepts electrons only; the 2H atoms are released as protons. For convenience the reduced ferredoxin is abbreviated to FdH_2. This is re-oxidised by NAD to produce $NADH_2$ which is then re-oxidised by butyryl-CoA and butyraldehyde.



Fermentation balance: Glucose → Butanol + 2 CO_2 + 2ATP

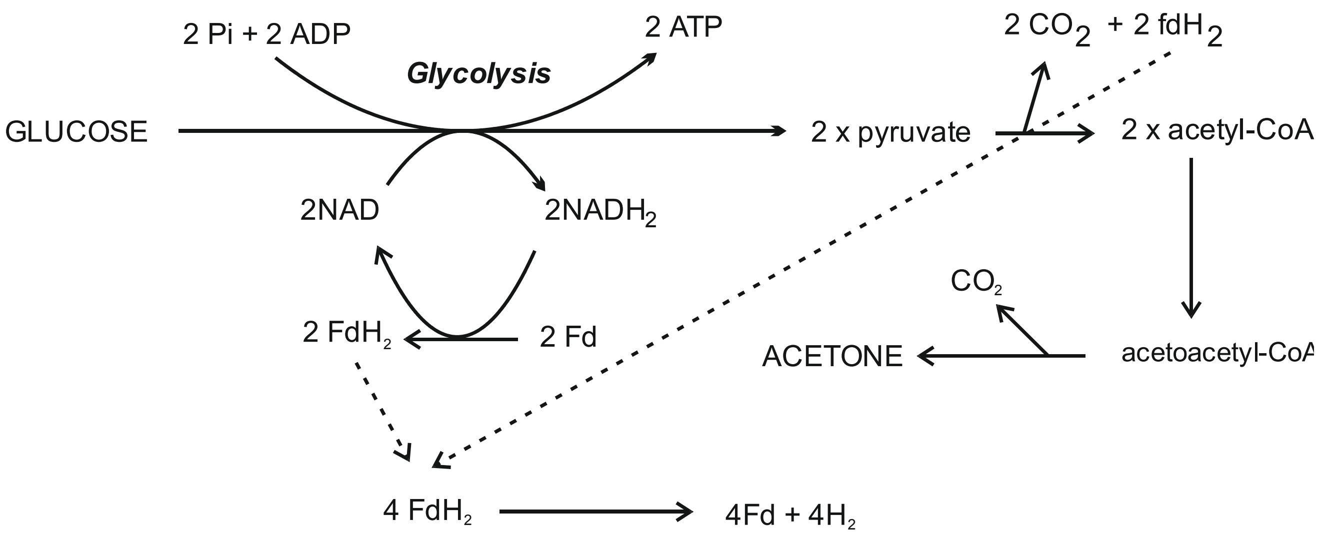
4. Butyric acid fermentation. By the same bacterium, *Clostridium*

The pathway is the same as for butanol fermentation except for the fate of butyryl-CoA which is converted to butyryl-phosphate which is used to make ATP. In this case oxidised ferredoxing must be regenerated from the reduced ferredoxin (FdH_2) by a different mechanism. This involves a special hydrogenase which takes the electrons from the ferredoxin to reduce 2 protons to produce hydrogen gas. 2 Fd(red) + 2 H^+ → 2Fd (ox) + H_2



Fermentation balance: Glucose → Butyric acid + 2 CO_2 + 2 H_2 + 3ATP

5. Acetone fermentation from glucose. By the same *Clostridium sp* and nearly the same pathway as for butanol and butyric acid fermentation. Note: in this case all reduced compounds ($NADH_2$ and reduced ferridoxin) are re-oxidised by production of hydrogen gas.



Fermentation balance: Glucose ⟶ Acetone + 3 Co_2 + 4 H_2 + 2 ATP

Citric acid fermentation *by Aspergillus sp.*

This is not a true fermentation as it is Aerobic and it is only occurs when the metabolism has been modified. It is wrongly called this because it is used industrially on a large scale and this expression is often wrongly used for any process that produces and end product.