

## Short Course: Methane on Mars

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### Biology: Potential Life in the Martian Context

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The problem with Life: It's hard to define !!

Does life have to be like earthly life? Why?

Could we detect it if it was different? How ?

Can one devise a non-EC strategy?

Which properties of life are universal?

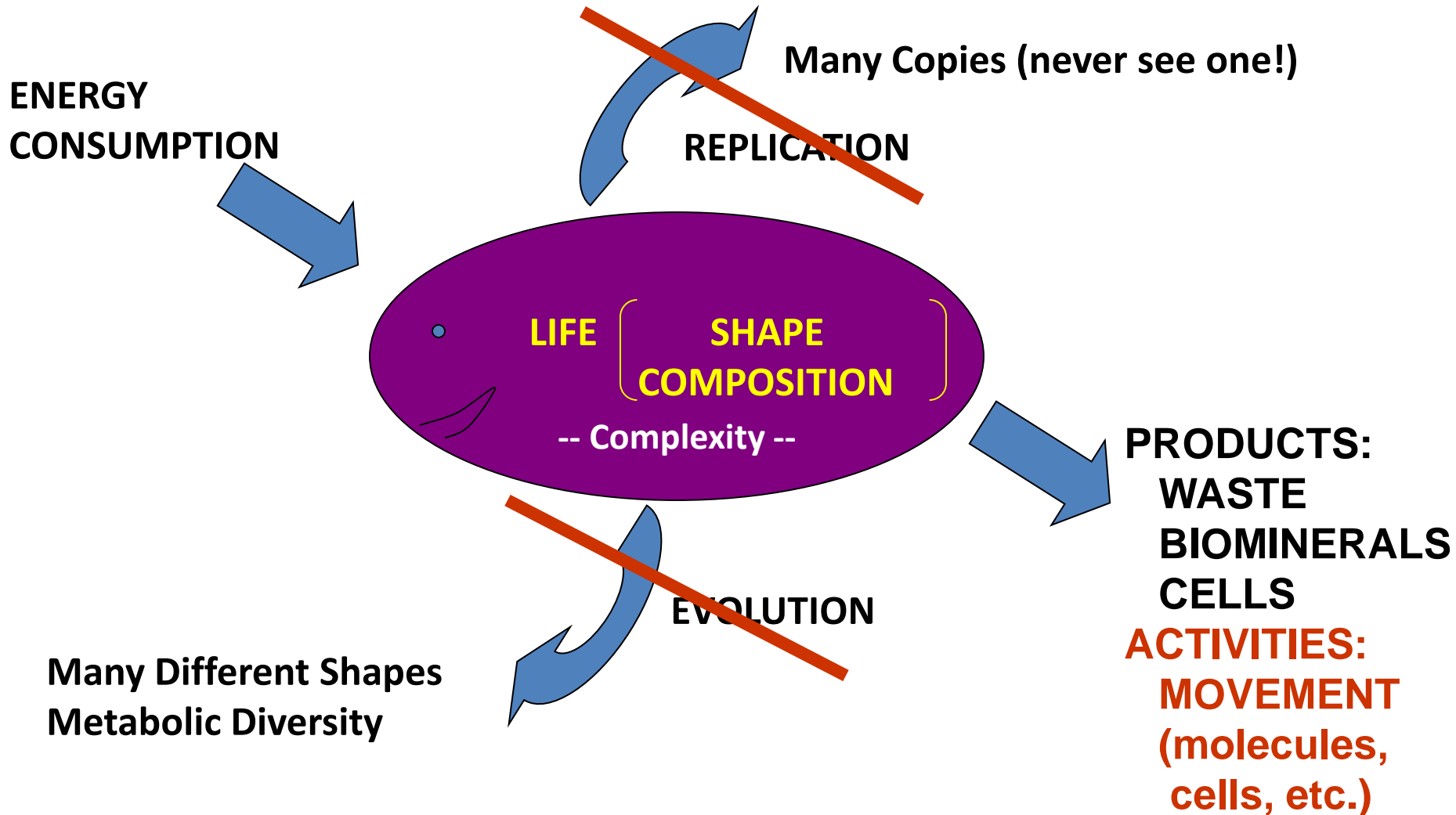
Which properties of life can be quantified ?

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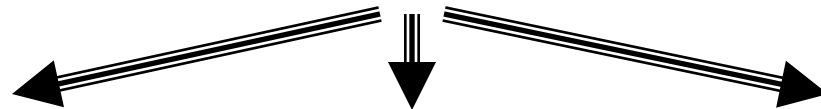
## Characteristics of Living Systems

1. **Complexity of structure**  
(elemental composition; monomer compositions; chirality, etc.)
  - A. Cellular structure separating inside from outside: (membranes)
  - B. Complex machines (enzymes)
  - C. Elemental composition (non-mineral)
  - D. Proteins, Nucleic acids, Lipids, etc.
  
2. **Complexity of function**  
Uptake, metabolism, excretion
  - A. Enzyme Catalysts speed up reactions
  - B. Transport systems take up “food”
  - C. Complex metabolism converts energy
  - D. Transport systems dispose of waste
  
3. **Observable environmental effects**  
establishment of chemical gradients and layers
  - A. Consumption or production at fast rates – gradient formation/LMC’s
  - B. Kinetic isotope effects
  - C. Food disappears; waste appears
  
4. **Non-random movement**
  - A. All life is capable of movement of some kind !

# Fundamental Features of Life



# What is general about life?



## **Structure and Chemistry**

- A. Find the structures**
- B. Determine their Chemistry**
  - Elemental composition
  - Chiral composition
  - Isotope fractionation
  - Complex molecules

## **Thermodynamics and Kinetics**

- A. Define the system**
  - Energy sources
  - Electron donors
  - Electron acceptors
- B. Identify temporal and spatial extents of energy disequilibria**
  - Layer formation
  - Temporal disruptions

