The Earth, and every living organism on it, are thermodynamically open systems

“Life” can be usefully thought of as a natural/chemical phenomenon whereby information directs work to reduce entropy

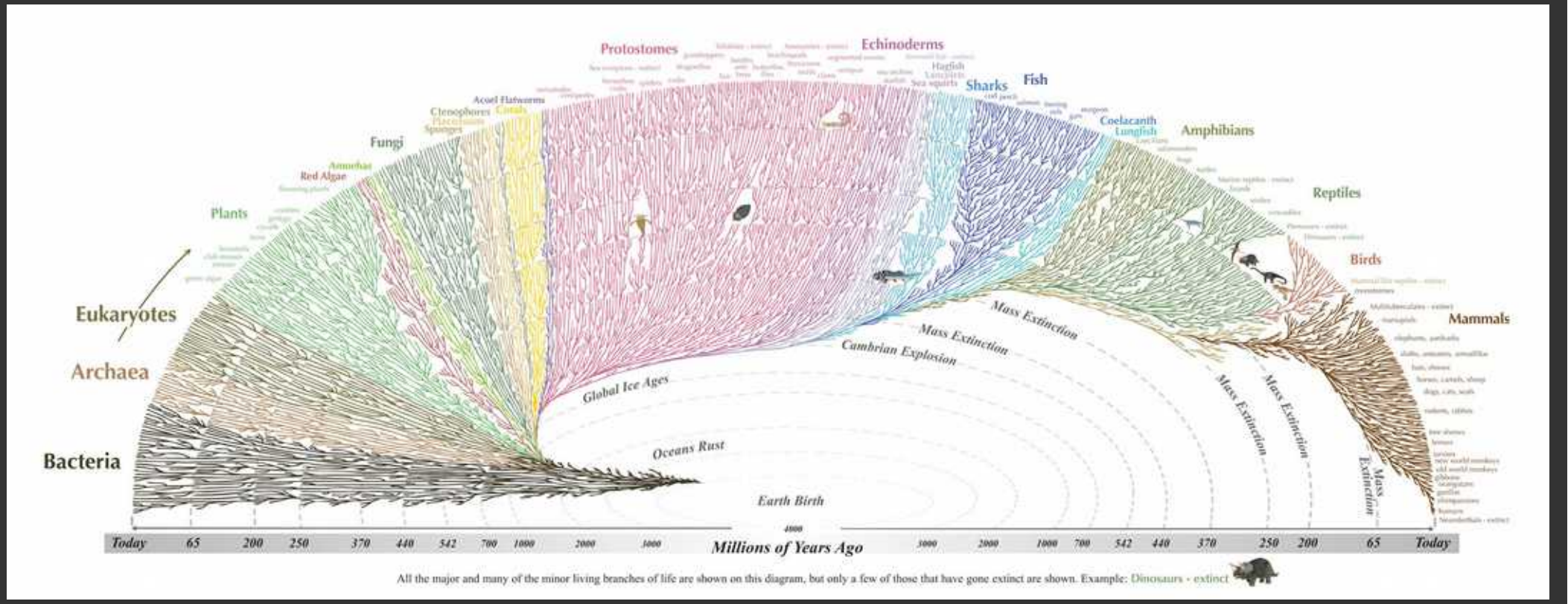
Components of metabolism
- Energy, electrons, carbon

