Energy and Agriculture By C. Kohn, WUHS

Imagine you're a dairy farmer. Would you want a cow that eats a lot and produces very little milk? Or would you rather have a cow that eats the same amount but produces much more milk? Obviously, you'd want more milk for the same amount of feed because it means you will make more money.

Maybe instead you grow corn and soybeans. How could you make your crops grow larger with the same amount of fertilizer? You may not even know how these crops grow larger! After all, you don't have to *feed* your crops…so how do they grow? How do they get larger? And how can we make them larger without spending any extra money?

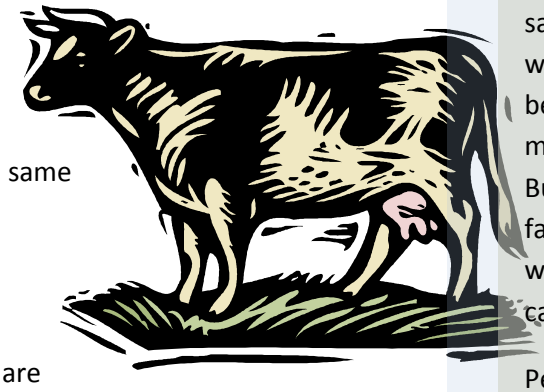
Agricultural Efficiency

In all of agriculture, the main concern is getting the maximum amount of product to sell for the minimum amount of cost. Consumers, on the other hand, want bigger products but don't want to pay extra for their extra food.

In the end, we want agriculture to be efficient. The more milk or meat a cow produces given the same amount of feed, the more **efficient** that cow is. For example, if our first cow (let's call her Buttercup) produces 70 lbs of milk, and our second cow (her name is Petunia) produces 35 lbs of milk, we'd know that Buttercup is more efficient than Petunia if they both cost the same to feed.

The same is true for crops, fruits, and vegetables. If Tree A produces 60 apples and Tree B produces 100 Apples, Tree B is the more efficient tree if everything else is the same. Simply put, we want our plants and animals to produce the maximum amount of product with the minimum amount of resources and cost.

What makes Buttercup more efficient than Petunia? What made Tree B produce more apples than Tree A? For a long time we didn't know! Farmers simply bred the most efficient animals or crops, leaving out the less efficient animals and plants. This made agriculture as a whole more efficient. Cows used to be the size of Great Danes! Sheep used to only come up to your knee! Wild strawberries are the size of peas, and corn used to only have a few kernels on every ear! Agriculture has rapidly changed because farmers knew to breed only the most efficient crops and animals. By selecting only those plants and animals with efficient genes, farmers were able to produce more food for the same amount of cost, making food more available and more affordable.



Cellular Biology

While it's often simple to identify which plants animals are most efficient, what is not simple is explaining *WHY* they are so efficient. To understand what makes Buttercup better at producing milk than Petunia, we have to look at the smallest functioning part of any living plant or animal – the cell.

The Story of Buttercup and Petunia

Once upon a time, there was a cow named Buttercup. Buttercup was a special cow. She ate the same amount of corn and hay each day. However, she gave lots more milk than all the other cows.

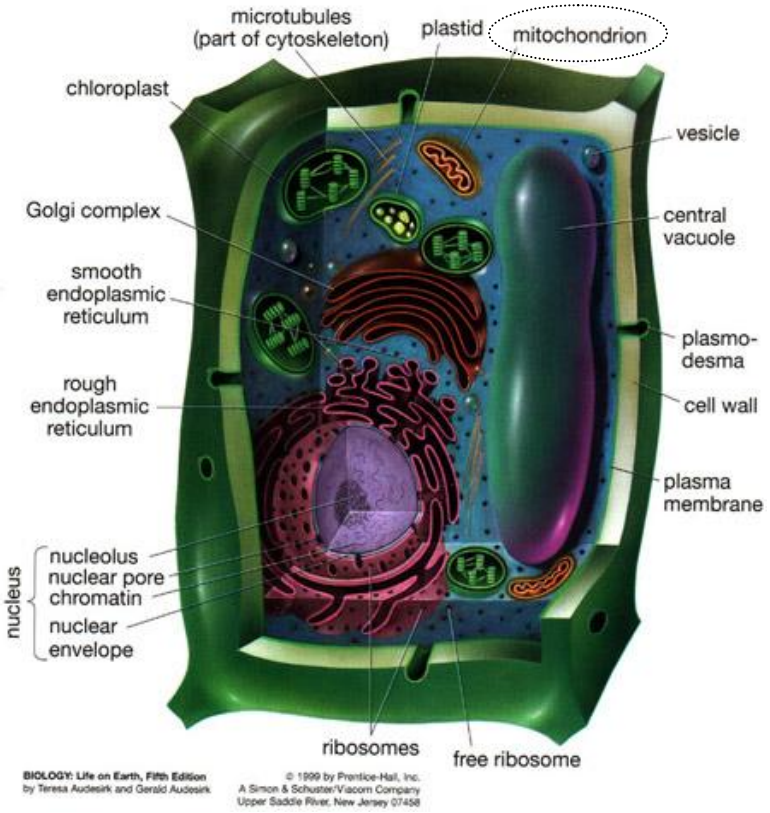
Petunia was a cow too, but she didn't really like Buttercup. Petunia would eat and eat and eat, but she never gave any more milk.