## **Non-Random Movement**

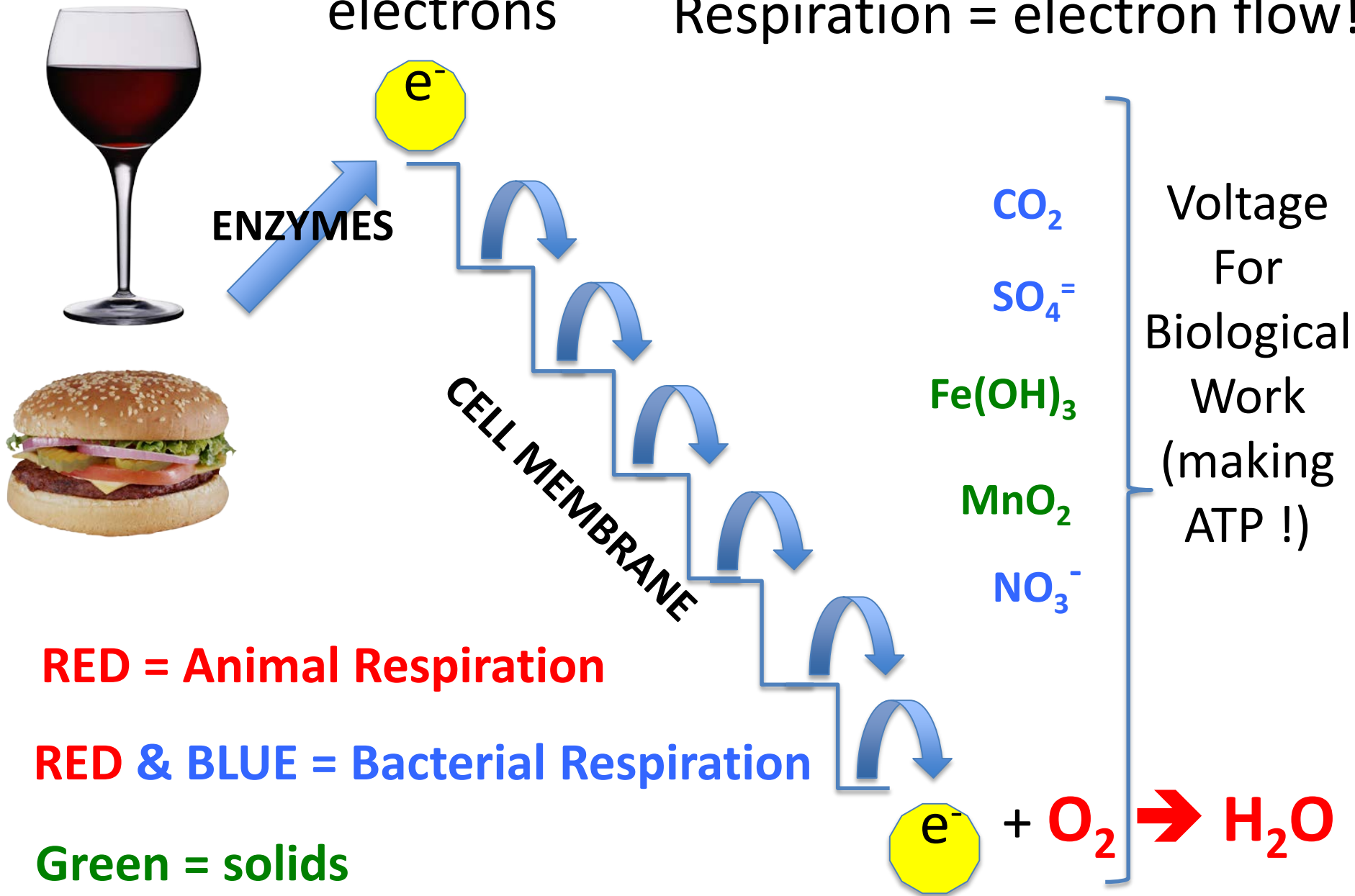
- A. Observe Movement**
  - Spatial scales
  - Temporal scales
  - Data treatment

## So: what does life require?

1. Solvent: Very hard to catalyze organic reactions without water (hydration and dehydration are the essence of biochemistry)
2. Source of nutrients (food) = electron donors and electron acceptors
3. Structural nutrients: Carbon, hydrogen, oxygen, nitrogen, phosphorous, sulfur
4. Functional nutrients: Carbon, nitrogen, phosphorous, sulfur, plus metals

electrons

Respiration = electron flow!



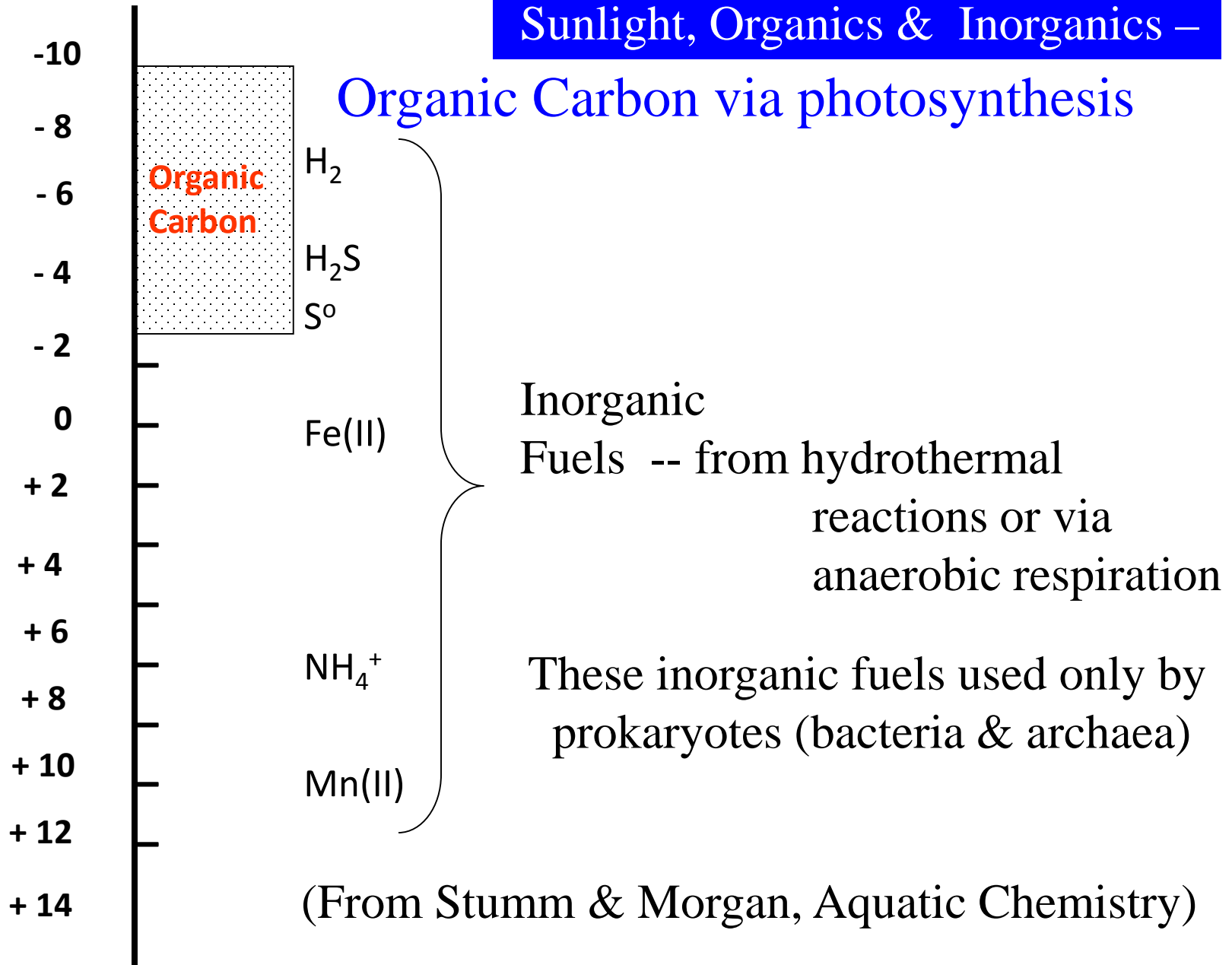
**RED = Animal Respiration**

**RED & BLUE = Bacterial Respiration**

**Green = solids**

Fuels of Life: (electron donors)  
Sunlight, Organics & Inorganics –

Relative Voltage ( $P\epsilon^{\circ}(W)$ )





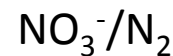
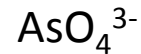
## Oxidants of Life: (electron acceptors)

