Chapter 8

Topics in lectures 15 and 16

- **Metabolism**
  - Chemical foundations
  - Catabolism
  - Biosynthesis

Metabolism

- Chemical Foundations
  - Enzymes
  - REDOX
- Catabolism
  - Pathways
- Anabolism
  - Principles and pathways

Enzymes

- Catalysts for chemical reactions

Reactants <-----------> Products

- Lower the energy needed for the reaction to occur (activation)
  - Endergonic or exergonic

    ===> Insight 8.1

Redox reactions

- **Red**uction and **ox**idation reaction
- Electron carriers transfer electrons and hydrogens
  - Electron donor
  - Electron acceptor
- Energy is also transferred and captured by the phosphate in form of ATP

REDOX

RED

OXIDANT + electron <==> REDUCTANT

OX

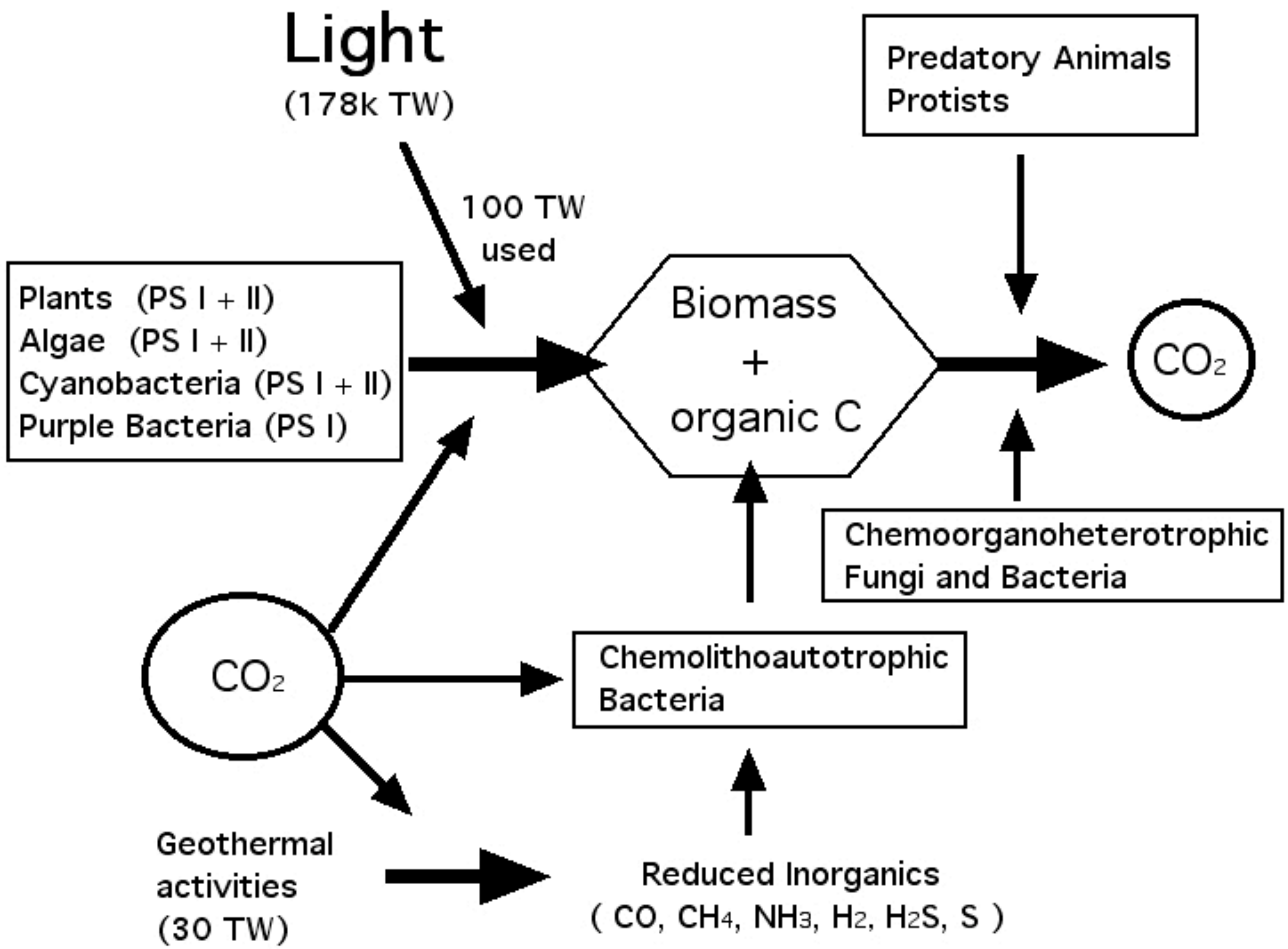
ELECTRON ACCEPTOR

ELECTRON DONOR

OIL --- RIG

Energy

- **Cell energetics**
  - **Exergonic**
  - **Endergonic**
- **Redox reaction**
- **Electron carrier**
- **Adenosine Triphosphate (ATP)**



Integrated model of energy and carbon flow

Metabolism

- Chemical Foundations
  - Enzymes
  - REDOX
- **Catabolism**
  - Pathways
- **Anabolism**
  - Principles and pathways

Catabolism

- Enzymes are involved in the **harvest of energy** from the environment and their transformation into cell-own, useable energy. Some of this energy needs to be spent in the process on the accession of energy and nutrients (e.g., chemotaxis, transport).

Anabolism

- Enzymes are involved in the **use of energy** from catabolism in order to synthesize simple and complex compounds, macromolecules and cell structures from simpler compounds).

The relationship between catabolism and anabolism.