The farmer liked Buttercup more because she gave so much more milk but didn't eat any more feed than any of the other cows.

The farmer took Buttercup to the fair. The judge at the fair said that Buttercup was the best cow because she made so much milk. Because Buttercup won the fair, all the farmers wanted one of her calves.

Petunia decided to move to Cleveland.

The End



The cell is a truly amazing miracle of nature. Though it is so small that it can usually only be seen with a microscope, it is more complex than our most advanced technology. Your body is the equivalent of a trillion F-16 fighter jets all working in unison to help you function!

Every cell has a few key ingredients that help them to do their jobs. The Command Center of every cell is the **nucleus**. The nucleus is where your **DNA** is stored. Your DNA is the instruction book for every cell, telling it exactly what to do and when to do it. If your cells do anything, it is because your DNA instructed them to do it. Without DNA, your cell has no ability to do anything. If your cell is like an F-16, your nucleus is like the cockpit, and DNA is the pilot.

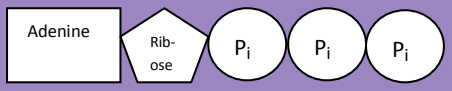
Your cells can't do anything without energy, and they get their energy from their mitochondria. The mighty **mitochondria** are the powerhouse of every cell. It produces a chemical form of energy that your cell uses for every function it performs. Your muscle cells are able to grow and shrink every time you move a finger because they can use the energy created in the mitochondria. White blood cells are able to engulf and destroy invading bacteria using energy from the mitochondria. Your nerve cells are able to create and send electrical signals because of the energy created in the mitochondria. If a cell does anything, it needs the energy created in this powerhouse of the cell.

ATP and ADP

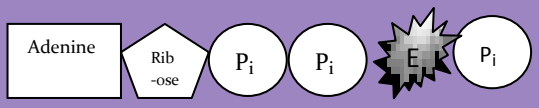
The chemical energy the mitochondria create is called **ATP**. ATP is exactly like a rechargeable battery. It can power different parts of the cell and then be recharged over and over again. ATP is simply a molecule with three phosphate molecules on it. You don't need to know what a "phosphate" is, just that there are THREE of them on ATP when it is charged. Think "A Triple Phosphate", and you'll always remember what ATP is!

When ATP binds to part of the cell, it can transfer its energy to that part. For example, your muscle cells can grow and shrink because of special fibers. When ATP attaches to those fibers, they can shrink themselves using that energy. Just like putting batteries into a remote control car gives it energy to race around a room, attaching ATP to a substance in your cell gives it energy to perform some kind of work.

ATP is a special energy-carrying molecule. It has three phosphate molecules and needs all three to carry energy.



When one phosphate (P_i) is removed, ATP becomes ADP with TWO phosphates.



The third phosphate molecule can then be re-attached to enable it to do work again.

For example, by attaching the third phosphate to a muscular protein, that protein then has the energy necessary to contract. This causes the muscle to tighten. This is only possible because of the increased energy the protein has because of that third phosphate group.

When the energy of ATP is used up, a phosphate molecule "falls off". ATP now becomes **ADP** and P_i. In other words, ATP goes from A Triple Phosphate to A Double Phosphate and a

lone phosphate all by itself. ADP has no chemical energy to give to other parts of the cell. In order to 'recharge' ADP so that it can do work again, we have to add on another phosphate so that ADP can become ATP once and again.