Oxygen is best oxidant  
(most energy)

Used by “all” eukaryotes

Inorganic compounds are  
used only by prokaryotes  
(Bacteria and Archaea)

Now Add things like  
chlorinated hydrocarbons  
(man-made oxidants)



Organic  
Carbon

-10

- 8

- 6

- 4

- 2

0

+ 2

+ 4

+ 6

+ 8

+ 10

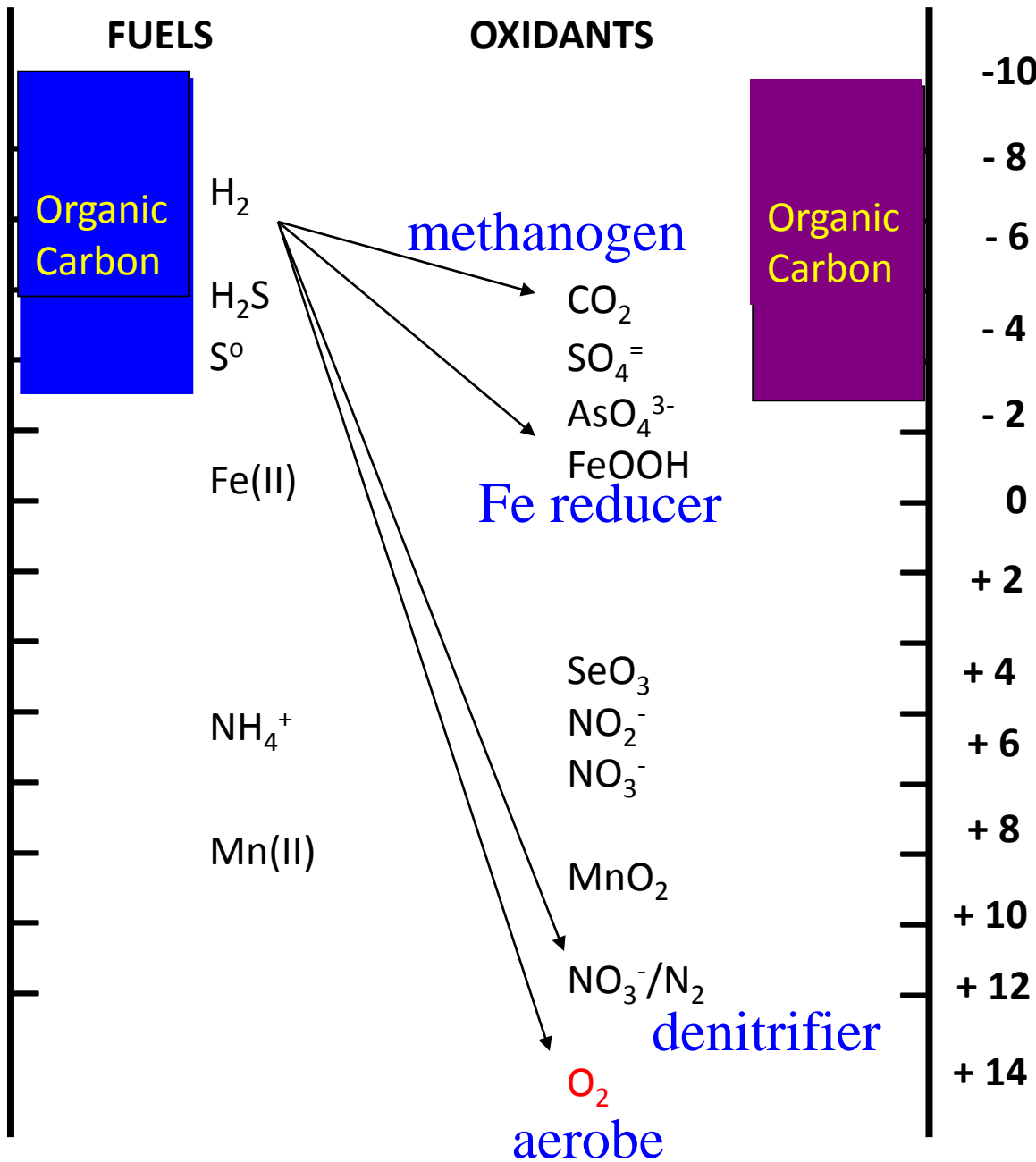
+ 12

+ 14

Relative Voltage ( $P\epsilon^{\circ}(W)$ )

Relative Voltage ( $P\epsilon^{\circ}(W)$ )

The Geological Environment Supplies Many Oxidants And Reductants That Life has Learned to Utilize !!



Let's put This Together NOW !!

Voltage Available For Charging Biological Capacitor!

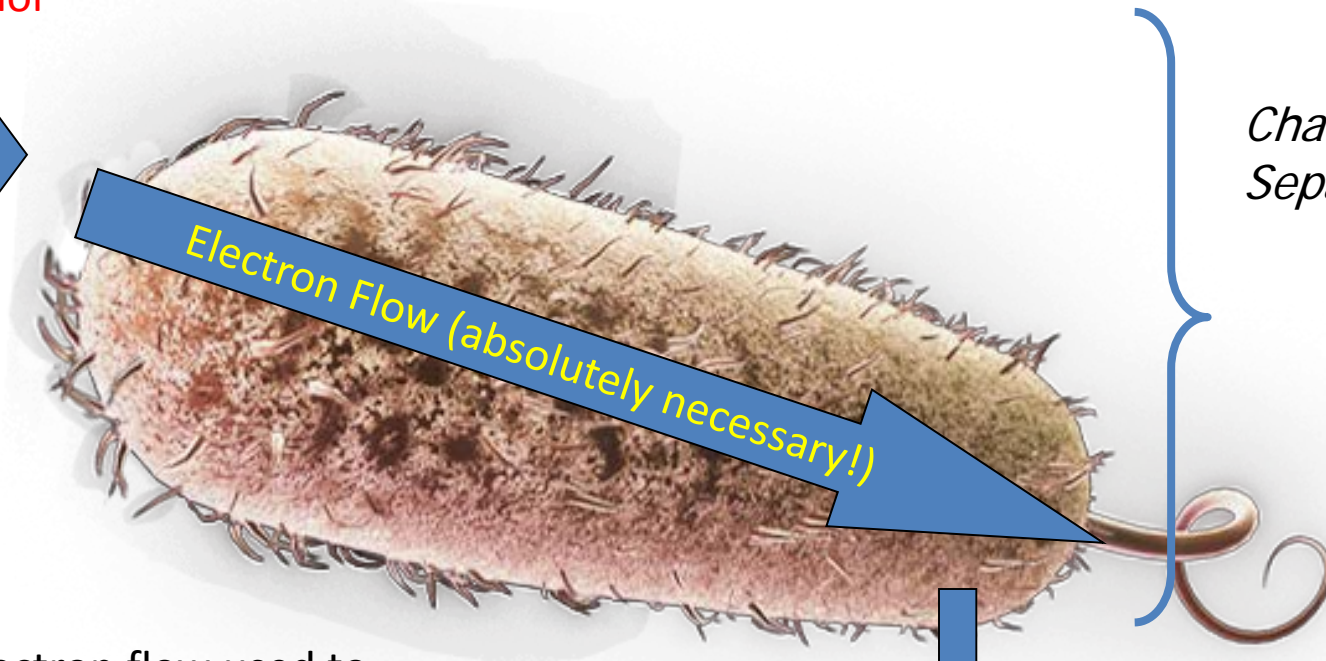
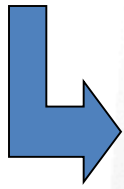
## HOW LIFE WORKS (on Earth!)