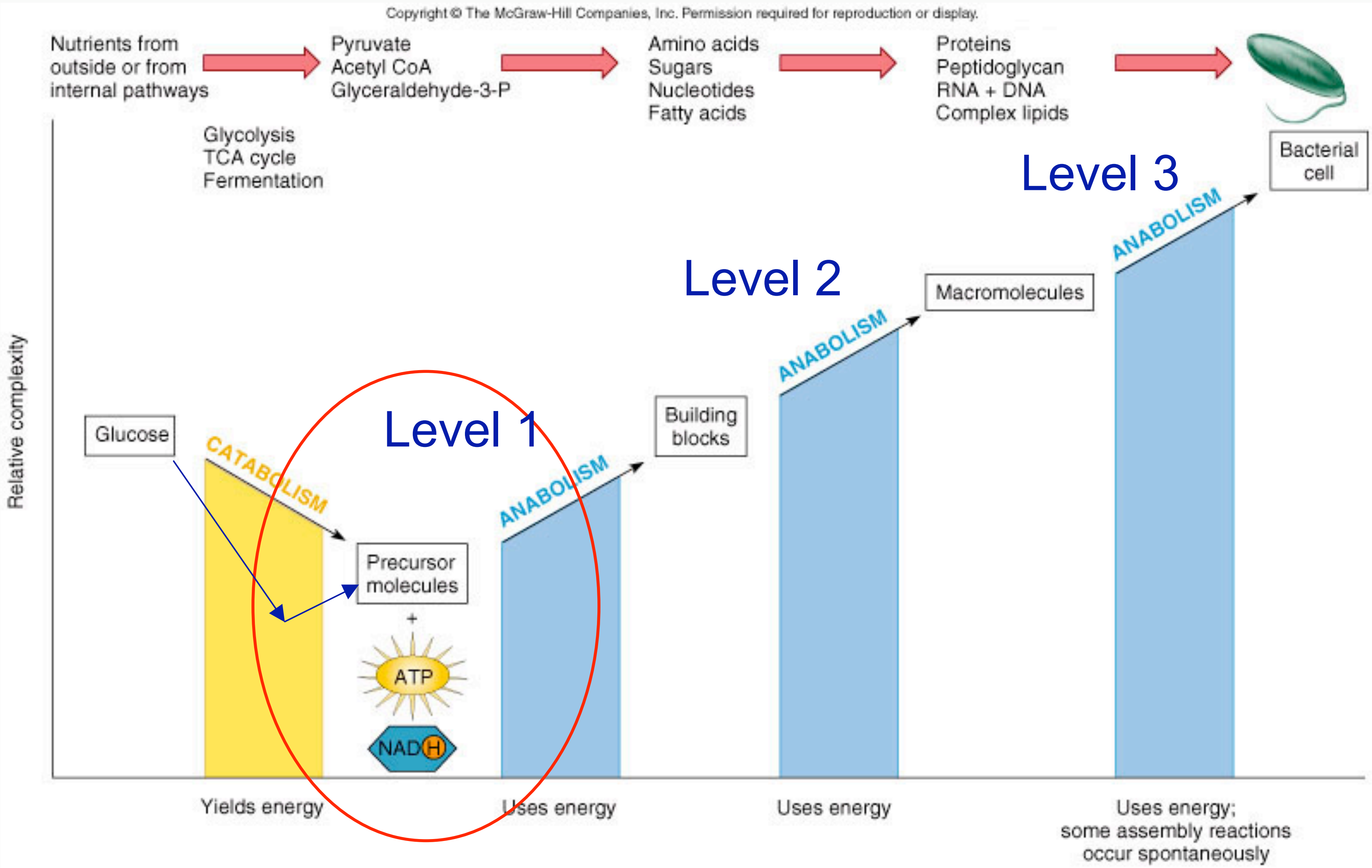


Fig. 8.1 Simplified model of metabolism

Pathways leading to the 12 precursors

- Central Pathways
  - Mostly catabolism
    - Embden-Meyerhof-Parnas (EMP) pathway [glycolysis]
      - 5 precursors: G6P, 3PG, DHAP,PEP,pyruvate
    - Tricarboxylic acid cycle (TCA)
      - 3 precursors: OAA, alpha-KG, succinyl~CoA
  - Mostly anabolism
    - Pentose phosphate pathway
      - 2 precursors: R5P, E4P
  - Acetyl~CoA,
- Alternate pathways
  - G1P

The general scheme associated with metabolism of organic molecules, the redox reaction, and the capture of energy in the form of ATP.