Major nutritional groups
- Photo / Chemo
- Organo / Litho
- Auto / Hetero

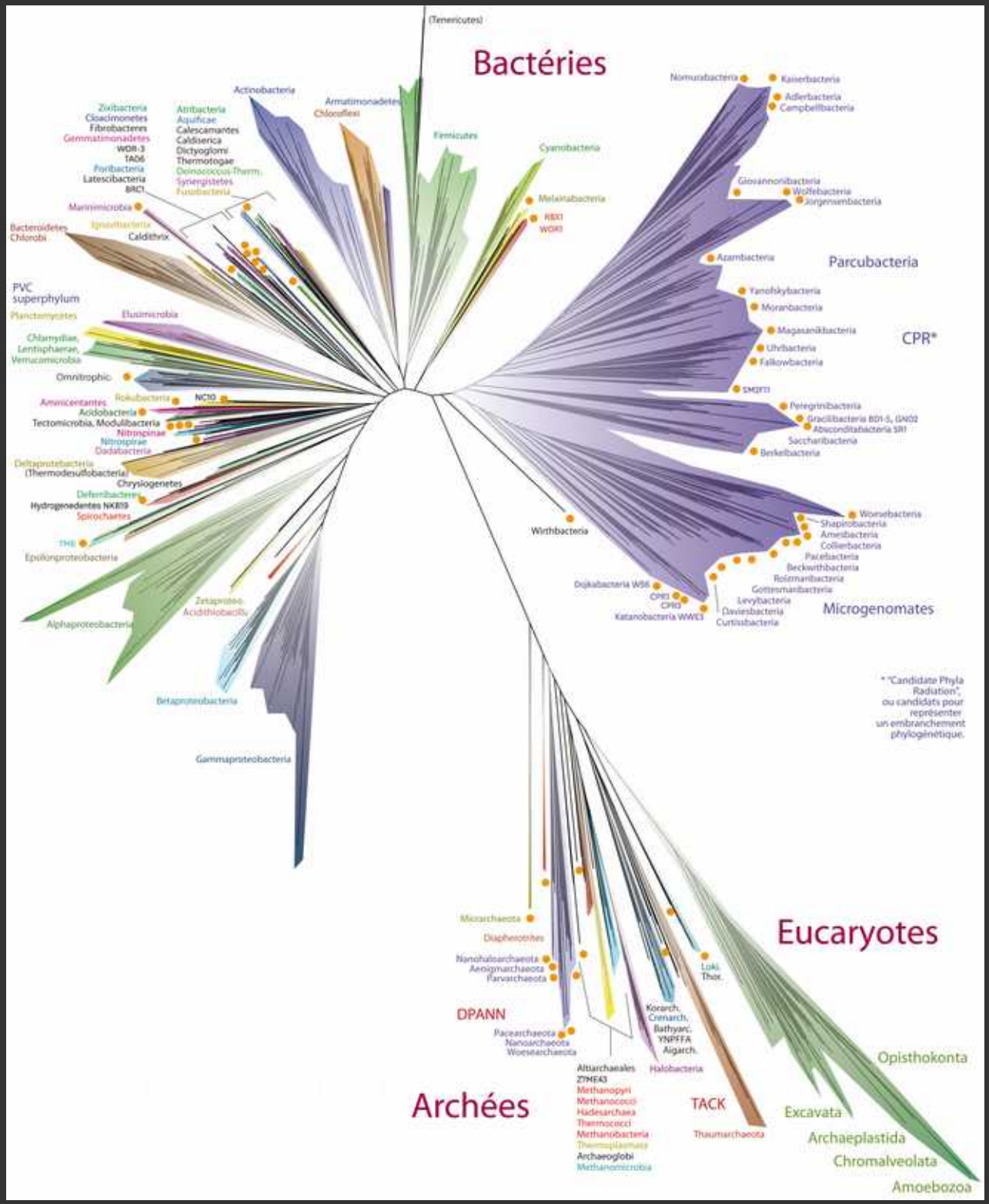
Overview of tree of life

Distribution of metabolic groups across phylogeny

A quick survey of the tree of life

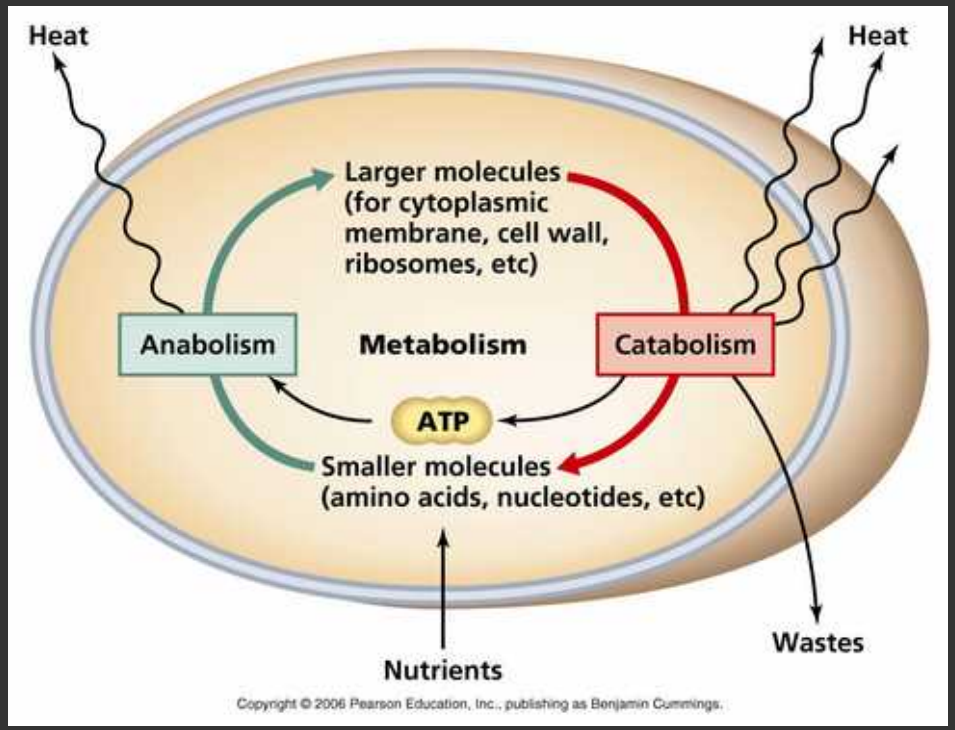


This tree is kinda dumb.


