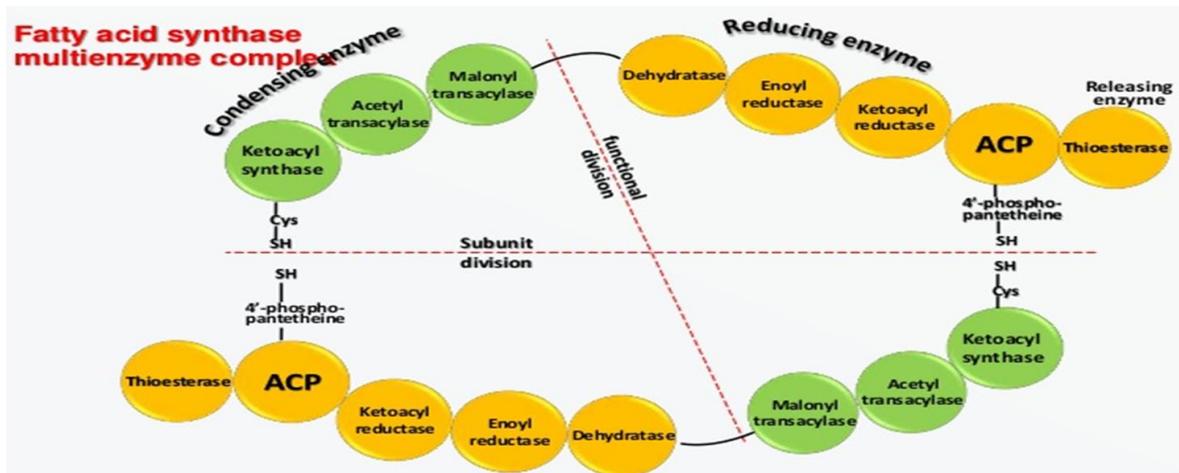


Fatty acids metabolism



Dr/ Heba M. Abd el kareem
Assistant prof. Medical Biochemistry,
Mutah University

Biosynthesis of F.A.s

- F.A.s biosynthesis starts with **acetyl CoA**.
- The enzyme systems are involved in this process.
- 1- Extra-mitochondrial (cytosolic) system. 2- Microsomal system.

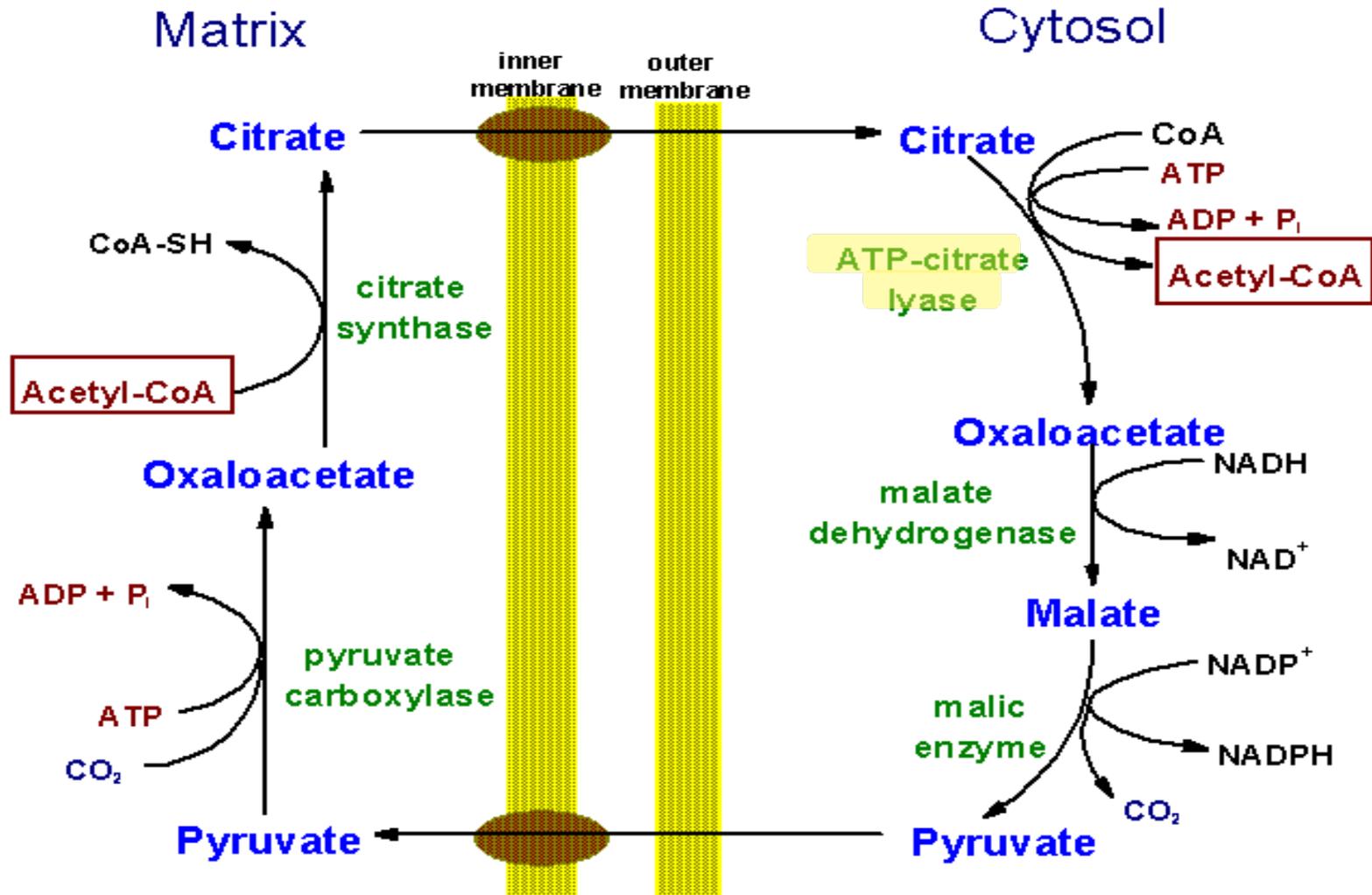
Requirements; acetyl CoA, NADPH+H⁺ and group of enzymes called collectively fatty acid synthase complex.