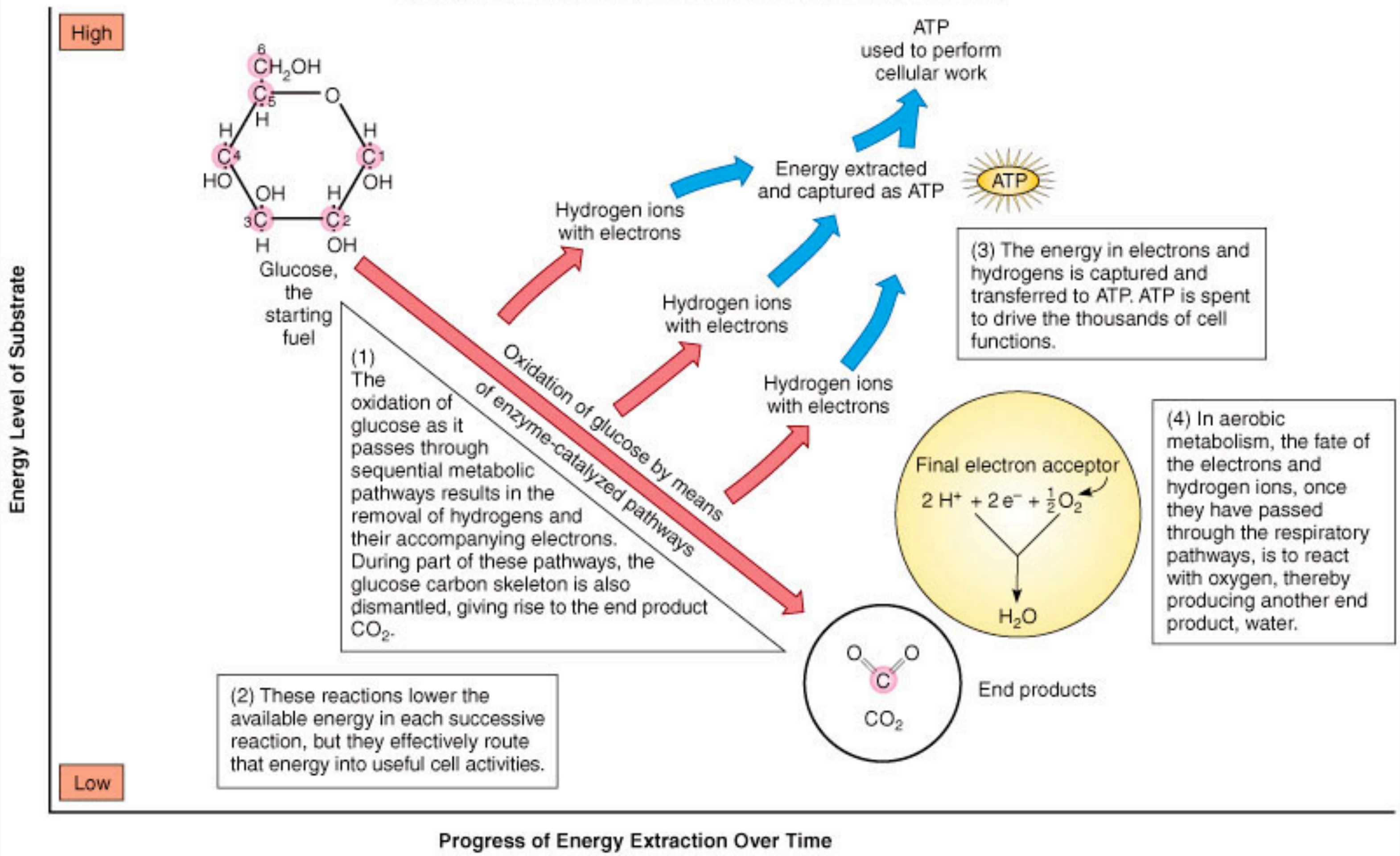


Fig. 8.12 A simplified model that summarizes the cell's energy machine.

A summary of the metabolism of glucose and the synthesis of energy.

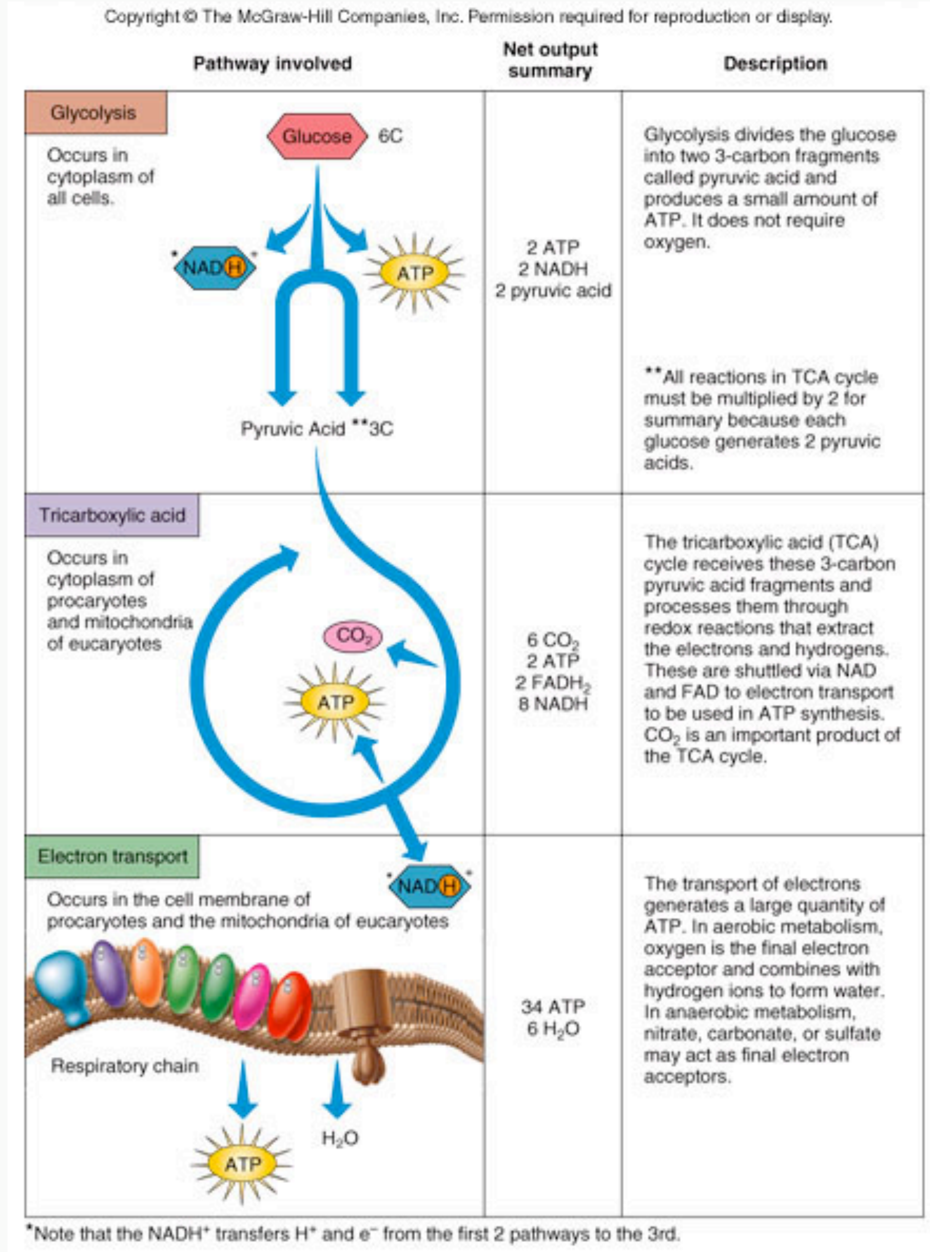


Fig. 8.17 Overview of the flow, location, and products of Pathways in aerobic respiration.

The glycolytic steps associated with the metabolism of glucose to pyruvic acid (pyruvate).