Bactéries
(Tenericutes)
Actinobacteria
Armatimonadetes
Chloroflexi
Firmicutes
Cyanobacteria
Melainabacteria
RBX1
WOR3
Zixibacteria
Cloacimonetes
Fibrobacteres
Gemmatimonadetes
WOR-3
TA06
Poribacteria
Latescibacteria
BRC1
Atribacteria
Aquificae
Calescamantes
Caldiserica
Dictyoglomi
Thermotogae
Deinococcus-Therm.
Synergistetes
Fusobacteria
Marinimicrobia
Ignavibacteria
Calditrix
Bacteroidetes
Chlorobi
PVC superphylum
Planctomycetes
Elusimicrobia
Chlamydiae,
Lentisphaerae,
Verrucomicrobia
Omnitrophic
Rokubacteria
NC10
Armicentantes
Acidobacteria
Tectomicrobia, Modulibacteria
Nitrospinae
Nitrospirae
Dadabacteria
Deltaproteobacteria
(Thermodesulfobacteria)
Chrysiogenetes
Deferribacteres
Hydrogenedentes NKB19
Spirochaetes
TM6
Epsilonproteobacteria
Alphaproteobacteria
Zetaproteo.
Acidithiobacilli
Betaproteobacteria
Gammaproteobacteria
Nomurabacteria
Kaiserbacteria
Adlerbacteria
Campbellbacteria
Giovannonibacteria
Wolfebacteria
Jorgensenbacteria
Azambacteria
Parcubacteria
Yanofskybacteria
Moranbacteria
Magasanikbacteria
Uhrbacteria
Falkowbacteria
SM2F11
CPR*
Peregrinibacteria
Gracilibacteria BD1-5, GN02
Absconditabacteria SR1
Saccharibacteria
Berkelbacteria
Wirthbacteria
Woesebacteria
Shapirobacteria
Amesbacteria
Collierbacteria
Pacebacteria
Beckwithbacteria
Roizmanbacteria
Gottesmanbacteria
Levybacteria
Daviesbacteria
Curtissbacteria
Dojkabacteria WS6
CPR1
CPR3
Katanobacteria WWE3
Microgenomates
* "Candidate Phyla Radiation", ou candidats pour représenter un embranchement phylogénétique.
Eucaryotes
Opisthokonta
Excavata
Archaeplastida
Chromalveolata
Amoebozoa
Archées
Micrarchaeota
Diapherotrites
Nanohaloarchaeota
Aenigmarchaeota
Parvarchaeota
DPANN
Pacearchaeota
Nanoarchaeota
Woesearchaeota
Altiarchaeales
ZIM E43
Methanopyri
Methanococci
Hadesarchaea
Thermococci
Methanobacteria
Thermoplasmatales
Archaeoglobi
Methanomicrobia
Korarch.
Crenarch.
Bathyarc.
YNPFFA
Aigarch.
Halobacteria
Loki.
Thor.
TACK
Thaumarchaeota

Metabolism Definition

Cellular biochemical reactions that build biomass and generate E, sum total of biochemical reactions



Metabolism

3 components of metabolism:

Source of energy

Source of reducing equivalents (electrons)

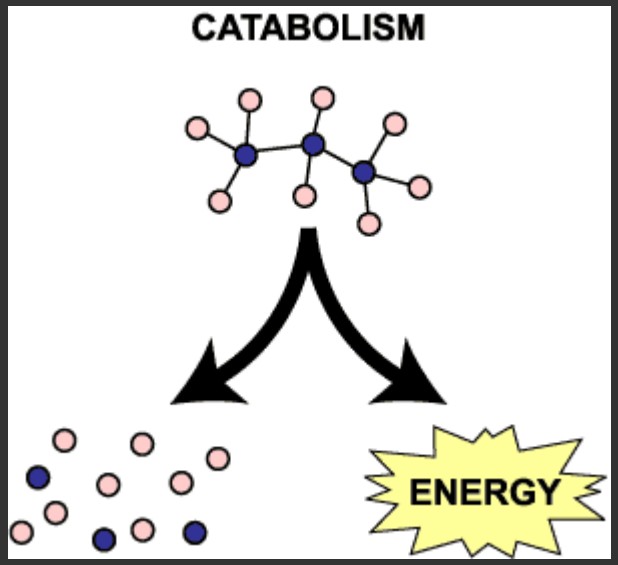
Source of carbon

Reactions either yield energy, exergonic or consume energy, endergonic

Both types occur in metabolism

Biosynthesis results from endergonic reactions

Catabolism

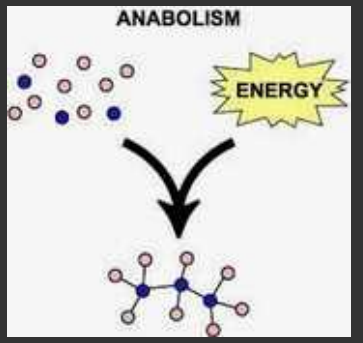


Dismantling of organic substrates
Obtaining E from break down of E-rich organic compounds
(Chemotrophs)

