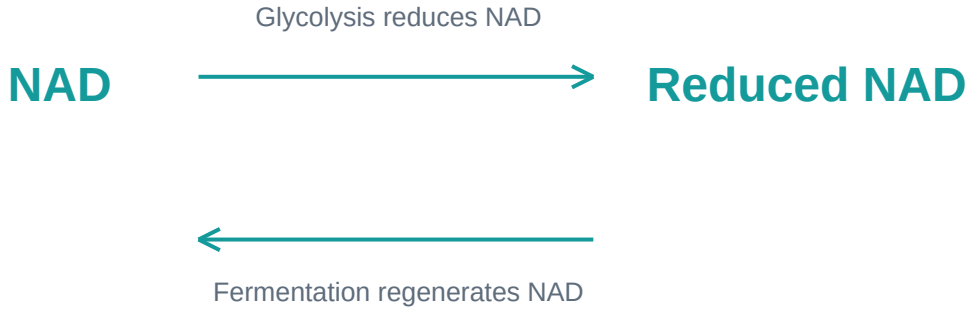
Keep glycolysis running

Anaerobic respiration and respiratory substrates: how cells recycle NAD without oxygen, and how different fuels change energy yield and gas exchange.

1. THE BOTTLENECK IS NAD

Without oxygen as the final electron acceptor, mitochondrial electron transport cannot continue. Reduced NAD cannot be reoxidised by this route. Glycolysis needs a supply of oxidised NAD to accept hydrogen, so it too would stop without an alternative.

2. RECYCLE THE HYDROGEN CARRIER



Hydrogen is passed to an organic acceptor: pyruvate in mammals, or ethanal in yeast. The carrier is recycled rather than used up.

3. A SMALL BUT USEFUL ATP SUPPLY

The net yield is 2 ATP per glucose, made by substrate-linked phosphorylation in glycolysis. Conversion of pyruvate into lactate or ethanol does not add more ATP. Its essential role is NAD regeneration.

Why aerobic yield is greater: complete oxidation transfers much more energy to ATP, especially through oxidative phosphorylation. Lactate and ethanol still contain substantial chemical energy.

Terminology: these mammal and yeast pathways are fermentation; some microbes have a different anaerobic pathway using an electron transport chain.

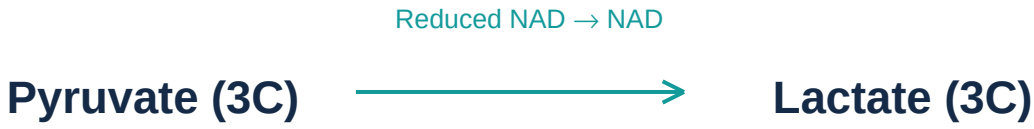
NAD recycling and fermentation: OpenStax, Biology 2e 7.5.
ATP yield and incomplete oxidation: Cooper, The Cell, Metabolic Energy.

Scope: Cambridge 9700, 12.1 outcomes 4-6; 12.2 outcomes 10-11, pp. 32-34.

Two routes from pyruvate

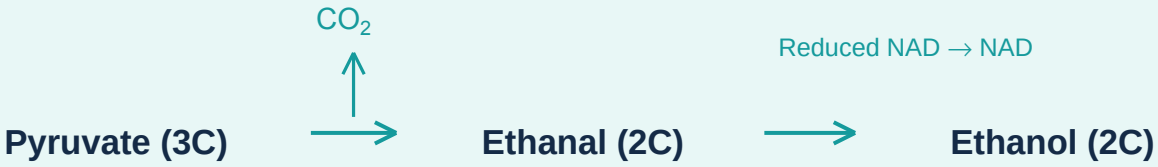
Both pathways operate in the cytoplasm. Follow the carbon atoms and identify which reaction regenerates NAD.

1. MAMMALS: LACTATE FERMENTATION



Pyruvate accepts hydrogen and is reduced to lactate. All three carbon atoms remain, so no CO_2 is released in this conversion. This supports glycolysis when oxygen supply cannot meet muscle demand.

2. YEAST: ETHANOL FERMENTATION



a) Decarboxylation removes one carbon as CO_2, forming ethanal.
b) Ethanal accepts hydrogen from reduced NAD, forming ethanol and regenerating NAD. Ethanal is also called acetaldehyde.

Per glucose: two pyruvates give two ethanol molecules and two CO_2 molecules. The 2 net ATP were already made in glycolysis.

3. THE COMPARISON THAT MATTERS

Mammals: lactate, no carbon dioxide from fermentation. Yeast: ethanol plus carbon dioxide. Both regenerate NAD and permit a low ATP yield without oxygen; neither uses oxygen as the acceptor in the fermentation step.

Mammal and yeast pathways: OpenStax, Biology 2e 7.5.
Pyruvate reduction and energy transfer: Cooper, The Cell, Metabolic Energy.

Scope: Cambridge 9700, 12.1 outcomes 4-6; 12.2 outcomes 10-11, pp. 32-34.

Compare fuels using RQ

Respiratory substrates supply carbon and hydrogen for energy-releasing reactions. Carbohydrates, lipids and proteins enter the pathways at different points.

1. SUBSTRATES IN AEROBIC RESPIRATION

Fuel	Entry and energy	Typical RQ
Carbohydrate	Glucose enters glycolysis. Readily available fuel; lower energy per gram than lipid.	1.0
Lipid	Glycerol can enter glycolysis; fatty acids form acetyl CoA. More reduced: more hydrogen and energy per gram.	About 0.7
Protein	Amino acids are deaminated; carbon skeletons enter respiration. Energy values vary; usually below lipid.	About 0.8

2. CALCULATE THE RESPIRATORY QUOTIENT

$$RQ = CO_2 \text{ produced} / O_2 \text{ consumed}$$

Use numbers of molecules, moles, or gas volumes measured at the same temperature and pressure. The ratio has no units.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ RQ = 6/6 = 1

3. INTERPRET A MEASUREMENT

If 14 cm^3 of CO_2 is produced while 20 cm^3 of O_2 is consumed, RQ = 14/20 = 0.70, consistent with predominantly lipid oxidation. Mixed fuels give intermediate values; RQ is evidence, not proof of one pure substrate.

Do not divide by zero: in purely anaerobic conditions, O_2 uptake is zero, so a finite RQ cannot be calculated.

Fuel entry routes: OpenStax, Biology 2e 7.6.
Substrate RQ values: Neuhouser et al., RQ calibration study (2013).

Scope: Cambridge 9700, 12.1 outcomes 4-6; 12.2 outcomes 10-11, pp. 32-34.