MMG 301, Lecture 22 Bioenergetics

Comparisons of Energy Mechanisms

Oxygenic Photosynthesis
- ATP and NADPH are made in large amounts
- Requires a *very* complex machinery
- Produces oxygen (toxic)

Anoxygenic Photosynthesis
- ATP made in large amounts
- NADP reduction requires an external reductant
- Fairly complex machinery, no oxygen made

Aerobic Respiration (organotroph or lithotroph)
- ATP and NADH are made in abundance
- Requires electron transport chain and oxidase
- Requires oxygen (toxic)

Anaerobic Respiration
- ATP easily made and NAD easily reduced
- Requires ETC and terminal reductase
- Requires external electron acceptor

Fermentation
- Little ATP, no net NAD reduction, no membranes, MOST SIMPLE SYSTEM

Multiple options in a single microbe

-- Some microorganisms grow via a single bioenergetic mechanism (e.g., only ferment or only carry out oxygenic photosynthesis)

-- Other microbes are more versatile (e.g, a few microbes can grow by fermentation, aerobic respiration, anaerobic respiration, and anoxygenic photosynthesis)

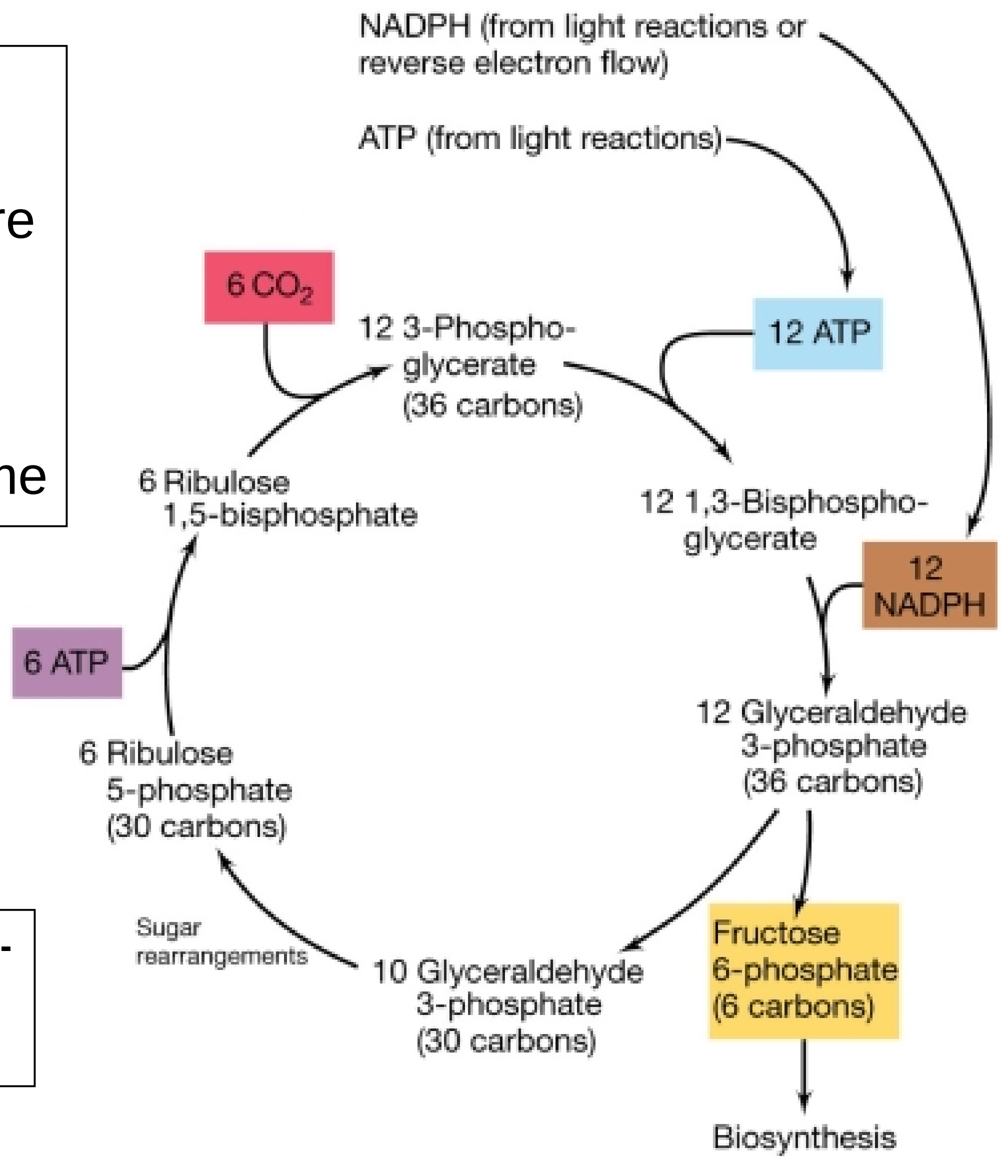
-- When capable of growing by multiple approaches, the different systems are generally tightly regulated (e.g., only make photopigments when growing phototrophically)