Other organisms use inorganic compounds to obtain E
(also chemotrophs)

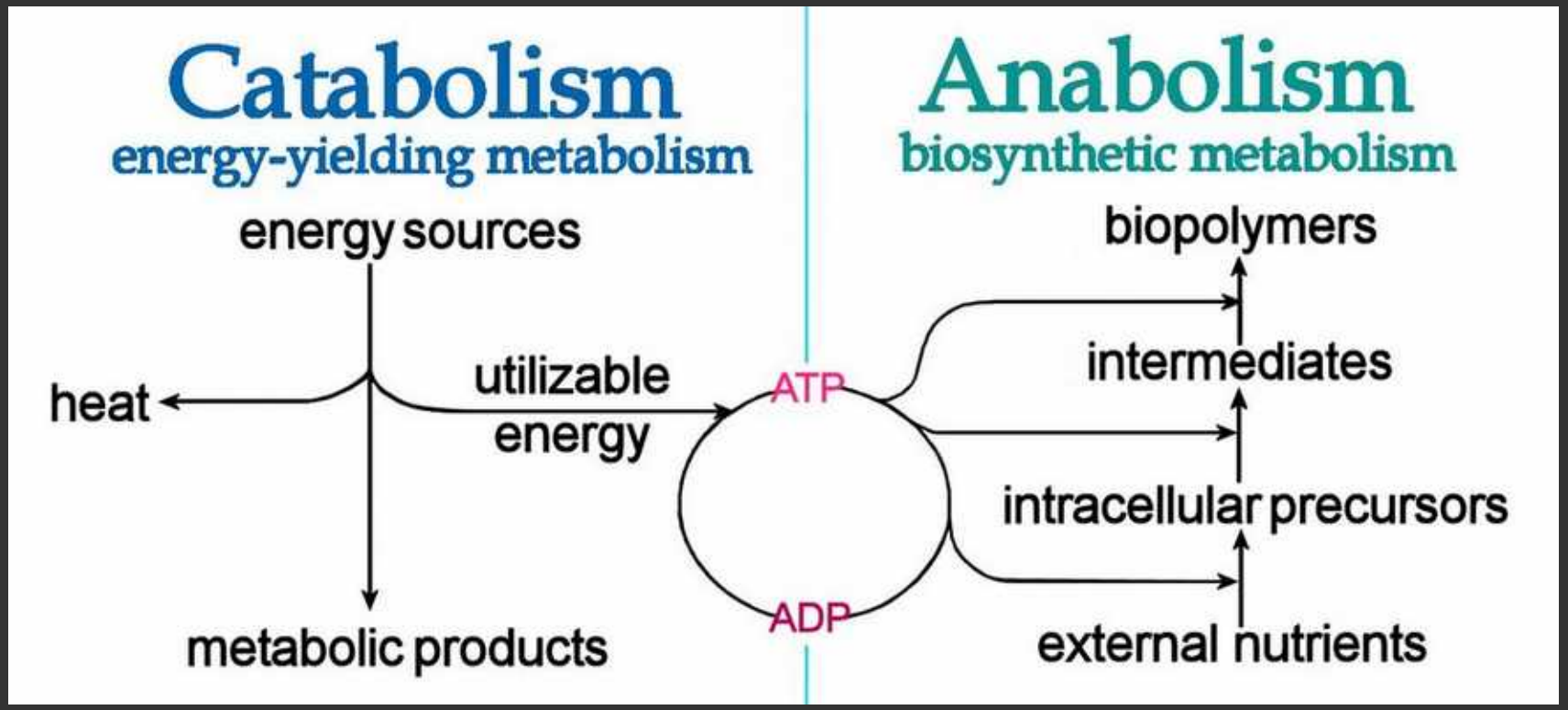
Other organisms use light as E source
(i.e., phototrophs)

Anabolism



Processes that build up biomass (growth)