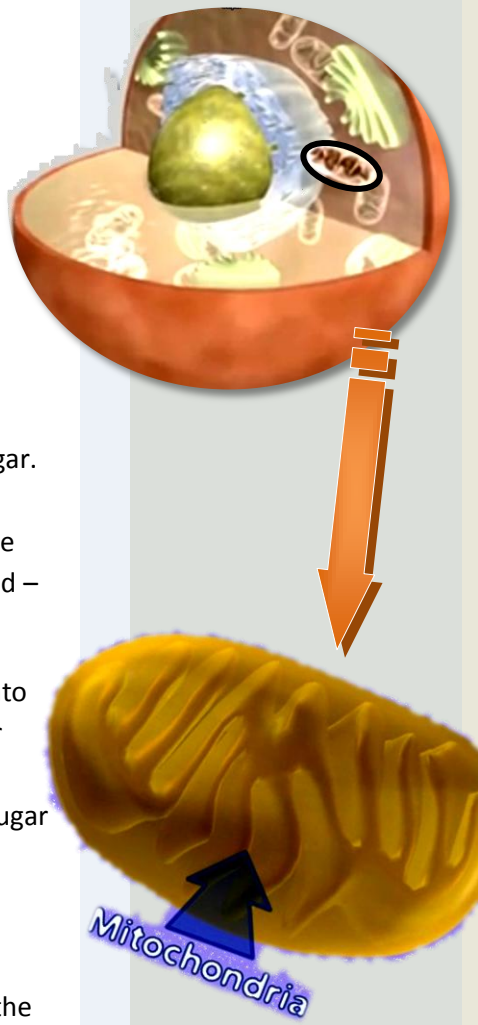
The Mighty Mitochondria…Creator of ATP

This is where the mitochondria come in. Within the structure of the mitochondria, ADP and P_i are 'smashed' together to create ATP. This is the same thing as putting a drained battery back into the battery charger. ADP goes into the mitochondria uncharged and comes out recharged and ready to do work.

How do the mitochondria charge ADP into ATP? It's a complicated process that begins with the food you eat and ends with the air you breathe.

When you eat simple sugars, carbohydrates, or fiber, you are eating the same thing – sugar. Simple sugars are very short 'trains' of sugar molecules, while starchy carbohydrates are medium length 'trains' of sugar and fibers are very long 'trains'. The shorter the train, the sweeter something tastes. This is why white bread tastes sweeter than whole grain bread – the whole grain bread has more fiber, or 'longer trains' of sugar.

When you eat any kind of carbohydrate, it is broken down in your mouth and stomach into individual sugar molecule "train cars". This is necessary because the entire train of sugar molecules is too big to get inside of your cell to your mitochondria. When every carbohydrate is broken down into each individual 'train car' or molecule of sugar, each sugar train car molecule is small enough to get inside every one of your cells. Your blood transports the individual sugar molecules to every single one of your cells all throughout your body.



Once inside your cells, each sugar molecule makes its way to your mitochondria. Inside the mitochondria, the sugar molecules unload their cargo…hydrogen atoms (H^+). These hydrogen atoms, which are also called **protons** or H^+, are stuffed into the shell of every mitochondrion. Protons hate each other…they're like a family that always fights