Acetyl CoA formed from pyruvate within the mitochondria doesn't diffuse readily to the cytosol, the principal site of F.A. synthesis.

- Translocation to cytosol involves condensation with oxaloacetate to form citrate. (CITRATE SHUTTLE)

- When citrate is formed in excess of TCA cycle requirement, it diffuses into cytosol.
- By the aid of ATP citrate lyase, citrate is splitted down into acetyl CoA and oxaloacetate.
- **Acetyl CoA** may also pass through mitochondrial membrane into cytosol in the form of acetyl carnitine by carnitine acetyl transferase

Translocation of acetyl CoA to cytosol



Note: Acetyl CoA used for fatty acid synthesis always derived from glucose and never from fatty acids. This is because insulin hormone secreted after meal stimulates both glucose oxidation (+acetyl CoA) and lipogenesis (=Fatty acid synthesis) and Inhibits lipolysis (+Fatty acid oxidation+Acetyl CoA).

NADPH+H⁺: It is provided by 3 sources:

a) Pentose phosphate pathway.

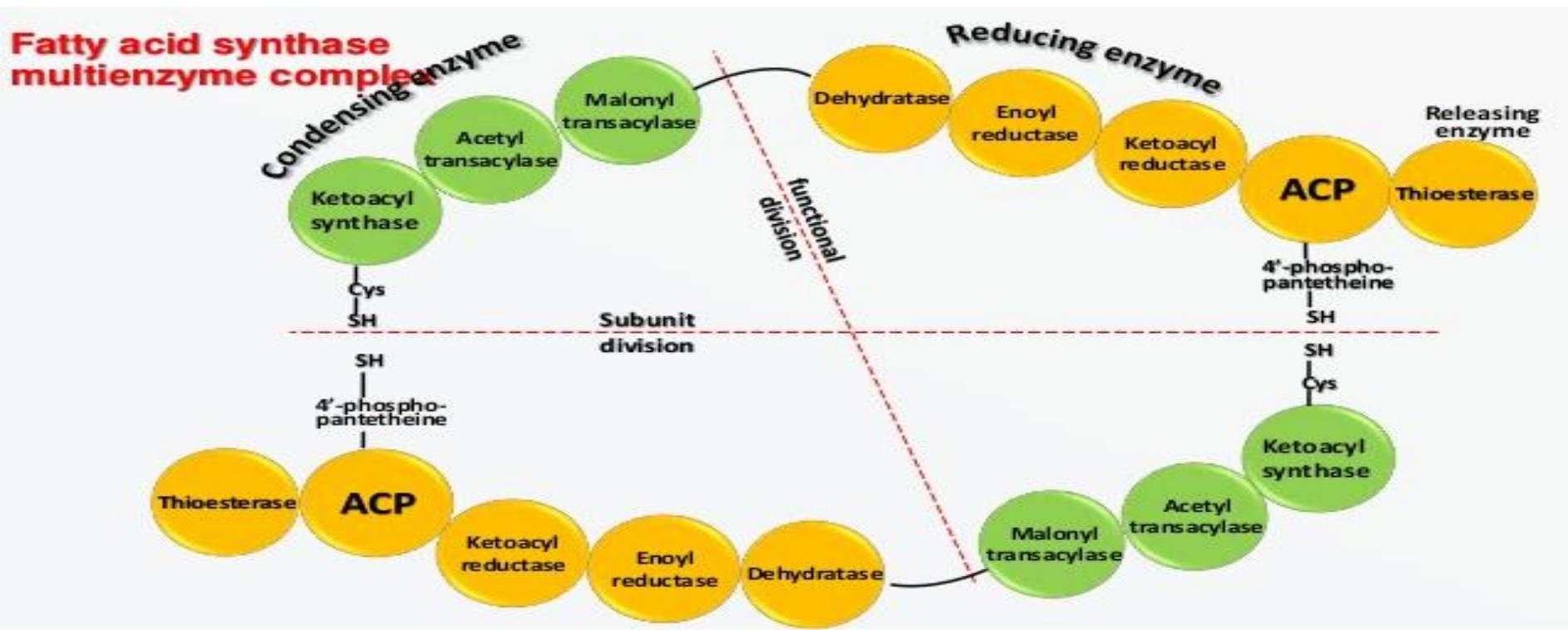
b) Action of cytoplasmic isocitrate dehydrogenase on isocitrate. It is similar to mitochondrial one but it uses NADP⁺ as hydrogen carrier.