Incorporating C into biological molecules



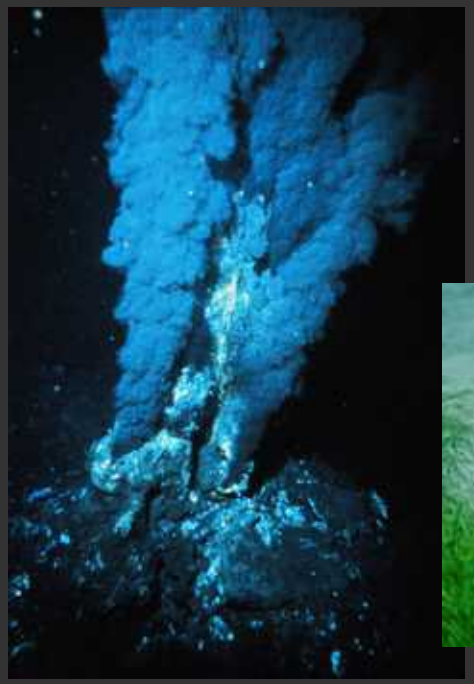
Sources of Energy:

Chemotrophs -

Obtain energy from organic or inorganic molecules to catalyze reactions

Phototrophs -

Use solar energy to catalyze reactions



Sources of reducing power:

- Organotrophs

Organisms that obtain reducing equivalents (i.e., stored electrons) from organic compounds (usually heterotrophs also)

Example: PO_3^{3-} (phosphite) → PO_4^{3-} (phosphate) + e^-

- Lithotrophs

Organisms that obtain reducing equivalents from inorganic compounds (usually autotrophs also)

Example: $2H_2O$ (water) → $O_2 + 2H_2 + 2e^-$

Sources of carbon:

Autotrophs - Inorganic carbon source (Primary producers, “fix” carbon)