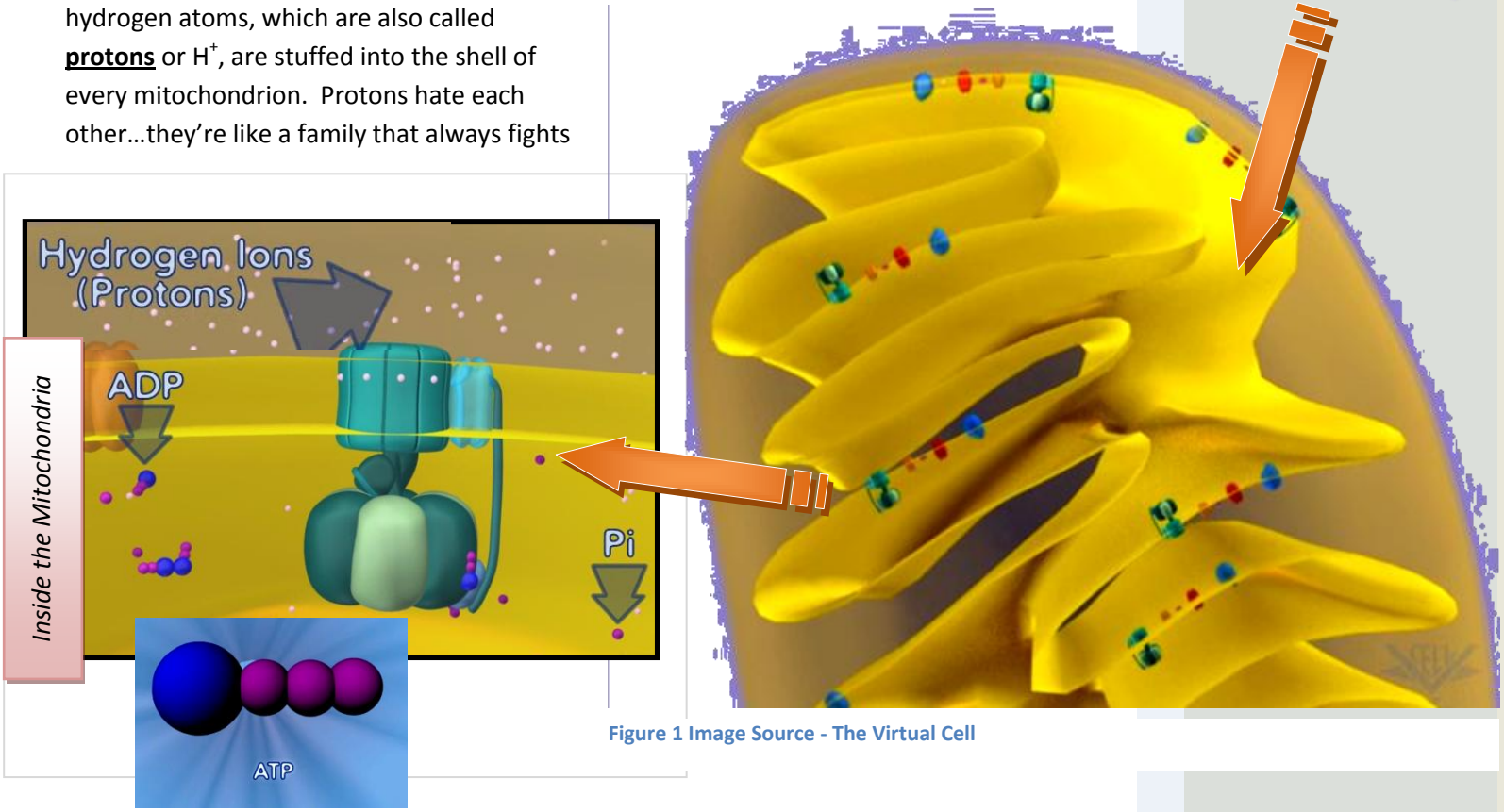
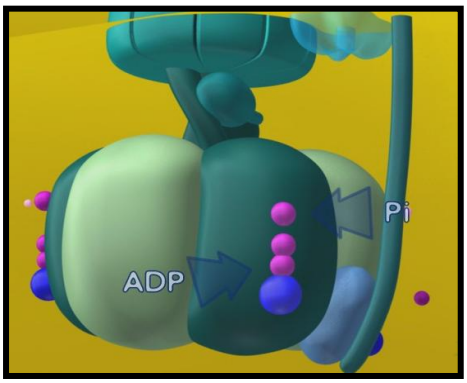


Figure 1 Image Source - The Virtual Cell

when they are together. They hate being stuffed into this tight membrane and will do anything to get out. It is sort of like going on a cross country trip on Thanksgiving…when you get to where you are going, you want to get out of the car as soon as possible. Maybe you have to use the bathroom. Maybe your brother kept sticking his stupid finger in your face, crying "I'm not touching you…I'm not touching you". Maybe your dad listens to NPR and you HATE public radio. Whatever it may be, you just want to get out and dive from the car as soon as it stops.

Protons are the same way. They just hate being around each other. To make things worse, they're crammed so tight into these mitochondria, they can't help but bump into each other, and that just makes them madder and madder. Luckily for them, the mitochondria have doors…revolving doors to be exact. That's right – these tiny structures inside your cells have tiny revolving doors. This might seem ridiculous, but trust me, it's true.