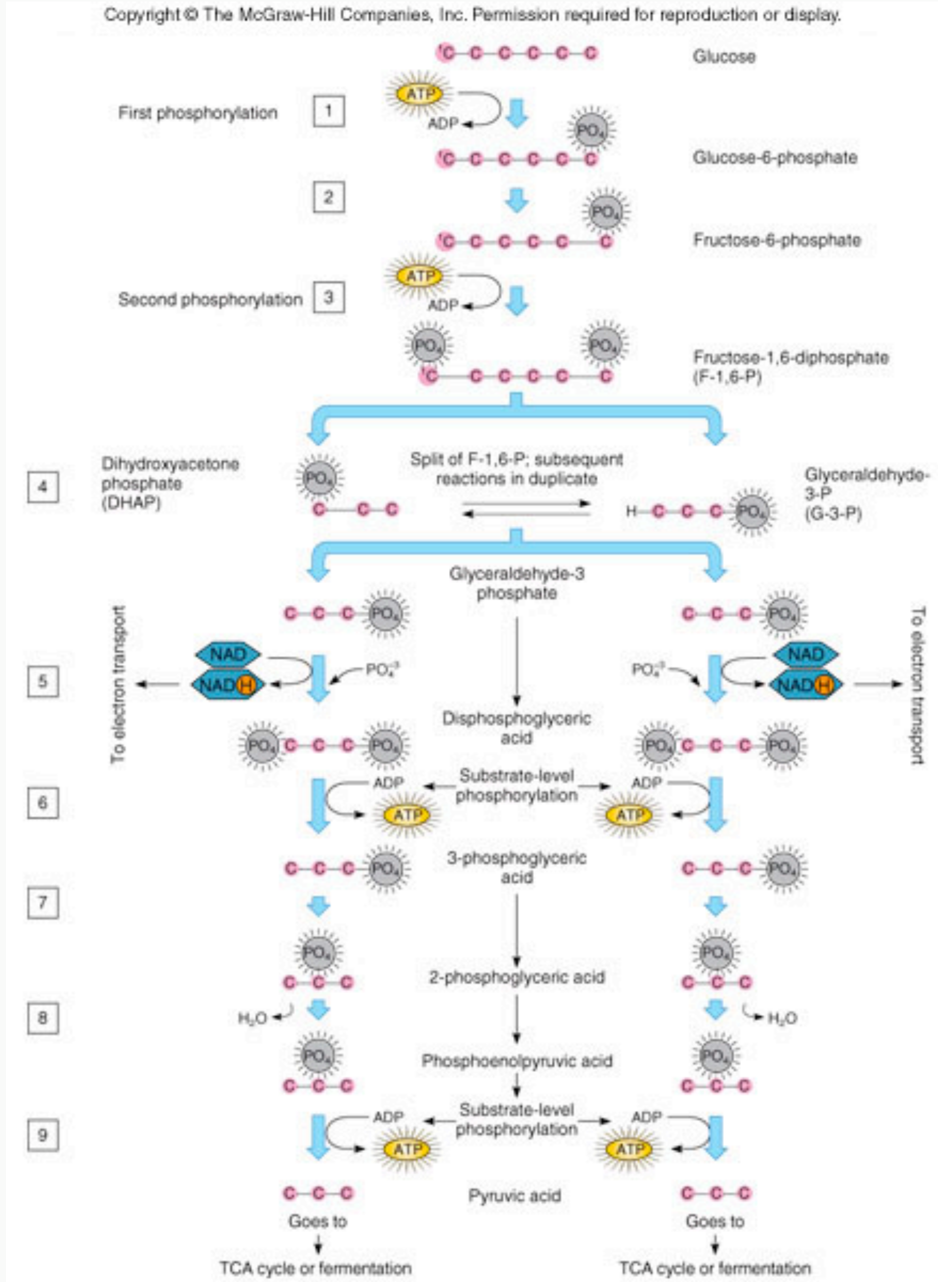


Fig. 8.18
Summary of
glycolysis

Glycolysis

- Oxidation of glucose to pyruvate
- Splits a 6 carbon sugar into two 3 carbon molecules
- Substrate-level-phosphorylation of some intermediates (Investment of 2 ATPs)
- 2 coenzymes NAD are reduced to 2 NADH
- 2 x substrate-level-phosphorylations (2 x 2 ATPs are synthesized)

Glycolysis continued

- Net yield: 2 ATP & 2 NADH molecules
- Final intermediates are two Pyruvic acid molecules
- Water is generated

The steps associated with TCA cycle.