c) Action of malic enzyme on malate to produce pyruvate:

Fatty acid synthase complex:

- This enzyme is a dimer i.e. formed of 2 subunits.
- Each unit, which is called monomer, contains 7 enzymes and a terminal protein called acyl carrier protein (ACP).

- ACP is a protein contains the vitamin pantothenic acid in the form of phosphopantotheine. ACP is the part that carries the acyl group.
- Each monomer contains 2 -SH groups, one provided by phosphopantotheine and attached to ACP. The other is provided by cysteine attached to the enzyme 3- ketoacyl synthase.
- The 2 monomers are arranged head to tail, so the -SH group of ACP of one monomer is very close to the -SH group provided by 3- ketoacyl synthase of the other monomer.



Extra-mitochondrial system

- It is the only system responsible for de novo synthesis of F.A.s from acetyl CoA, free palmitate is the main product.

Site:

Intracellular location: Cytosol.

8 molecules of acetyl CoA (C2) are used in the formation of palmitate (C16)

-7 acetyl CoA are converted into malonyl CoA by the enzyme acetyl CoA carboxylase.

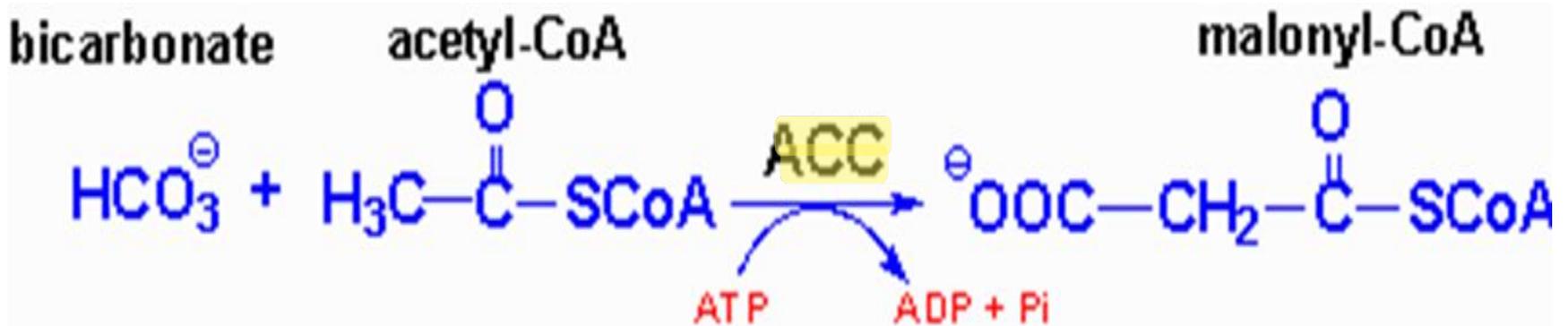
-The process occurs in 7 repeated cycles, each requires 2 mol of NADPH+H⁺, and liberates 1 mol of CO₂ and 1 mol of H₂O.