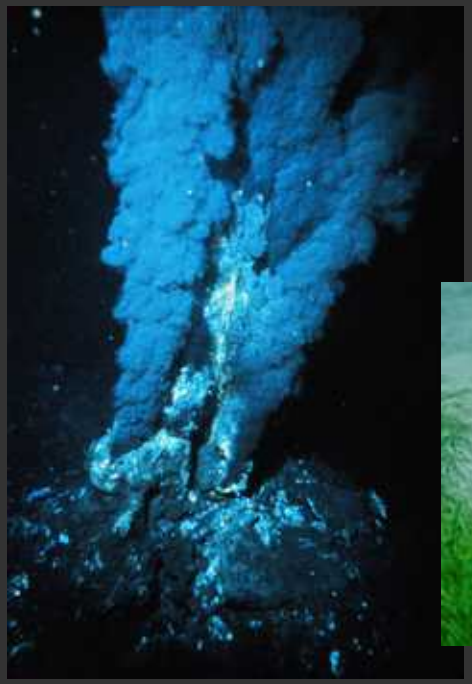
CO_2 / H_2CO_3

Heterotrophs – Organic carbon source

Usually chemoorganotrophs

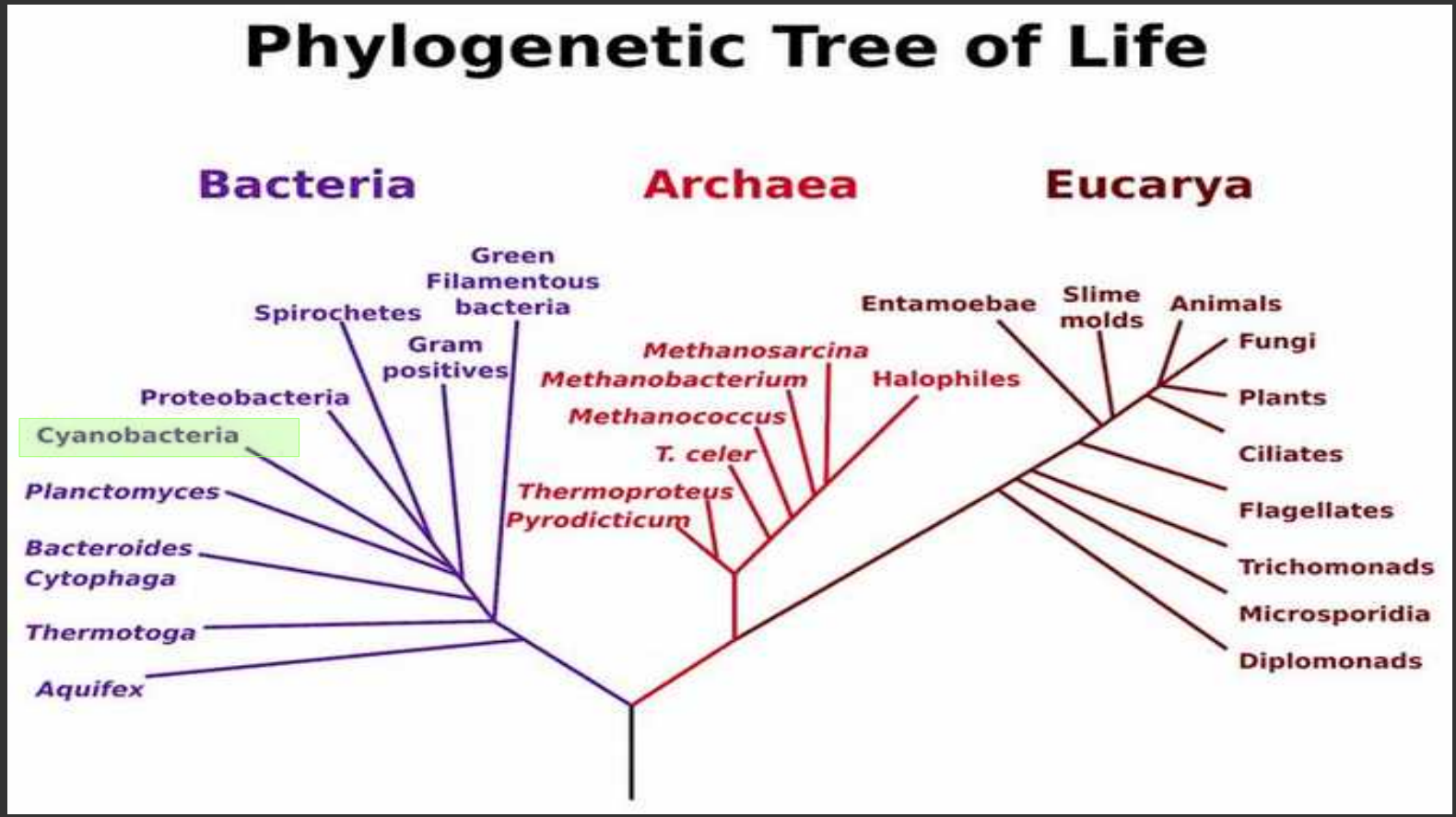
Obtain energy from oxidation of organic molecules

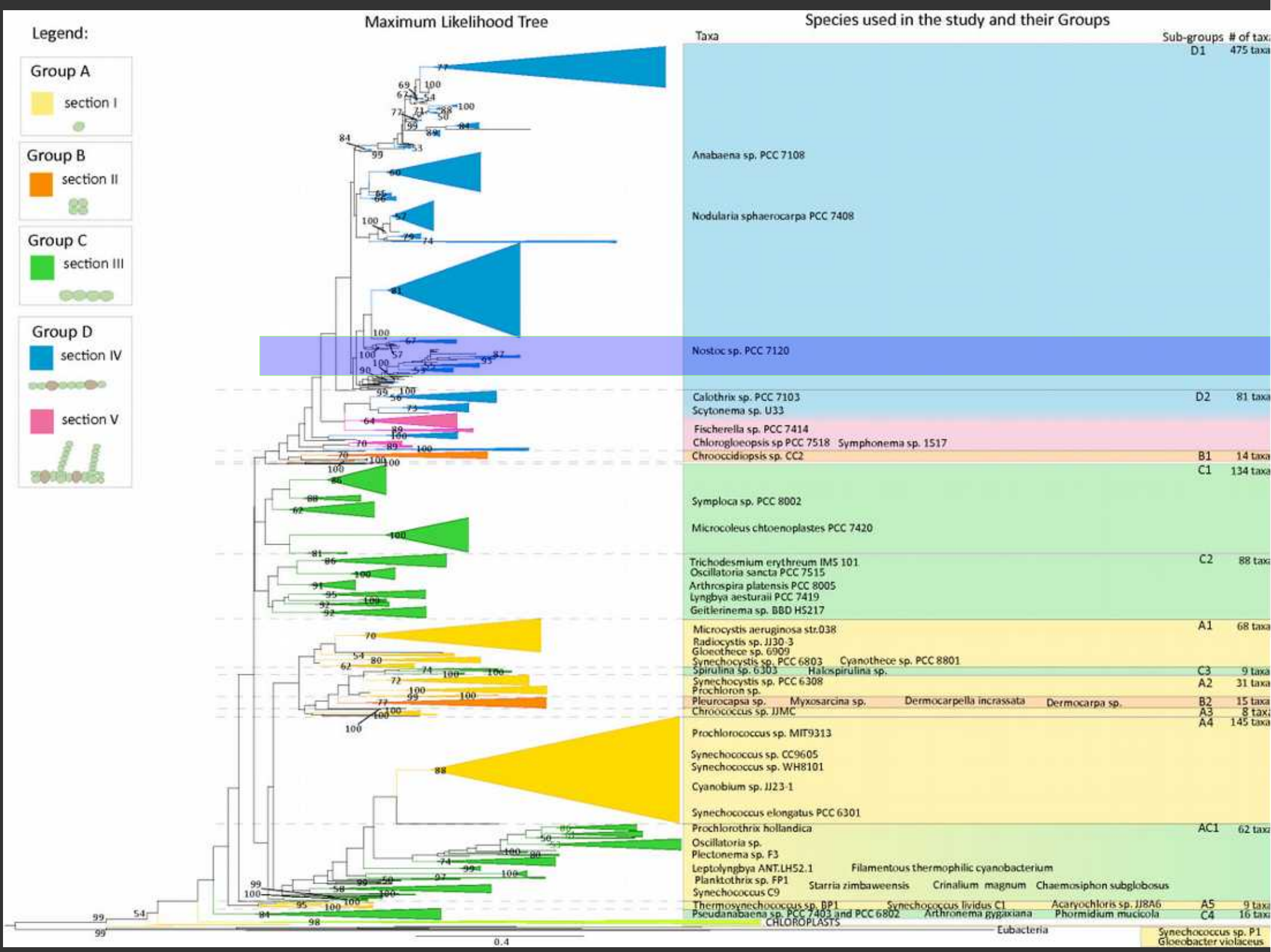
Use these products for growth (anabolic metabolism)