### Mitchell “Hypothesis”

1. Impermeable membrane to charged molecules
2. Membrane bound electron and H carriers
3. Alternation of these carriers
4. Spatial arrangement
  
5. Electrons flow from high to low energy state
6. Ultimately oxidized by some electron acceptor
  
7. During this process, protons transported to exterior
  
8. Reactions are (should be) reversible

# How Life Works\*\* (part I)

Electron Donor



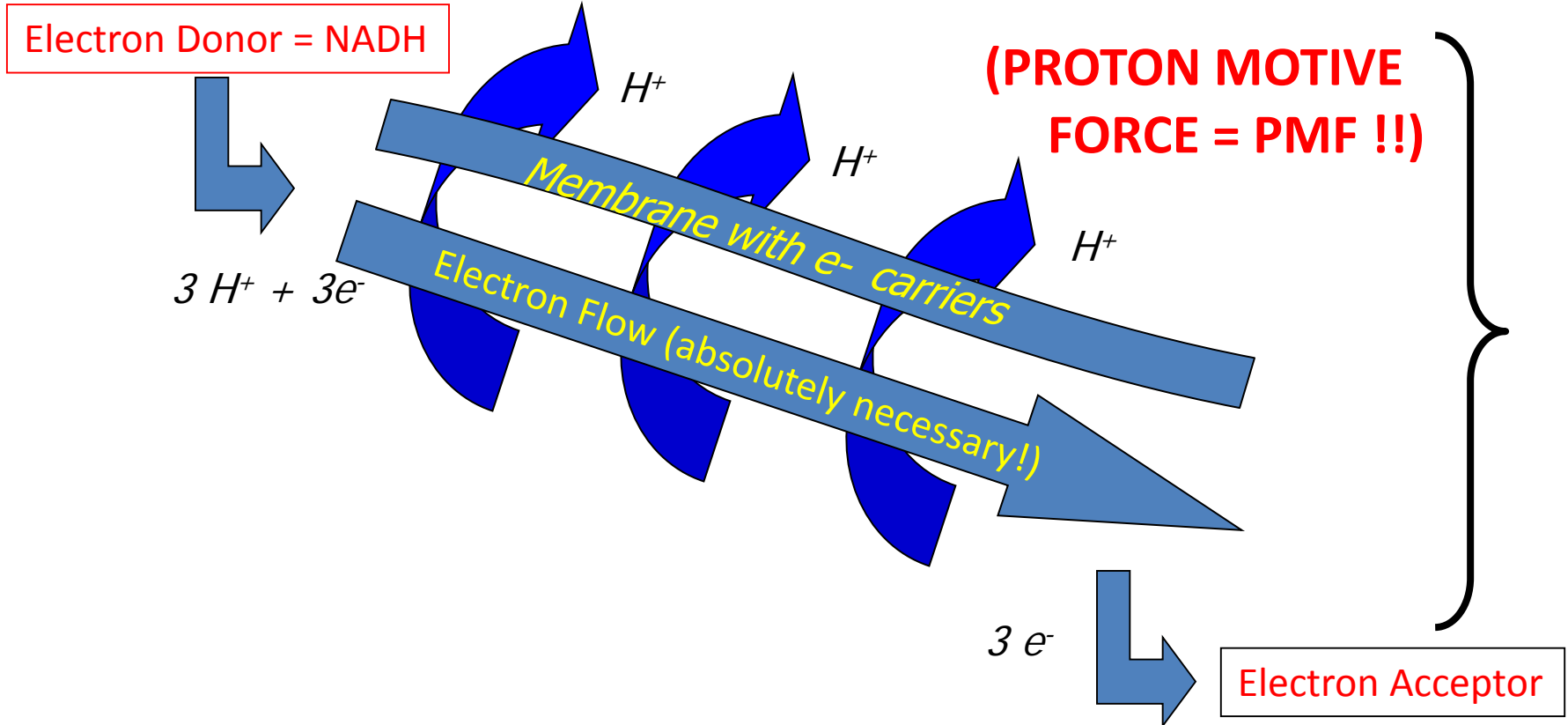
*Charge  
Separation !!*



Electron Acceptor

Energy from electron flow used to drive reactions of life -- Same idea for virtually all of life on Earth !

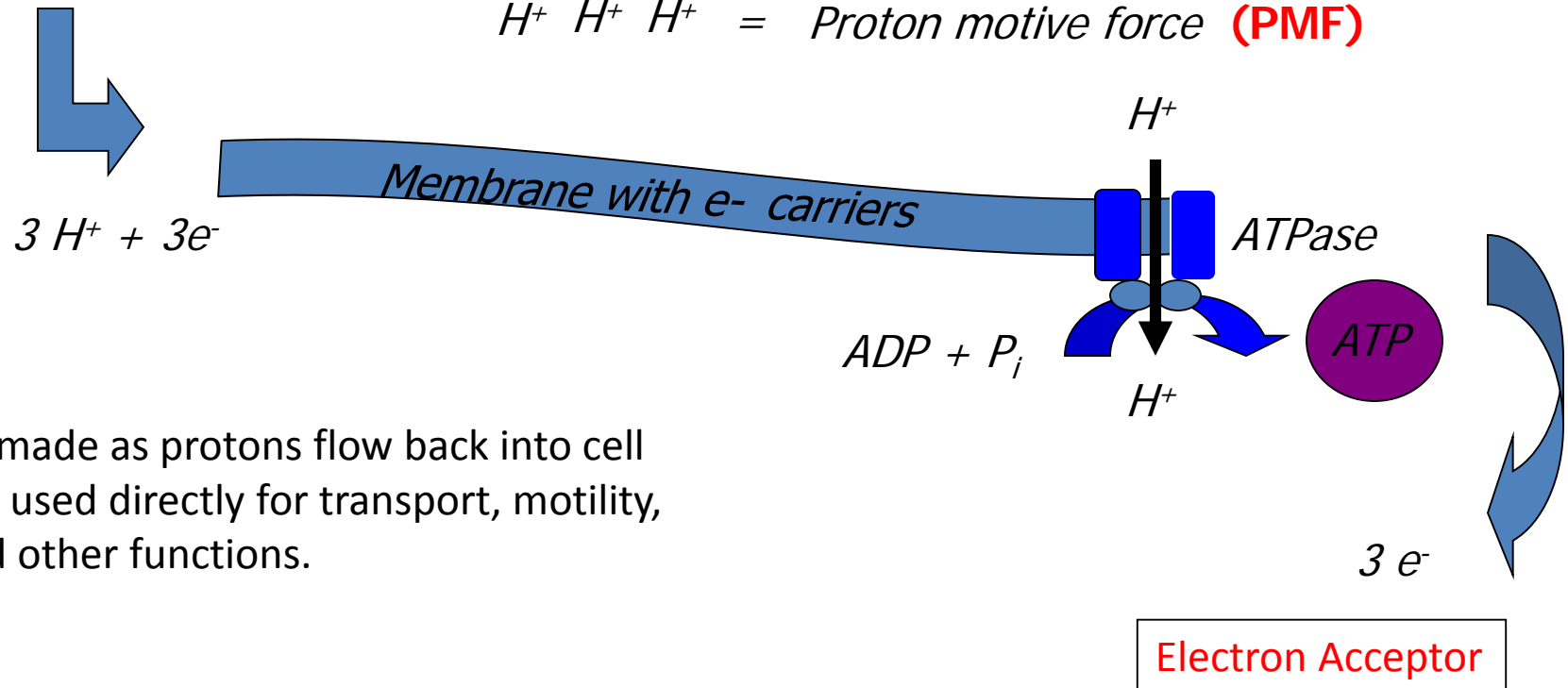
# How Life Works\*\* (part II)