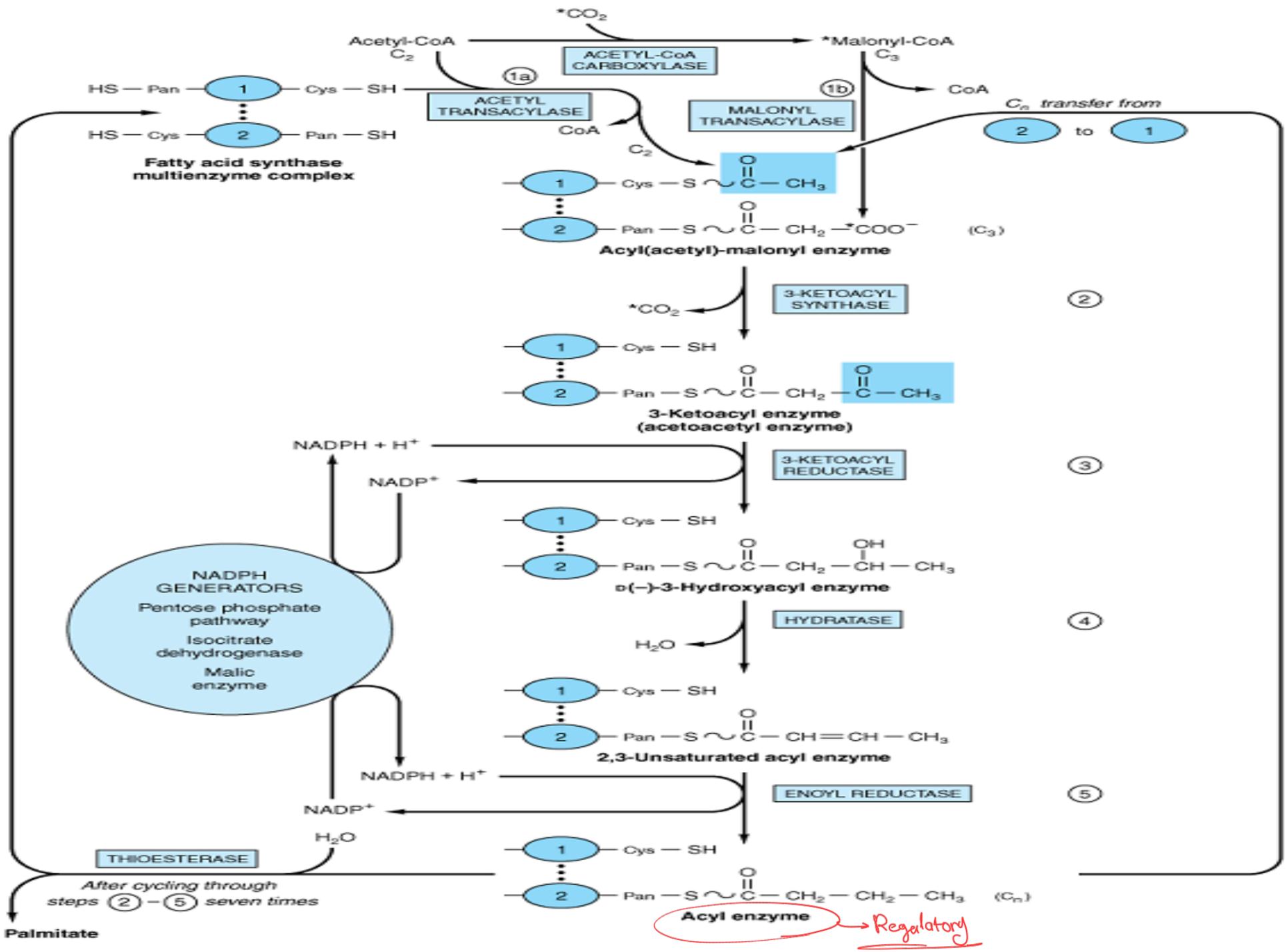


-The synthesis of malonyl-CoA is the first committed step of fatty acid synthesis and the enzyme that catalyzes this reaction, **acetyl-CoA carboxylase (ACC)**, is the major site of regulation of fatty acid synthesis.

-Like other enzymes that transfer CO₂ to substrates, ACC requires a **biotin co-factor**.

↓





Regulation of F.A.s synthesis

FOAT

1- Acetyl CoA carboxylase: Allosterically:

- Activated by citrate.
- Inhibited by long chain acyl-CoA.

2- Acyl CoA:

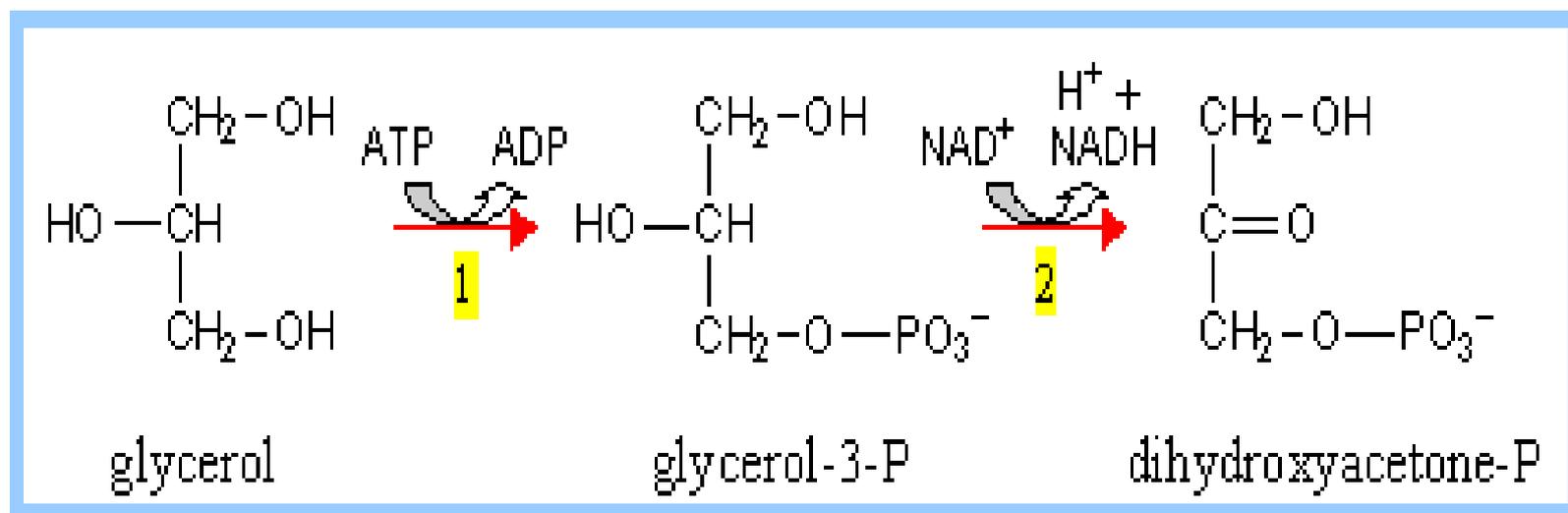
- Inhibits the transport of citrate from mitochondria to cytosol.
- Inhibits PDH and citrate synthase.