So, the angry protons see these revolving doors and make a mad dash to get out of the mitochondria membrane. When they go through the door, it turns. If you ever walked through a revolving door, you know that you have to spin them to get out, and these are no different. These doors are called **ATP Synthase**.



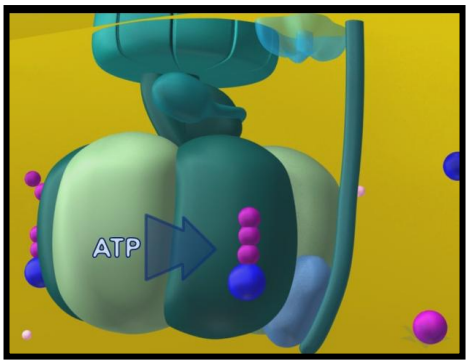


Figure 2 ATP Synthase producing ATP

As these doors spin, they combine ADP and P_i into ATP. It's sort of like a water wheel on a dam…on a dam, as the water flows by, it turns a wheel that does work. Your mitochondria work the same way…as protons move through the revolving door (ATP Synthase), they create ATP which can be used for work in other parts of the cell.

Oxygen – The Molecular Garbage Truck

When ATP is made, we have a final problem…we have all these ingredients left over! Sugar molecules are made from Carbon, Hydrogen, and Oxygen – $C_6H_{12}O_6$ to be exact. When we strip off the hydrogen protons, we're left with a whole mess of C, H, and O atoms to get rid of. Some of the carbon is used by your body…your body is 50% carbon! The remaining carbon and oxygen is combined to make Carbon Dioxide, or CO_2. This should seem familiar…you know that you breathe in oxygen (O_2) and you breathe out CO_2.

The reason you have to breathe in oxygen, or O_2, is because of those left-over hydrogen protons. After they go through the revolving doors of the mitochondria, their job is done. They don't provide a whole lot of good for your body once the ATP is made. This is why you need oxygen…it's a molecular garbage truck! Oxygen is breathed in, enters your blood stream, and travels to your cells. There, oxygen binds with the hydrogen protons that were used to make ATP. For every oxygen atom, two hydrogen atoms get picked up. This creates the molecule H_2O. Every time you see your breath on a cold fall day, you are seeing the final product of your mitochondria – water! The main reason we need oxygen is to simply remove the hydrogen that is left over from making ATP. In a very real sense, the oxygen we breathe is a garbage truck needed for picking up the hydrogen protons used by the mitochondria to make ATP.

Conclusion

This process of making and using ATP is crucial to agriculture. The more efficient the livestock animals' cells are at making ATP, the more milk, meat, wool, or eggs they will produce. If more ATP can be made with the same amount of hydrogen (from sugar, starch, and fiber as well as fat), the more an animal will produce with the same amount of feed. Buttercup produced more milk than Petunia with the same amount of feed because Buttercup had cells that most efficiently produced and used ATP.

This is true in plants as well. If the mitochondria of corn can make more ATP with the same amount of plant sugar, the more capable that corn plant will be at producing large ears of corn. The more efficient carrot cells are at using their ATP, the larger they will grow. All of this efficiency in plant and animal cells is determined by their DNA. Slight changes in the instructions from DNA will make a cell more or less efficient at using and producing ATP energy. Animals and plants with more efficient DNA instructions will be bred more and those animals and plants will become larger and more efficient over time. This is why cows are now more than double the size they used to be even 100 years ago. This is why they can produce triple the amount of milk. This is why stalks of corn can tower 10 to 12 feet above our heads in experimental fields. This is why eggs can lay extra large eggs with stronger shells and more nutrition. It all comes down to how efficiently the mitochondria can produce ATP, and how efficiently the rest of the cell can use ATP.