Electron flow pumps protons to exterior –  
proton and pH gradient used to make biological energy  
“charging the biological capacitor” !! = **PMF !!**

# How Life Works: (ATP synthesis)

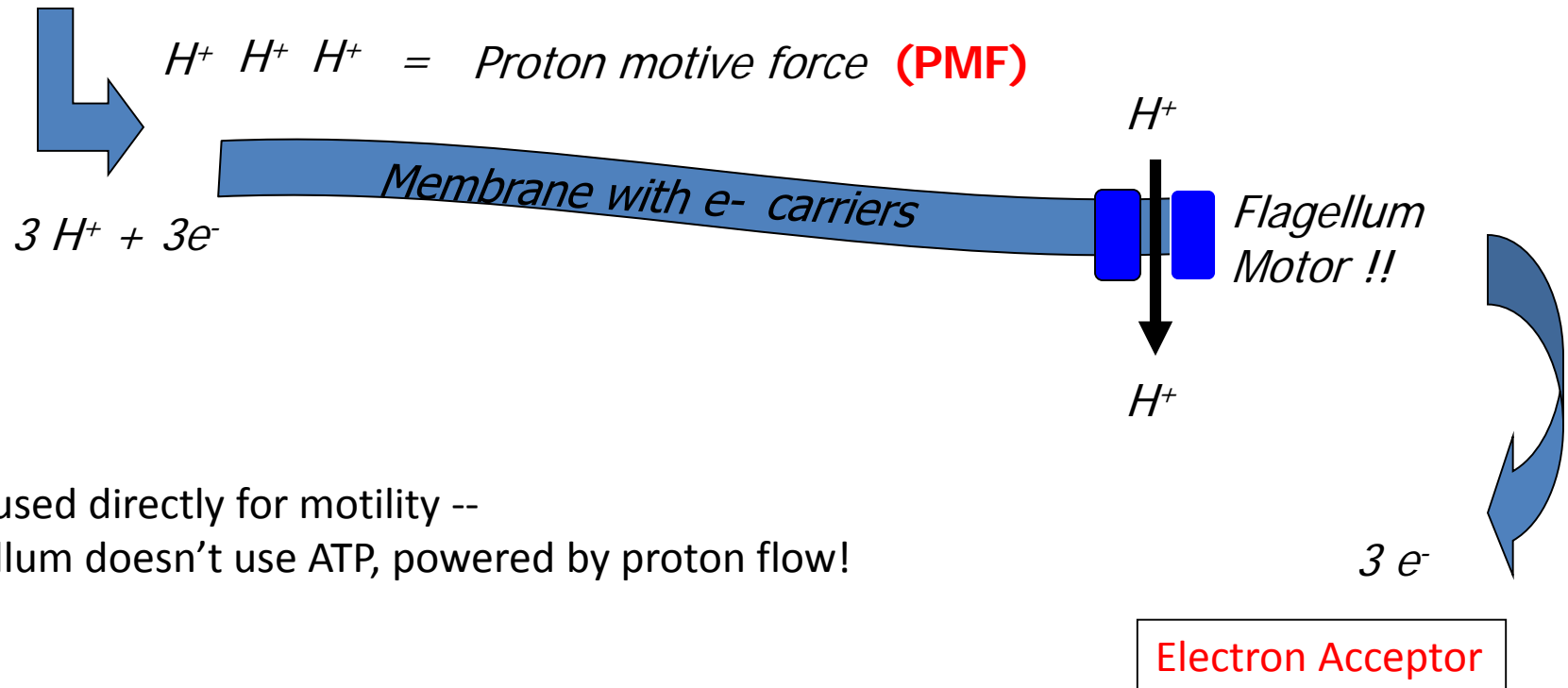
Electron Donor



ATP made as protons flow back into cell  
PMF used directly for transport, motility,  
and other functions.

# How Life Works: (motility)

Electron Donor



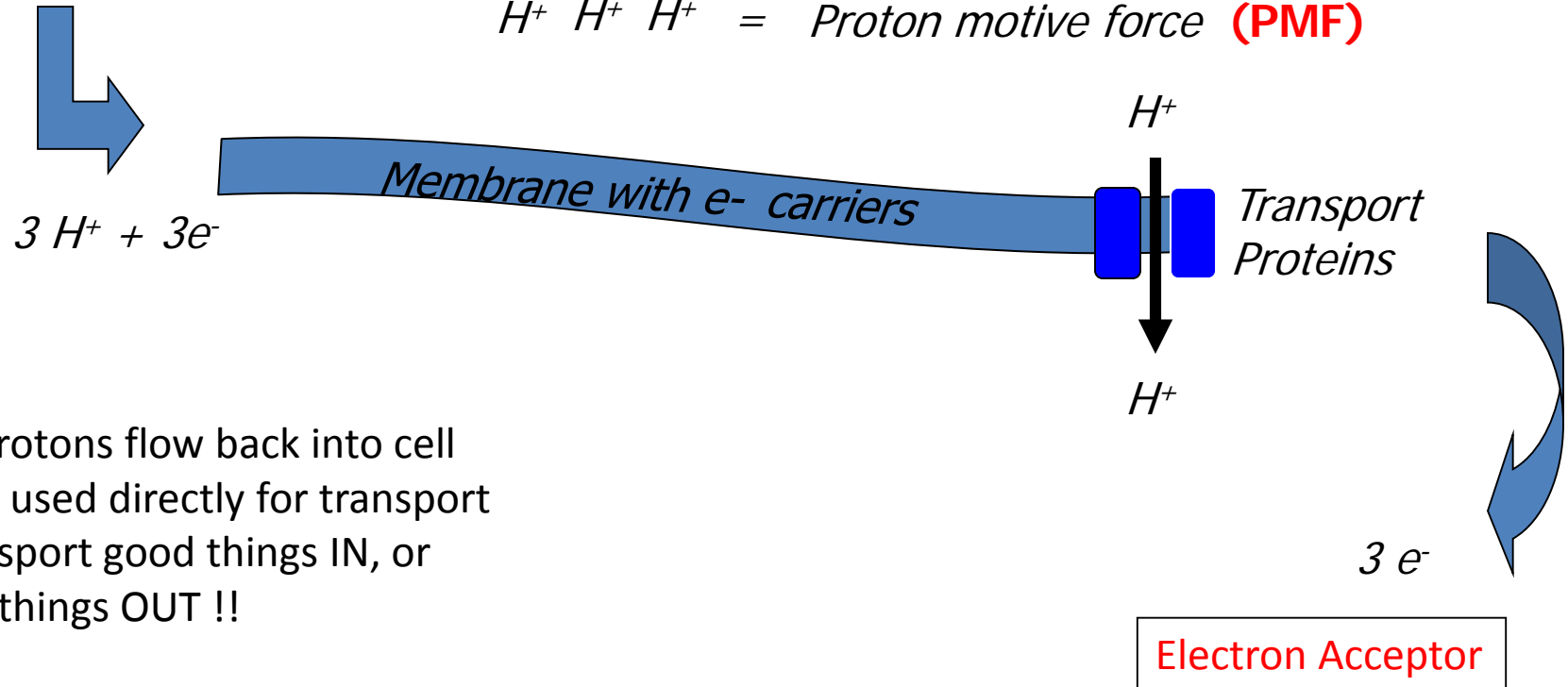
PMF used directly for motility --

Flagellum doesn't use ATP, powered by proton flow!