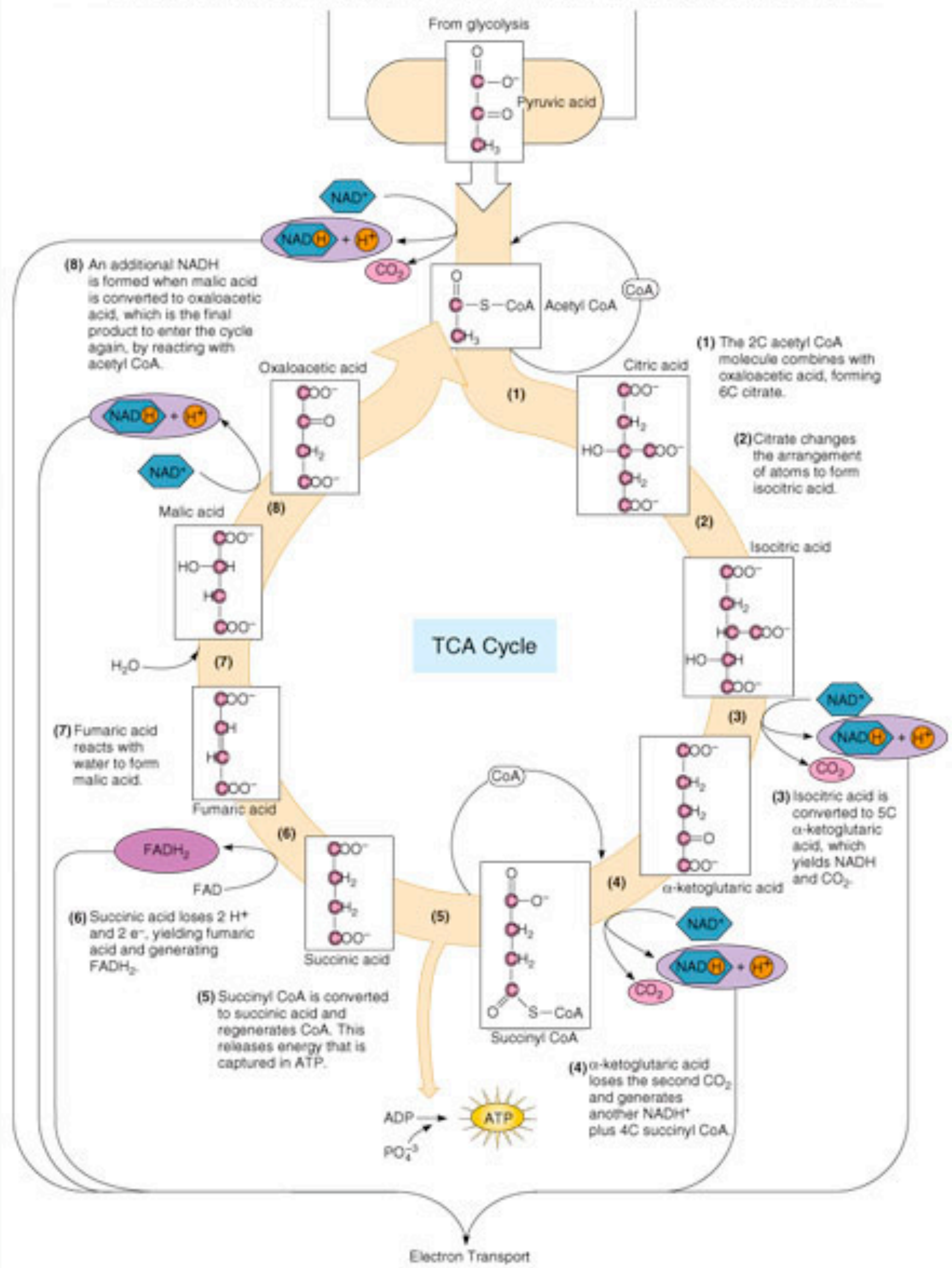


Fig. 8.20 The reaction of a single turn of the TCA cycle

TCA cycle

- Each pyruvic acid can be processed to enter the TCA cycle
- CO_2 is generated
- Coenzymes NAD and FAD are reduced to 8 NADH and 2 $FADH_2$
- Net yield of two ATPs
- Critical intermediates are synthesized

Aerobic respiration

- NADH from Glycolysis
- NADH and $FADH_2$ from TCA

donate electrons into electron transport chain

- Electron transport

- Electron is donated to Oxygen as inorganic, external terminal electron acceptor.

Anaerobic respiration

- NADH from Glycolysis
- NADH and $FADH_2$ from TCA

donate electrons into electron transport chain

- Electron transport

- Electron is donated to nitrate, nitrite, sulfate, sulfite & other oxidized inorganic, external terminal electron acceptors, but not to O_2.

Electron transport

- Membrane bound carriers transfer electrons (redox reactions)
- Proton motive force (PMF)
- Chemiosmosis

Chemiosmosis entails the electron transport and formation of a proton gradient (proton motive force).

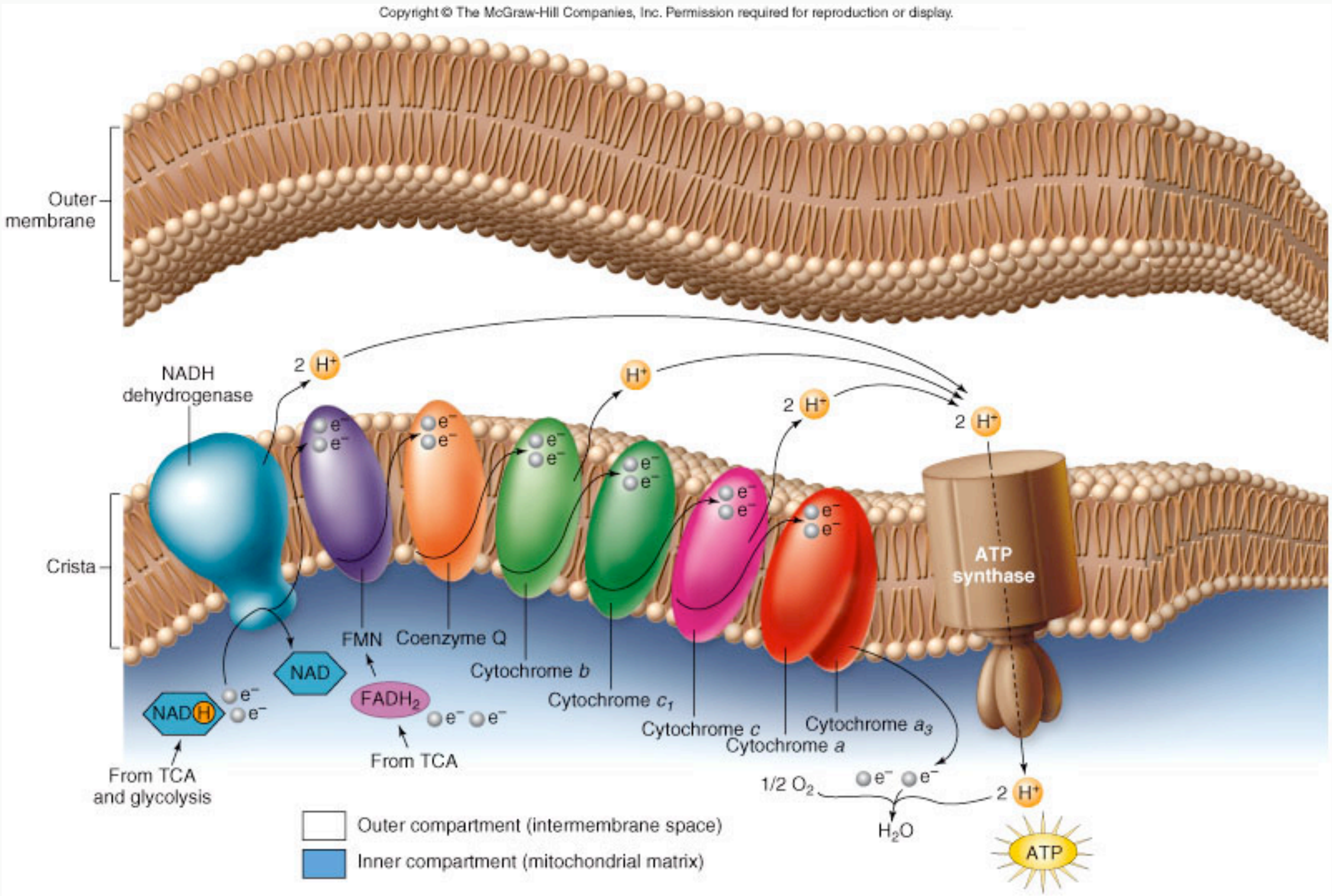


Fig. 8.22 The electron transport system and oxidative phosphorylation

Electron transport chain

- Cytoplasmic membrane
  - Prokaryotes
- Mitochondria
  - eukaryotes

Total maximum yield of ATP for one glucose molecule from aerobic respiration.