-- In these cases, the mechanism used is typically the one yielding the maximal amount of energy under those growth conditions (e.g., aerobic respiration > anaerobic respiration > fermentation)

How is the energy used? Consider autotrophy

1. Aerobic phototrophs (plants, algae, cyanobacteria) and chemolithotrophs (nitrifiers, sulfur oxidizers) “fix” CO_2 using the **Calvin Cycle:**
(key enzyme = ribulosebisphosphate carboxylase)

Sometimes these enzymes are found in an inclusion called a carboxysome

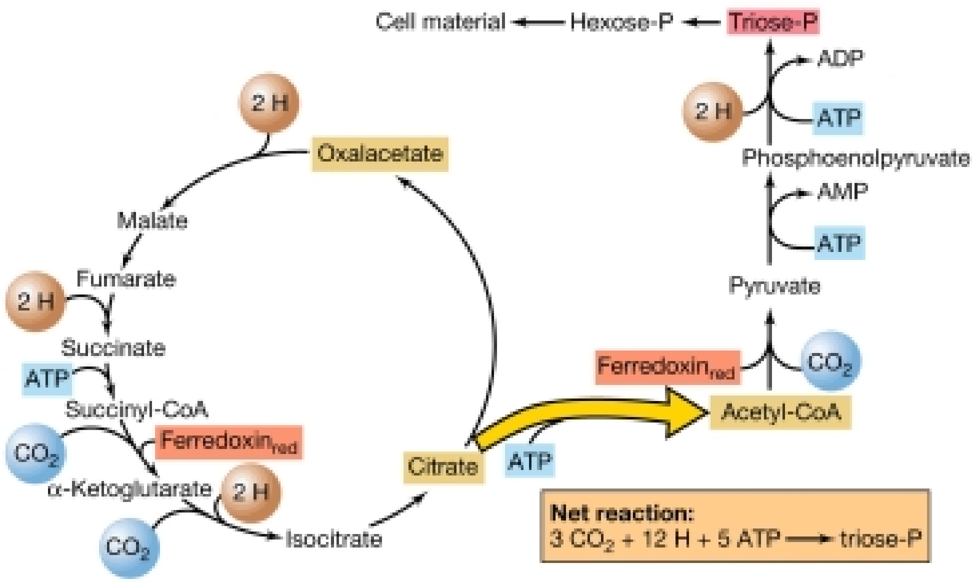


3 ATP + 4 e^- per CO_2

Overall stoichiometry:
$6\ CO_2 + 12\ NADPH + 18\ ATP \longrightarrow$
$C_6H_{12}O_6(PO_3H_2) + 12\ NADP^+ + 18\ ADP + 17\ P_i$

2. Two other less energy-expensive method for "fixing" CO_2 are found in Green Sulfur, Green Non-sulfur, and many other microbes:

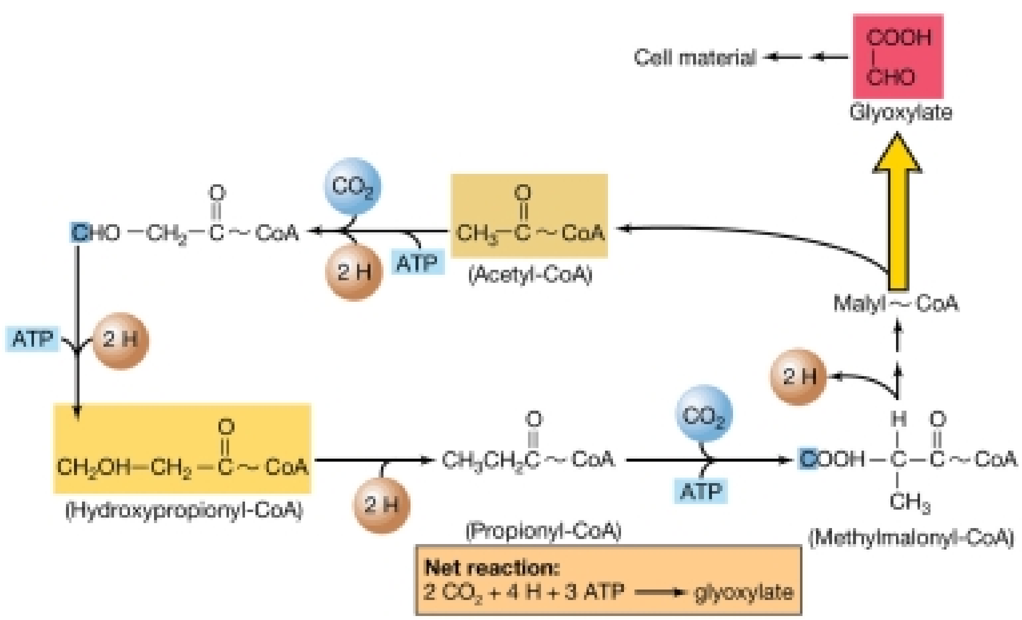
Reverse Citric Acid Cycle



<2 ATP + 8 e^- per CO_2

[Need external reductant]