3- Insulin:

- After a carbohydrate rich meal, insulin is secreted, it increases glycolysis, acetyl CoA, oxaloacetate (needed for acetyl radical transport and citrate production step) for FA synthesis.
- It inhibits lipolysis through cAMP inhibition which reduces the concentration of long chain acyl CoA (inhibitor of lipogenesis).
- It activates PDH, acetyl CoA carboxylase to the active dephosphorylated form.
- During starvation: The reverse occurs
- Citrate activates acetyl CoA carboxylase (the rate limiting step in fatty acids biosynthesis).

Synthesis of TAG (Lipogenesis):

- Fatty acids are stored for future use as triacylglycerols in all cells, but primarily in adipocytes of adipose tissue.
- Triacylglycerols constitute molecules of glycerol to which three fatty acids have been esterified.
- The major building block for the synthesis of triacylglycerols, in tissues other than adipose tissues is **glycerol-3-phosphate** which is formed from glycerol by glycerokinase or from glycolysis.
- Adipocytes and muscles lack **glycerol kinase**, therefore, dihydroxyacetone phosphate (**DHAP**), produced during glycolysis, is the precursor for triacylglycerol synthesis in adipose tissues.



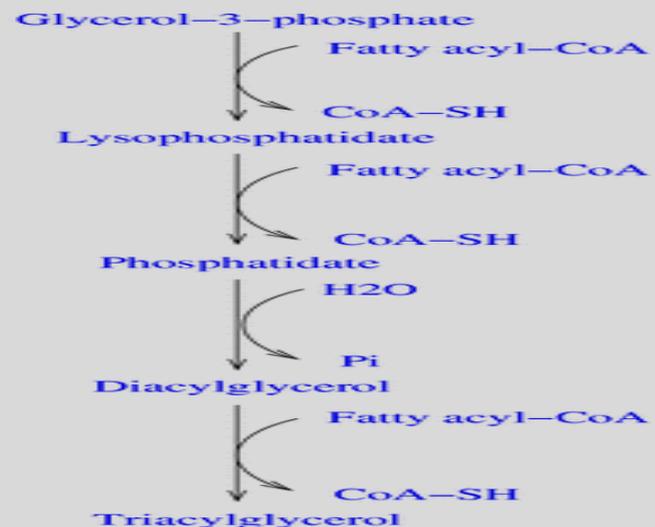
The fatty acids incorporated into triacylglycerols are activated to *acyl-CoA* through the action of acyl-CoA synthetases.

-Two molecules of acyl-CoA are esterified to glycerol-3-phosphate to yield 1,2-diacylglycerol phosphate (commonly identified as phosphatidic acid).

-The phosphate is then removed, by phosphatidic acid phosphatase, to yield 1,2-diacylglycerol, the substrate for addition of the third fatty acid.

N.B. After meal, insulin is secreted which stimulates glycolysis which supplies **DHAP** that is converted to glycerol phosphate in adipose tissue so **lipogenesis is stimulated**.

Triacylglycerol Synthesis



Catabolism of TAG (Lipolysis):

- Lipolysis is carried out by three enzymes present in adipose tissue :
 - 1.Hormone sensitive triacylglycerol lipase:
 - 2.Diacylglycerol lipase.
 - 3.Monoacylglycerol lipase.



- Glucose by gluconeogenesis.
 - Pyruvate by glycolysis.
 - Triacylglycerol by lipogenesis
 - Oxidation to give energy.
 - May remain in adipose tissue to be re-esterified into TAG
- **N.B.** Glycerol in adipose tissue cannot be used in re-esterification of fatty acids to form triacylglycerol due to deficiency of **glycerokinase enzyme.**

stool

Regulation of lipolysis

The key enzyme controlling lipolysis is **Hormone sensitive triacylglycerol lipase (HSL)**:

- This enzyme is **activated when phosphorylated** by 3' 5'-cyclic AMP-dependent protein kinase.
- 3' 5'-cyclic AMP is produced in adipocyte when one of several hormones (mainly epinephrine) binds to receptors on cell membrane and activates adenylate cyclase. In the presence of high plasma level of insulin and glucose, HSL is dephosphorylated, and become inactive. So during fasting → stimulation of lipolysis.
- Coffee contains caffeine and tea contains theophylline. Both inhibit phosphodiesterase enzyme → stimulation of lipolysis.