TABLE 8.4 Summary of Aerobic Respiration for One Glucose Molecule

	Glycolysis*	Net Output	TCA Cycle*	Net Output	Respiratory Chain	Net Output	Total Net Output per Glucose
ATP produced	2 × 2 =	2	1 × 2 =	2	17 × 2 =	34	40 − 2 (used) = 38**
ATP used	2		0		0		
NADH produced	1 × 2 =	2	4 × 2 =	8	0		10
FADH produced	0		1 × 2 =	2	0		2
CO_2 produced	0		3 × 2 =	6	0		6
O_2 used	0		0		3 × 2 =	6	
H_2O produced	2		0		3 × 2 =	6	8 − 2 (used) = 6
H_2O used	0		2		0		

*Products are multiplied by 2 because the first figure represents the amount for only one trip through the pathway, and two molecules make this trip for each glucose.
**This amount can vary among microbes.

Table 8.4 Summary of aerobic respiration for one glucose molecule

Fermentation

- NADH from only glycolysis is used to reduce the organic products
- NADH produced by TCA (if present) is not used
- Internal organic compounds serve as the final electron acceptors
- ATP yields are small (per glucose molecule), compared to respiration
- Must metabolize large amounts of glucose to produce equivalent of ATP from respiration

The fermentation of ethyl alcohol and lactic acid.

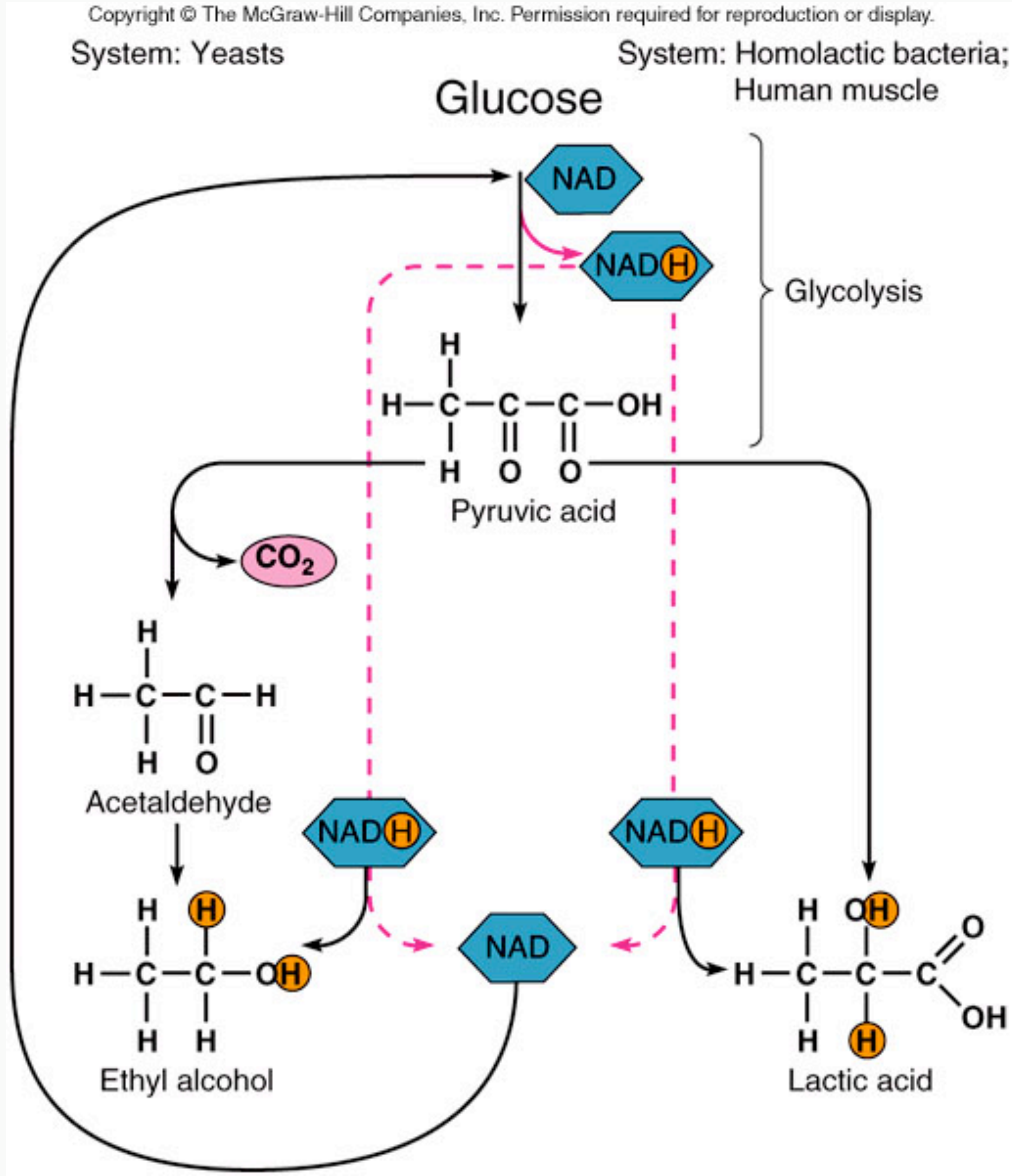


Fig. 8.24 The chemistry of fermentation systems

Types of fermenters

- Facultative anaerobes
  - Fermentation in the absence of oxygen
  - Respiration in the presence of oxygen
    - Ex. *Escherichia coli,* yeast

- Strict anaerobic fermenters
  - No respiration
    - Ex. *Clostridium botulinum, Streptococcus mutans*

Products of fermentation

- Alcoholic fermentation
- Acidic fermentation
- Mixed acid fermentation

An example of mixed acid fermentation and the diverse products synthesized.