Energy source	Oxidizing donor source	Carbon source	Name	Examples
Sun Light *Photo-*	Organic *-organo-*	Organic *-heterotroph*	Photoorganoheterotroph	Some bacteria (*Rhodobacter*)
		Carbon dioxide *-autotroph*	Photoorganoautotroph	???
	Inorganic *-litho-**	Organic *-heterotroph*	Photolithoheterotroph	*Halobacterium* in Great Salt Lake, yo!
		Carbon dioxide *-autotroph*	Photolithoautotroph	Some bacteria (blue green algae), some eukaryotes (eukaryotic algae, land plants). Photosynthesis.
Breaking Chemical Compounds *Chemo-*	Organic *-organo-*	Organic *-heterotroph*	Chemoorganoheterotroph	Some eukaryotes (heterotrophic protists, fungi, animals)
		Carbon dioxide *-autotroph*	Chemoorganoautotroph	Some archaea (anaerobic methanotrophic archaea).[8] Chemosynthesis.
	Inorganic *-litho-**	Organic *-heterotroph*	Chemolithoheterotroph	Some bacteria (*Oceanithermus profundus*)[9]
		Carbon dioxide *-autotroph*	Chemolithoautotroph	Some bacteria (*Nitrobacter*, Methanobacteria). Chemosynthesis.

Wikipedia: “Primary nutritional groups”


Phylogenetic Tree of Life
Bacteria
Archaea
Eucarya
Green
Filamentous
bacteria
Spirochetes
Gram
positives
Proteobacteria
Cyanobacteria
Planctomyces
Bacteroides
Cytophaga
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
T. celer
Thermoproteus
Pyrodicticum
Entamoebae
Slime
molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads


Legend:
Group A
section I
Group B
section II
Group C
section III
Group D
section IV
section V
Maximum Likelihood Tree
Species used in the study and their Groups
Taxa
Sub-groups
# of taxa
D1
475 taxa
Anabaena sp. PCC 7108
Nodularia sphaerocarpa PCC 7408
Nostoc sp. PCC 7120
Calothrix sp. PCC 7103
Scytonema sp. U33
D2
81 taxa
Fischerella sp. PCC 7414
Chlorogloeopsis sp PCC 7518
Symphonema sp. 1517
Chrooccidiopsis sp. CC2
B1
14 taxa
C1
134 taxa
Symploca sp. PCC 8002
Microcoleus chtoenoplastes PCC 7420
Trichodesmium erythreum IMS 101
Oscillatoria sancta PCC 7515
Arthrospira platensis PCC 8005
Lyngbya aesturaii PCC 7419
Geitlerinema sp. BBD HS217
C2
88 taxa
Microcystis aeruginosa str.038
Radiocystis sp. JJ30-3
Gloeothece sp. 6909
Synechocystis sp. PCC 6803
Cyanothece sp. PCC 8801
A1
68 taxa
Spirulina sp. 6303
Halospirulina sp.
C3
9 taxa
Synechocystis sp. PCC 6308
Prochloron sp.
A2
31 taxa
Pleurocapsa sp.
Myxosarcina sp.
Dermocarpella incrassata
Dermocarpa sp.
B2
15 taxa
Chroococcus sp. JJMC
A3
8 taxa
A4
145 taxa
Prochlorococcus sp. MIT9313
Synechococcus sp. CC9605
Synechococcus sp. WH8101
Cyanobium sp. JJ23-1
Synechococcus elongatus PCC 6301
Prochlorothrix hollandica
AC1
62 taxa
Oscillatoria sp.
Plectonema sp. F3
Leptolyngbya ANT.LH52.1
Filamentous thermophilic cyanobacterium
Planktothrix sp. FP1
Starria zimbaweensis
Crinalium magnum
Chaemosiphon subglobosus
Synechococcus C9
Thermosynechococcus sp. BP1
Synechococcus lividus C1
Acaryochloris sp. JJ8A6
A5
9 taxa
Pseudanabaena sp. PCC 7403 and PCC 6802
Arthronema gygaxiana
Phormidium mucicola
C4
16 taxa
CHLOROPLASTS
Eubacteria
Synechococcus sp. P1
Gloeobacter violaceus
0.4