Causes of excessive lipolysis: where there is a need for energy;

starvation, diabetes mellitus, low carbohydrate diet, and in certain infectious disease as in tuberculosis (due to high catabolic state).

Fatty acid Oxidation

Oxidation of fatty acids occurs in the mitochondria.

-The CoA derivatives of long chain F.A. can not penetrate the inner mitochondrial membrane (short chain F.A.s & their acyl CoA can penetrate).

- The transport of fatty acyl-CoA into the mitochondria is accomplished via an acyl – carnitine intermediate



- Fatty acids results from TAG hydrolysis in adipose tissue are taken up by most tissues and must be activated in the cytoplasm before being oxidized in the mitochondria.

- Activation is catalyzed by **fatty acyl-CoA synthetase** or (**thiokinase**).

Carnitine:

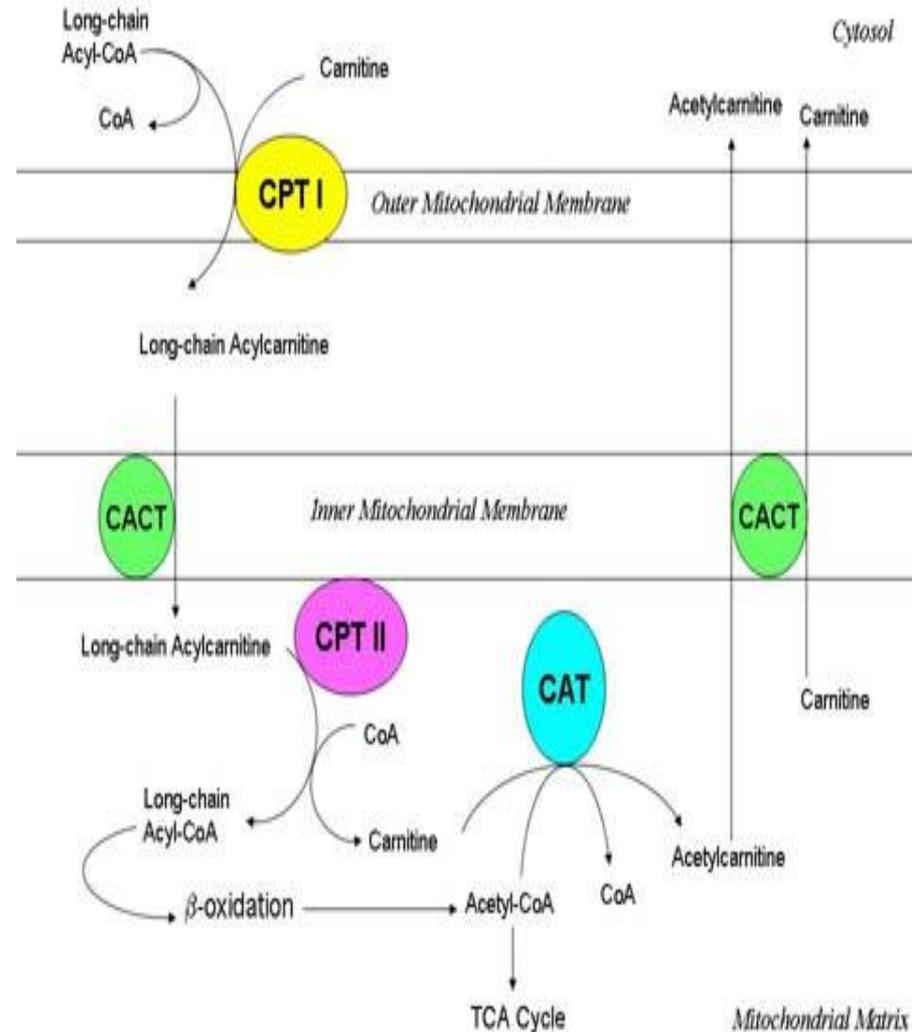
Long chain F.A.s transport

It is β -hydroxy - γ -trimethylamino butyric acid

- The enzyme carnitine-palmitoyl transferase I transfers the acyl radical from the acyl-CoA to the hydroxyl group of carnitine, forming acylcarnitine