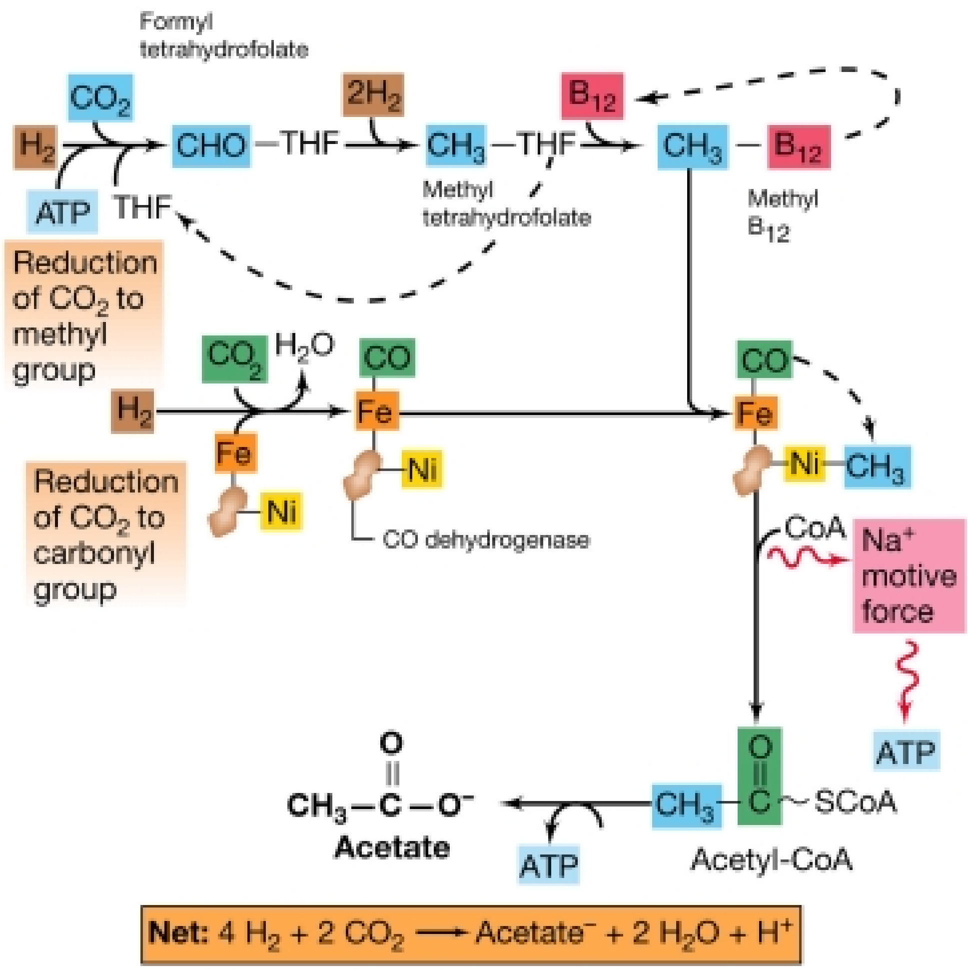
Hydroxypropionate Cycle



1.5 ATP + 4 e^- per CO_2

3. Some strict anaerobes fix CO_2 using the **Acetyl-CoA synthase** pathway:

$4\ H_2 + 2\ CO_2 \rightarrow CH_3COOH \rightarrow$ other building blocks



One ATP is used then recovered, so <u>no net ATP</u>
Requires lots of an external reductant: hydrogen gas

Bottom line: Some forms of autotrophy require huge inputs of ATP and NAD(P)H

Other Energy needs in a cell

In addition to autotrophy, energy is needed for synthesis of all other cellular components. Consider:

Composition*	Percent dry weight
Protein	55
RNA (rRNA, tRNA, mRNA)	20.5
DNA	3.1
Lipid	9.1
LPS	3.4
Murein	2.5
glycogen	2.5
other organic	2.9
inorganic	1

Costs of biosynthesis from monomers

Cmpd	ATP/g cell	NAD(P)H/g
protein	7,287	11,523
RNA	6,540	427
DNA	1,090	200
lipid	2,578	5,270
LPS	470	564
murein	248	193
glycogen	154	0

[* for *E. coli* growing in **glucose** minimal medium; from Neidhardt et al., *Physiology of the Bacterial Cell*]

Costs of synthesis of the monomer building blocks

	Cmpd	ATP	NAD(P)H
Amino Acids	Ala, Asp, Glu, Gln, Gly, Ser	0	1
	Arg	7	4
	Asn	3	1
	Cys	4	5
	His	6	1
	Ile	2	5
	Leu, Val	0	2
	Lys	2	4
	Met	7	8
	Phe, Tyr	1	2
	Pro	1	3
	Thr	2	3
	Trp	5	3
nucleotides	ATP (dATP)	11	1 (2)
	GTP (dGTP)	13	0 (1)
	CTP (dCTP)	9	1 (2)
	UTP (dTTP)	7 (10.5)	1 (3)
	16 C-fatty acid	7	14