Summary

- Agriculturalists want efficient plants and animals. This means that each individual plant or animal can produce the maximum amount of a product (corn, milk, eggs, etc.) with a minimal amount of input (feed, fertilizer, etc.)
- The nucleus of a cell is like the cockpit of a fighter jet. The DNA in the nucleus is like the pilot – DNA controls the cell and provides all of the instructions for how to act.
- The mitochondria is powerhouse of the cell. It creates the chemical energy that the cell uses to function.
- The chemical energy created by the mitochondria is ATP. ATP is like a molecular battery. It can be recharged after its energy is used up. Every living species uses ATP as its source of cellular energy. From bacteria to berries to blue whales, ATP is universal.
- When ATP releases its energy, it becomes ADP and P_i. ATP has three phosphates (*A Triple Phosphate*) while ADP has two phosphates (*A Double Phosphate*). P_i is just a lone phosphate molecule. In order to carry a charge, P_i has to be 'crammed' back onto ADP to turn it into ATP.
- ATP is re-created in the "revolving doors" (ATP Synthase) of the mitochondria. As H^+ (hydrogen protons) move through these doors, they provide the energy needed to add on the third phosphate molecule. ADP and P_i go in. ATP comes out.
- The hydrogen protons come from the foods we eat, mostly the carbohydrates such as sugars, starches, and fiber. All carbohydrates are simply differing lengths of sugar molecule chains. Long chains of sugar are fiber; short chains are simple sugars (like the table sugar you put on cereal). Starches like white bread and potatoes are medium length chains of sugar molecules.
- During digestion, these chains are broken down into individual sugar molecules. This must occur in order for the sugar to be able to fit through the membrane of a cell to get inside.
- Once inside, the sugar molecules are stripped of their hydrogen protons (H^+), which are stuffed into the membrane of the mitochondria to be used to power the revolving doors (ATP Synthase) that create ATP from ADP and P_i. Breathed-in oxygen is used to remove the left over hydrogen. The water and CO_2 we breathe out is the result of this process.

Brown Fat & Mitochondria

You are probably familiar with the concept of fat – our bodies' stored supplies of energy. However, have you ever heard of *brown* fat?

Brown fat is most likely to be seen in babies and mammals in cold climates. Brown fat doesn't just insulate their bodies – it produces heat!

Brown fat happens to be brown because of the large number of mitochondria.

Brown fat produces heat because those mitochondria are *leaky* – the protons are able to find another way out.

This also creates more friction, and with friction, there is heat (just rub your hands together to see!). Heat from friction is a sign of inefficiency – for example, a car low on engine oil will overheat

However, here this inefficiency is actually a *good* thing – it keeps cold mammals and babies nice and toasty warm. *-CK*

Questions to Test Your Understanding

Complete on a separate sheet of paper. Keep this document for your own personal studying. Be sure to include your name, date, and hour! As always, see Mr. Kohn if you are unsure of something. Finally, be sure to answer the ENTIRE question – incomplete answers will be marked wrong.

1. At the Racine County Fair, a judge in a pig show will ask about rate of gain. Rate of gain is simply how many pounds of weight that pig will gain each day. If two pigs eat the same amount, but Pig X has a rate of gain of 1.5 lbs per day and Pig Y has a rate of gain of 2 lbs, which is more efficient? Choose a pig and **explain** your answer.

2. Where is the DNA of a cell found?
    a. What does it do for the cell?

3. What is mitochondria?
    a. What does it do?

4. True or false: the body uses sugar as its source of energy. Be sure to explain **WHY** this is true or false.

5. What happens to ATP when it loses its energy? What does it turn into?

6. What must be done to "re-charge" ATP so that it can carry energy again?

7. How are table sugar, a starchy carbohydrate, and a fiber similar and how are they different?

8. What must be done to any kind of carbohydrate before the body can use it in the cells?

9. How are carbohydrates used to produce ATP?

10. (2 pts) What is the 'revolving door' of the mitochondria called?
    a. How does it produce ATP?
    b. What would happen if there were the same number of protons on both sides of the mitochondrial membrane? What is necessary for protons to travel through this revolving door?

11. Why do we need to breathe oxygen?
    a. What role does oxygen play in our cells?

12. Where does the carbon dioxide that we exhale come from?

13. Would a more efficient animal produce more or less ATP with the same amount of food? Explain.

14. What is brown fat?
    a. How does it keep babies and some cold-climate mammals warm?

15. (5 pts) Imagine you are a research scientist. Design a pill that changes the function of the mitochondria so that people lose weight. Explain how this pill changes of the function so that less fat is created from our food.
    (*Hint: we want beef cattle to put on a lot of weight, so we breed for efficient mitochondria)*