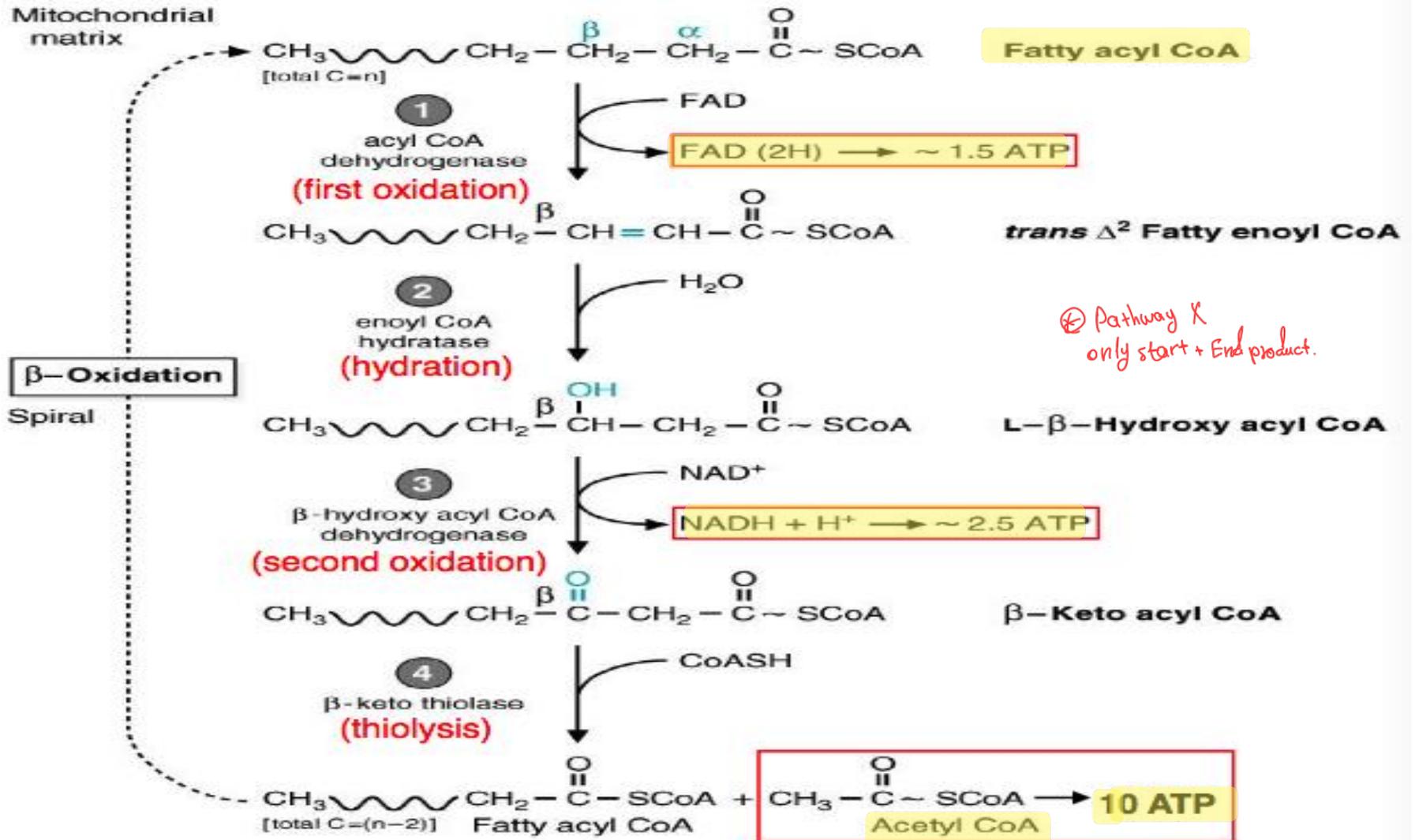
- It can cross the inner mitochondrial membrane in exchange with carnitine.
- Acyl carnitine transported to the inner mitochondrial membrane is accomplished by **carnitine acyl-carnitine translocase**.
- In mitochondria carnitine is regenerated by **carnitine palmitoyl transferase II enzyme**, and the active acyl CoA is now ready for oxidation and energy production.

Carnitine Shuttle



β -Oxidation

- In the mitochondrial matrix there is a group of enzymes called **F.A.s oxidase** that are responsible for F.A.s oxidation.
- The process is multi-cyclic, in each cycle 2 carbons as active acetate are removed.
- Also, two reduced coenzymes are produced (FADH_2 and $\text{NADH}+\text{H}^+$).
- Active acetate is oxidized in TCA cycle, producing also, reduced coenzymes.
- The net reduced coenzymes are oxidized via ETC for ATP production.
- β -oxidation occurs in many tissues except brain where F.A.s can not be uptaken by brain tissues and RBCs (because no mitochondria).
- It is termed β -oxidation since, it occurs through the sequential removal of 2-carbon units by oxidation at the β -carbon position of the fatty acyl-CoA molecule.



Energy production of β-oxidation

-Calculation formula of energy production for fatty acid oxidation :

$$= \{(N/2 - 1) \times 4 \text{ ATP}\} + (N/2 \times 10 \text{ ATP}) - 2 \text{ ATP}$$

where N represents the number of carbon atoms of fatty acid.

Regulation of fatty acid oxidation:

Through energy production: \uparrow ATP \rightarrow inhibit ETC \rightarrow inhibit β -oxidation.