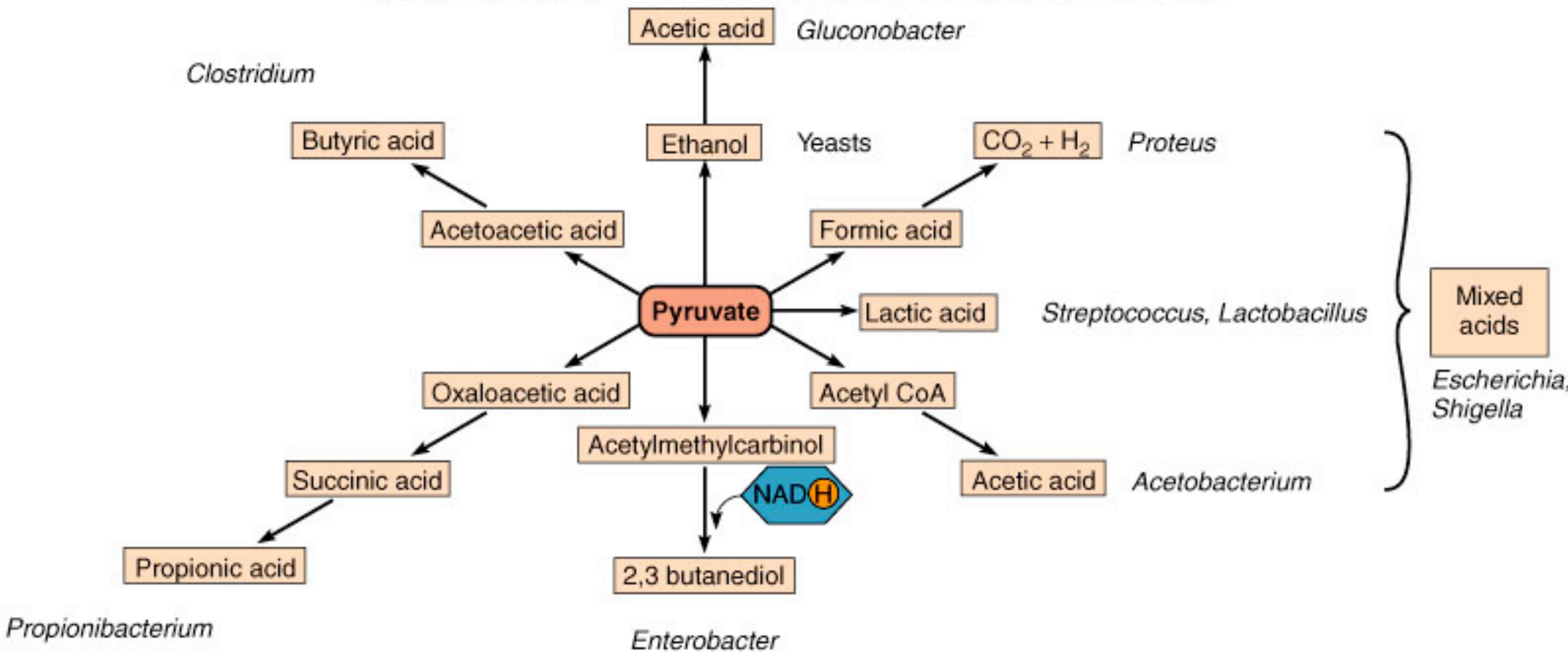


Fig. 8.25 Miscellaneous products of pyruvate

Biosynthesis - anabolism

Enzymes are involved in the **use of energy** from catabolism in order to synthesize simple and complex compounds, macromolecules and cell structures from simpler compounds).

The three levels of Anabolism

- **Synthesis of Building Blocks, namely complex compounds including the four monomers**
- **Synthesis of the four Macromolecules**
- **Assembly of Cellular Structures**

Monomer Intermediates

- Cellular building blocks include the four monomers needed for the synthesis of macromolecules:
  - Amino acids
  - Nucleotides
  - Monosaccharides
  - Glycerol and Fatty acids

Macromolecules

- The second level of anabolism is the synthesis of macromolecules:
  - **Proteins** (from amino acids)
  - **Nucleic** acids (from nucleotides) **Polysaccharides** (from monosaccharides)
  - **Lipids** (from glycerol and fatty acids)

Cellular Structures

- The third level of anabolism is the assembly of cellular structures from macromolecules:
  - Membranes (from lipids, proteins & polysaccharides)
  - Cell walls (from polysaccharides, proteins & lipids)
  - Ribosome (from nucleic acids & proteins)
  - Flagellum (from proteins)
  - Endospores (from lipids, proteins, nucleic acids & Polysaccharides
  - Inclusion bodies
  - Etc.

Examples for Biosynthesis

– Macromolecule synthesis
  • transcription and translation

– Gluconeogenesis

– Amination
– Transamination

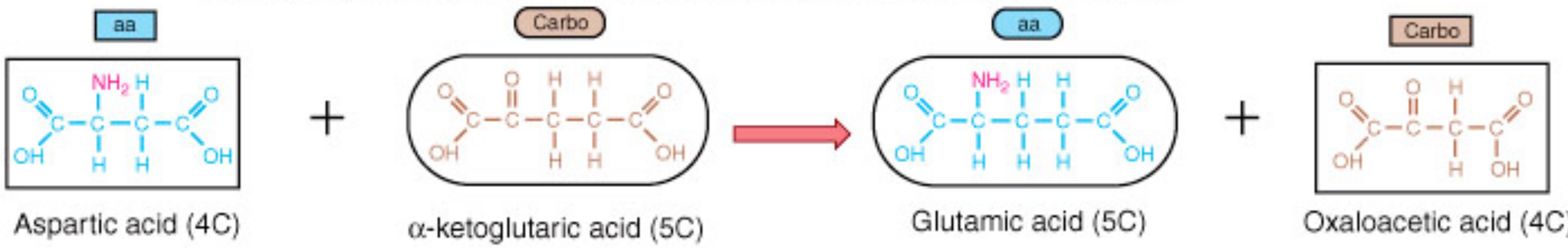
Gluconeogenesis

- When the glucose supply is low, Pyruvate (intermediate) can be converted to glucose.