Electrons flow, PMF generated, flagella rotate !!

# How Life Works: (transport)

Electron Donor



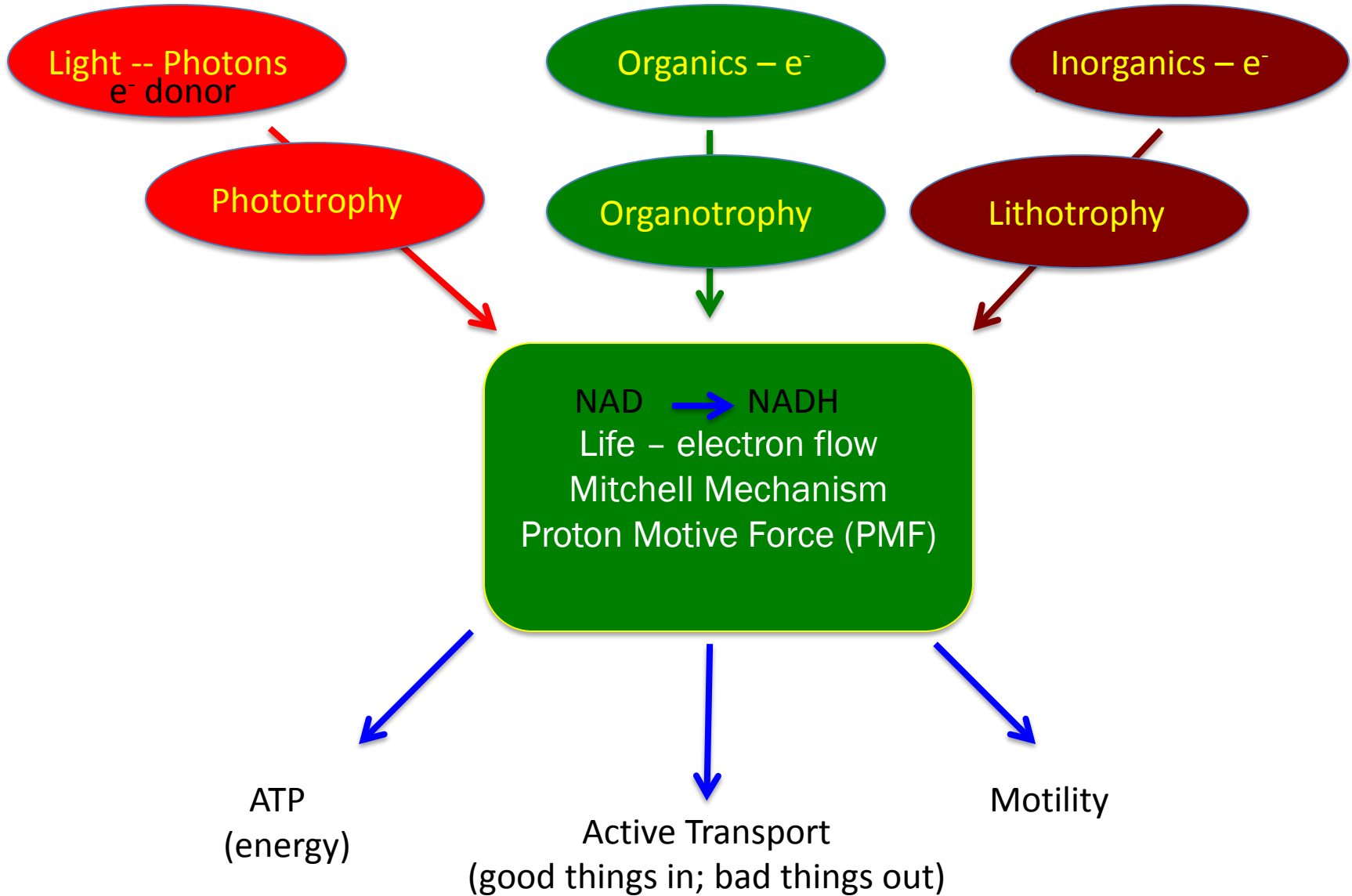
As protons flow back into cell  
 PMF used directly for transport  
 Transport good things IN, or  
 Bad things OUT !!