Importance of β -oxidation:

- 1- Energy production.
- 2- Production of acetyl CoA which enters in many pathways
- 3- Ketone body formation : Acetoacetyl CoA is the last 4 carbon atoms in the course of β -oxidation, it may be converted into acetoacetate; one of ketone bodies.

Disorders associated with impaired β -oxidation

- 1- **Carnitine deficiency**: It leads to accumulation of toxic amounts of free fatty acids and branched-chain acyl groups
- It occurs in patients with:
- 1- liver disease.
 - 2- malnutrition.
 - 3- In those with increased requirement of carnitine as severe infection and burns.
 - 4- During hemodialysis which removes carnitine from blood.

- Symptoms include **muscle cramps** during exercise, severe weakness
- **Muscle weakness** related to importance of fatty acids as long term energy source
- **Hypoglycemia and hypo ketosis are common findings**
- Diet containing medium chain fatty acids is recommended since they do not require carnitine shuttle to enter mitochondria.

⊛ Final result of Fatty-acid oxidation:

① Even number chain \Rightarrow acetyl coA

② Odd chain \Rightarrow Acetyl coA + 3 Fats
 \downarrow
 Preponate
 \leftarrow converted
 Succinyl coA

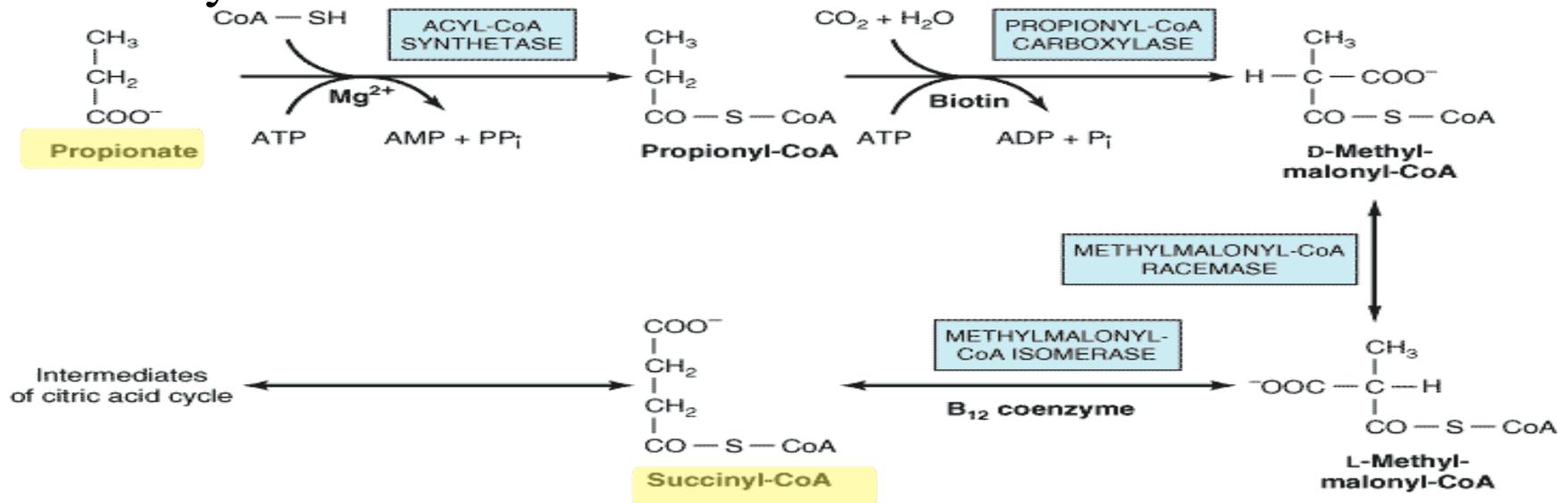
Elongation:

- Starts w/ acetyl coA
 and then we add malonyl coA

β - oxidation of odd chain fatty acids

-Fatty acids with an odd number of carbon atoms are oxidized by the pathway of β -oxidation, producing acetyl-CoA, until a three-carbon (propionyl - CoA) residue remains.

-This compound is converted to Succinyl-CoA, a constituent of the citric acid cycle



-The propionyl residue from an odd-chain fatty acid is the only part of a fatty acid that is glucogenic.

Fatty acids are synthesized and degraded by different pathways

Degradation (β -Oxidation)

- 1- In the mitochondria matrix
- 2- Intermediates are linked to CoA
- 3- No linkage of the enzymes involved
- 4- The oxidants are NAD^+ and FAD
- 5- Degradation by C_2 units \rightarrow Acetyl-CoA

Synthesis

- In the cytosol
- Intermediates are linked to an acyl carrier protein (ACP) complex
- Enzymes are joined in one polypeptide chain \rightarrow FA synthase
- The reductant is NADPH
- Elongation by addition of malonyl ACP + release of CO_2
- Synthesis stops at palmitate (C_{16}), additional enzymes necessary for further elongation