- Autotrophic organisms, which fix carbon solely form CO_2, funnel the resulting intermediate into reverse glycolysis.

Examples of amination, transamination, and deamination.

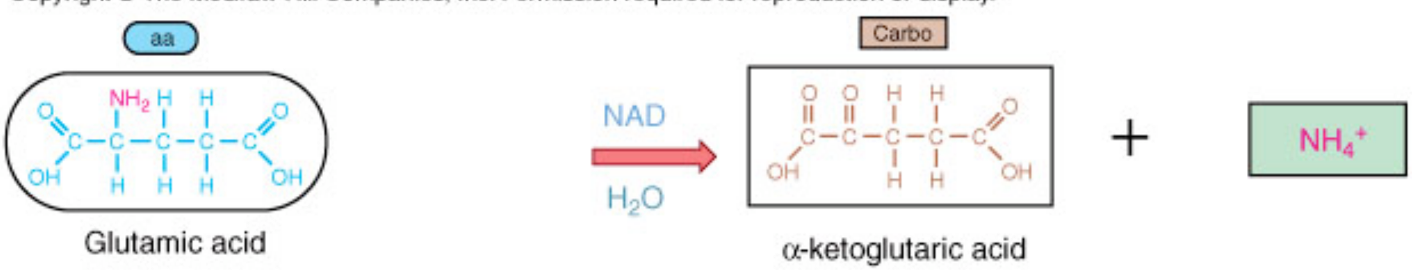
(a) **Amination**



(b) **Transamination**

anabolic

catabolic



(c) **Deamination**

Fig. 8.27 Reactions that produce and convert amino acids

Amphibolic

- Integration of the catabolic and anabolic pathways
- Intermediates serve multiple purposes

Intermediates can serve to synthesize amino acids, carbohydrates and lipids.

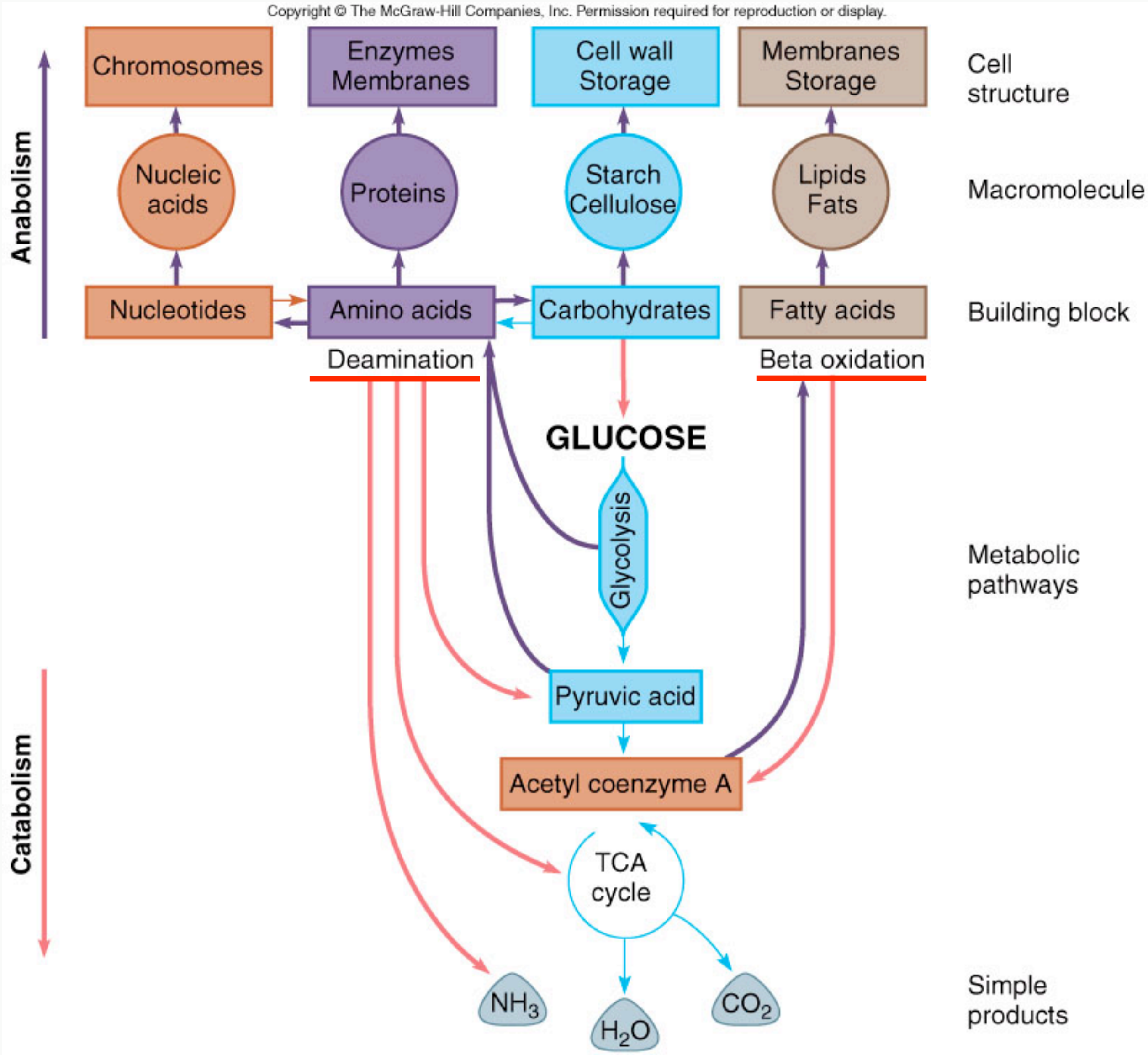


Fig. 8.26 An amphibolic view of metabolism

Beta oxidation

- Alternate catabolism of fatty acids into acetyl, which can then enter the TCA cycle as acetyl CoA.