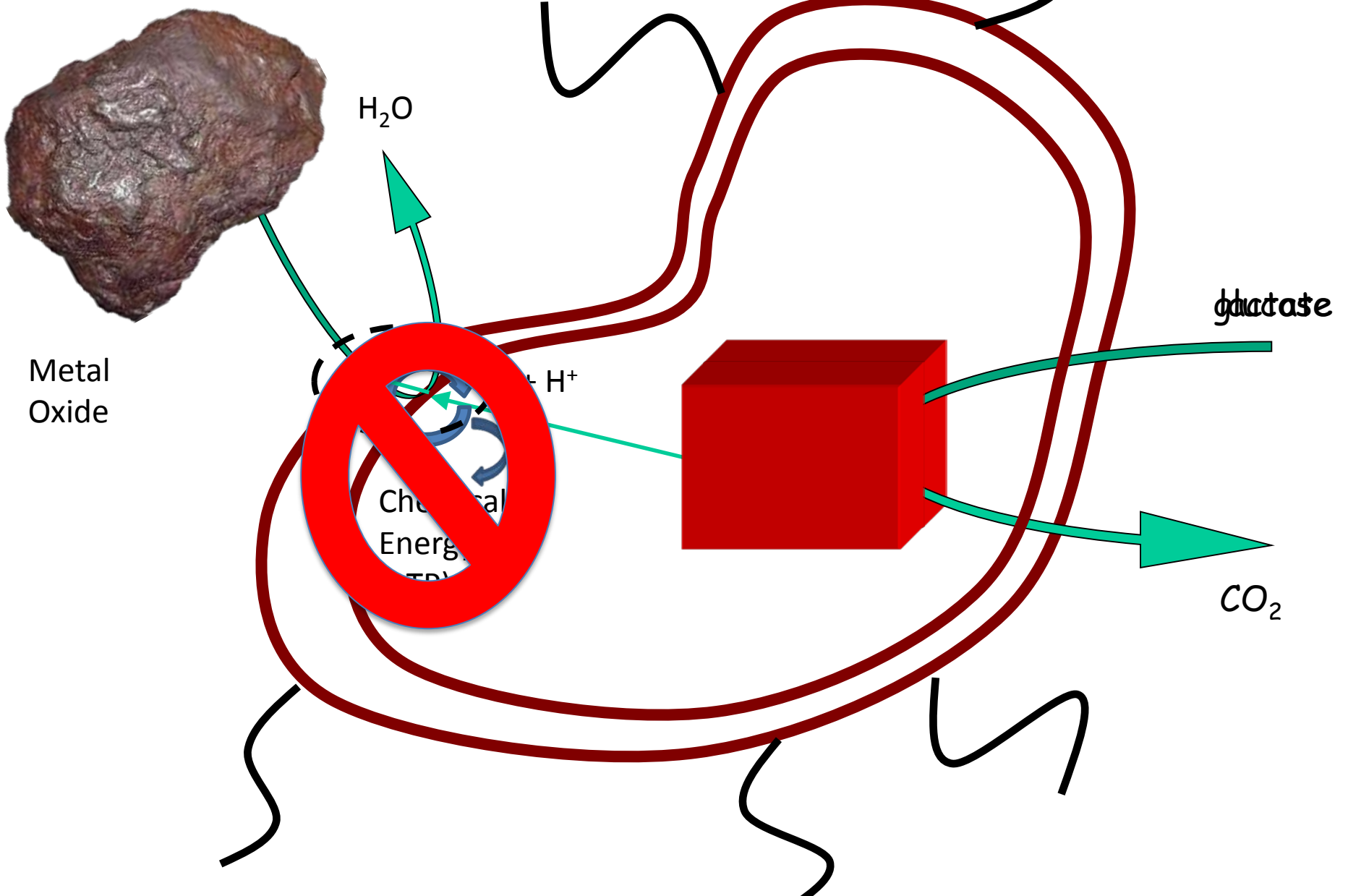
*Geobiology*

**USC**

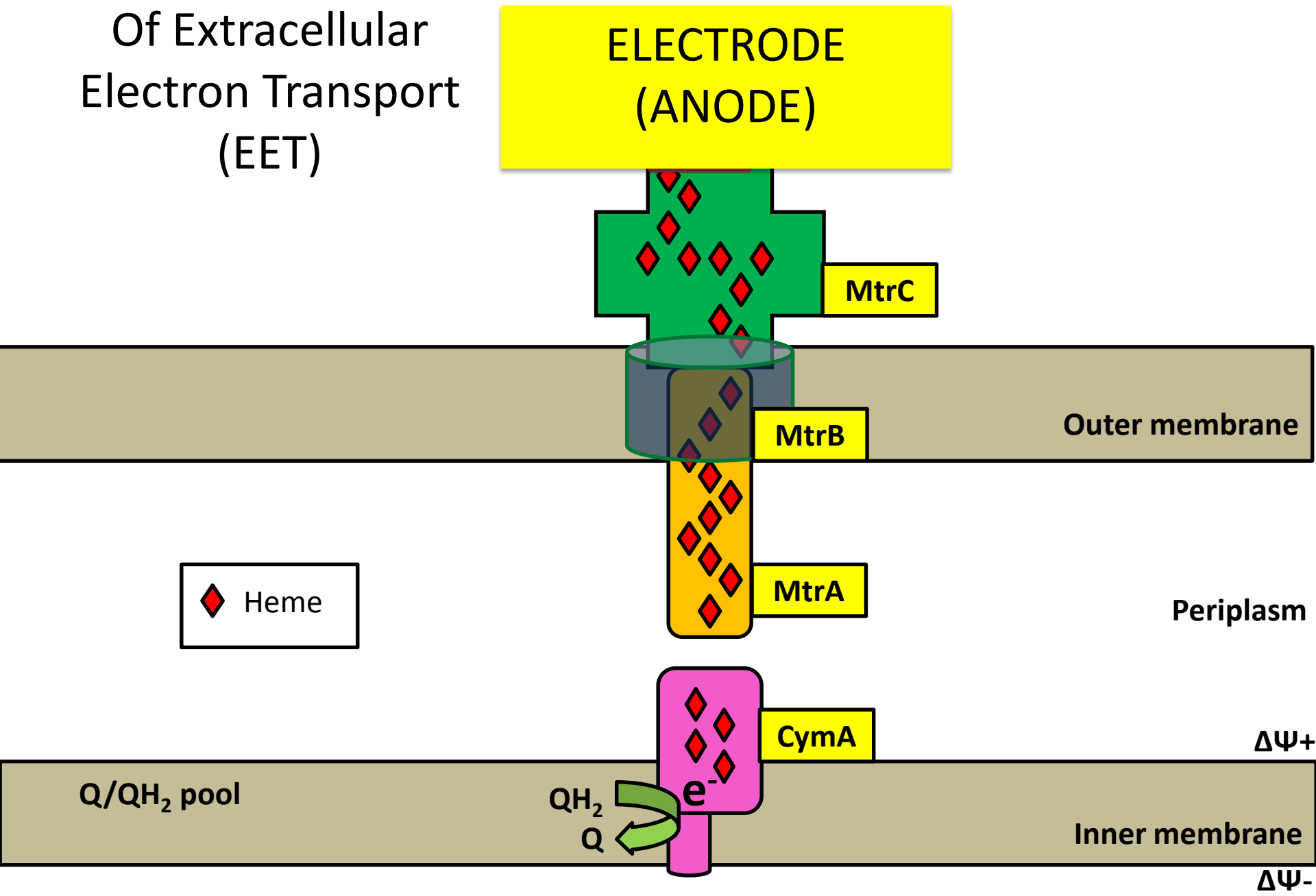
*Astrobiology*



# Bacterial respiration



The molecular machines  
Of Extracellular  
Electron Transport  
(EET)



## What does life require?:

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## What will sustain life on Earth?

**Water as a solvent:** we need more information, but with recent reports of flowing water on Mars, the stage is at least partially set.

### Energy (electron flow) -- Electron donors

Photons: light can power electron flow, but still need reductants for photosynthesis:  
On Earth, life uses  $\text{H}_2\text{S}$ ,  $\text{S}^0$ ,  $\text{H}_2$ ,  $\text{Fe}^{2+}$ , and  $\text{H}_2\text{O}$  – can't do electron flow without electrons

Inorganics: a wide array of inorganics can be used, including  $\text{H}_2$ , produced geologically can be used, with resulting reduction of  $\text{CO}_2$  to organic carbon, and/or methane.

Organics: methane is a high-energy substrate used by a number of prokaryotes both aerobically and anaerobically (the experts will be at the workshop!).

## What will sustain life on Earth?

**Energy (electron flow) -- Electron acceptors also needed**

Inorganics:

gases – oxygen & CO<sub>2</sub>

dissolved salts – NO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, etc.

**solids – Mn oxides; Fe oxides (Extracellular Electron Transport)**

EET: Well-documented for iron and manganese oxides

EET: Well-documented for soluble metals that become insoluble on reduction (U,Cr,Se, etc.)

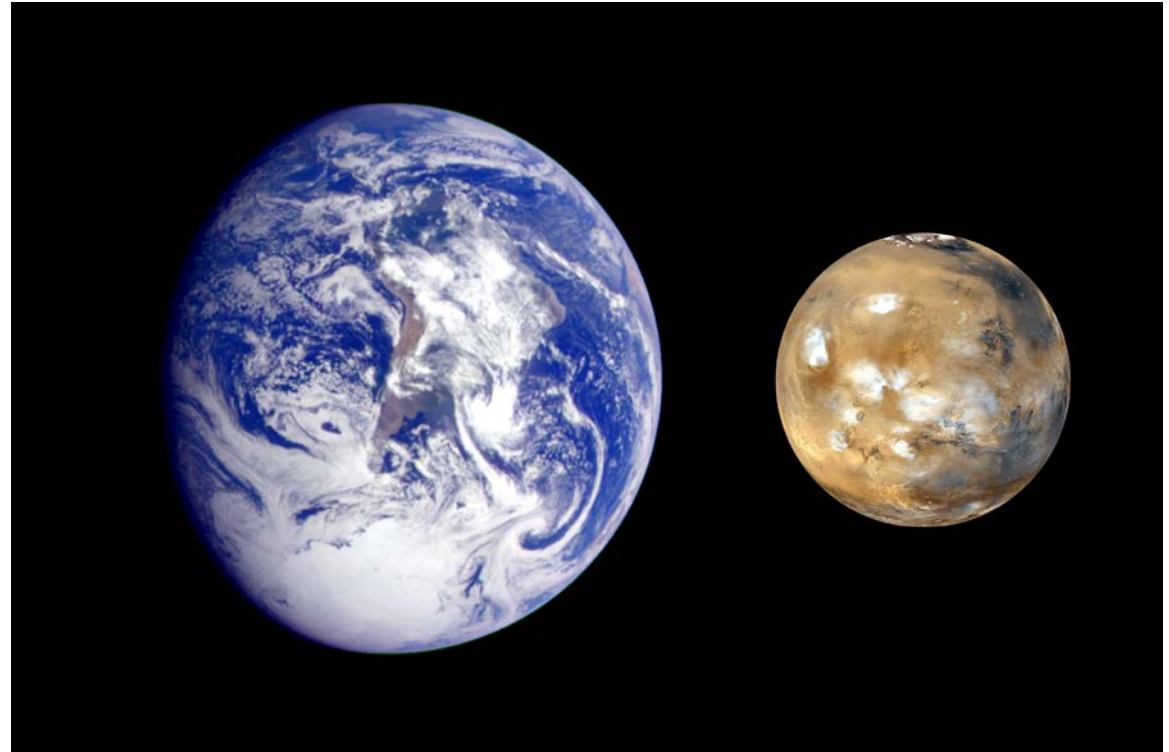
EET: Well-documented for microbes that grow on reduced solids (S<sup>0</sup>, FeS<sub>x</sub>, etc.)

EET: Well-documented for microbes that grow on electrodes

anodes: electron acceptors

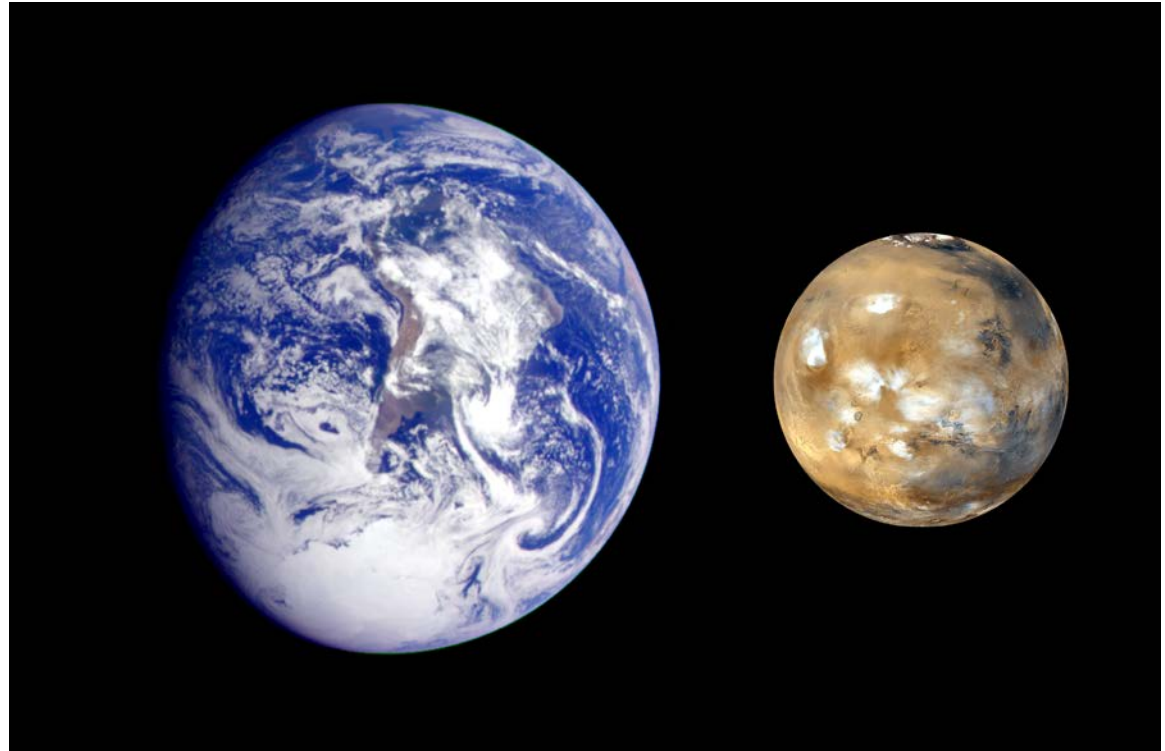
cathodes:electron donors

What can we learn by studying the Earth, that will help us in the search for life on Mars?



- 1. Life is tough – extremophiles !**
- 2. Life is tenacious (long survival times)**
- 3. Life is metabolically diverse (it eats anything, (it breathes anything !!)**
- 4. Life is intimately connected with the geosphere – minerals and rocks are the product of life's interaction with geosphere!**

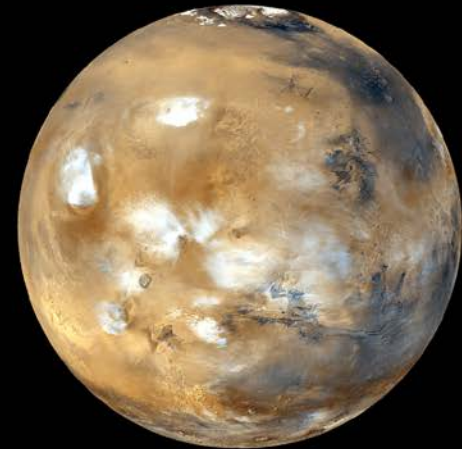
**What do we need to learn about Mars in order to ascertain whether life is (or was) present on the red planet?**



- 1. The presence over time of a suitable solvent (water)**
- 2. The types and abundances of electron donors over time.**
- 3. The types and abundances of electron acceptors over time**
- 4. Detailed analyses of Martian minerals and structural materials:**
  - a) Elemental analyses;**
  - b) organic analyses;**
  - c) stable isotopes**



**LET'S THINK ABOUT THIS TOGETHER !!**



**THANKS FOR YOUR ATTENTION  
KEN NEALSON**