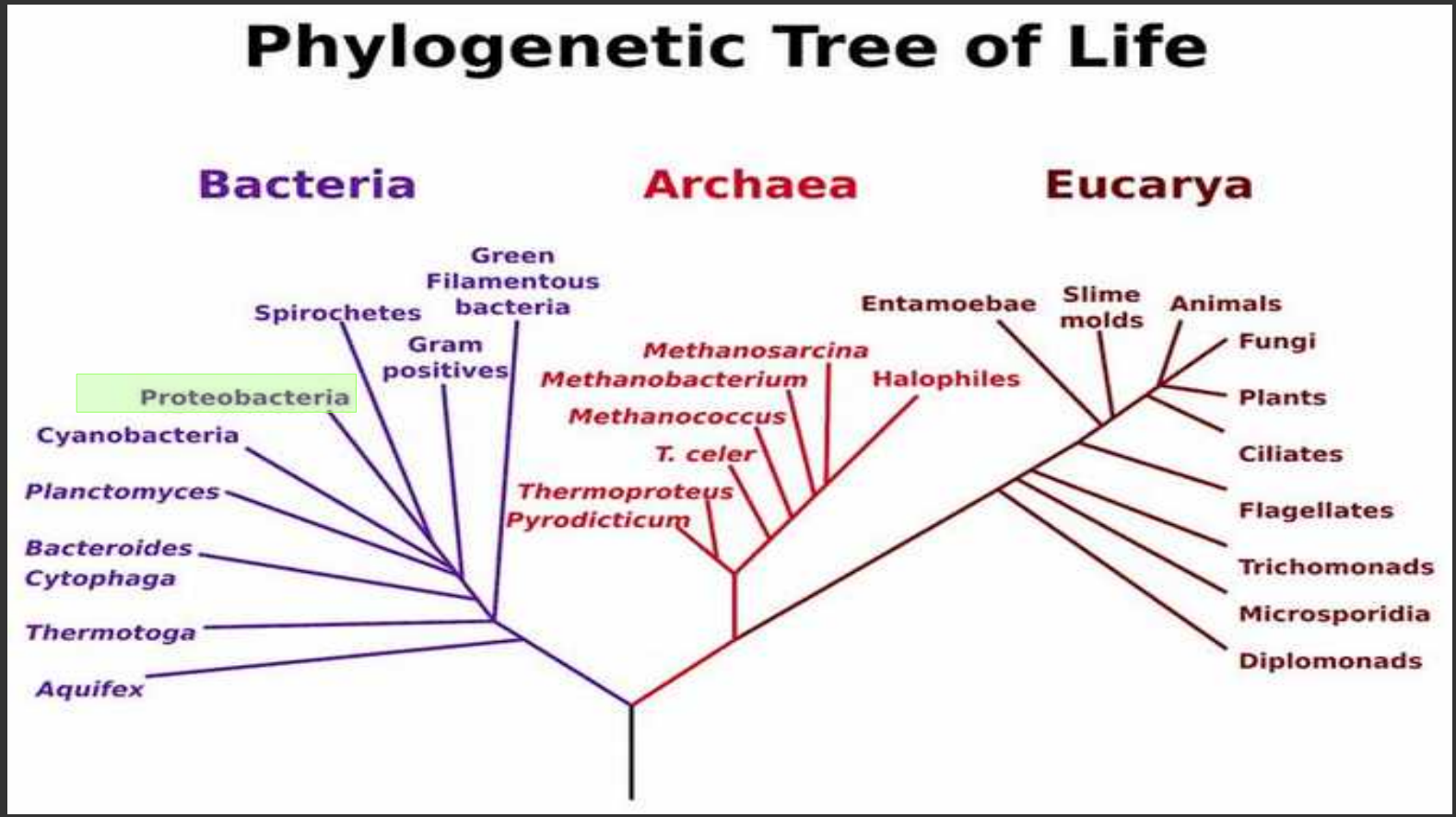
Nostoc sp.

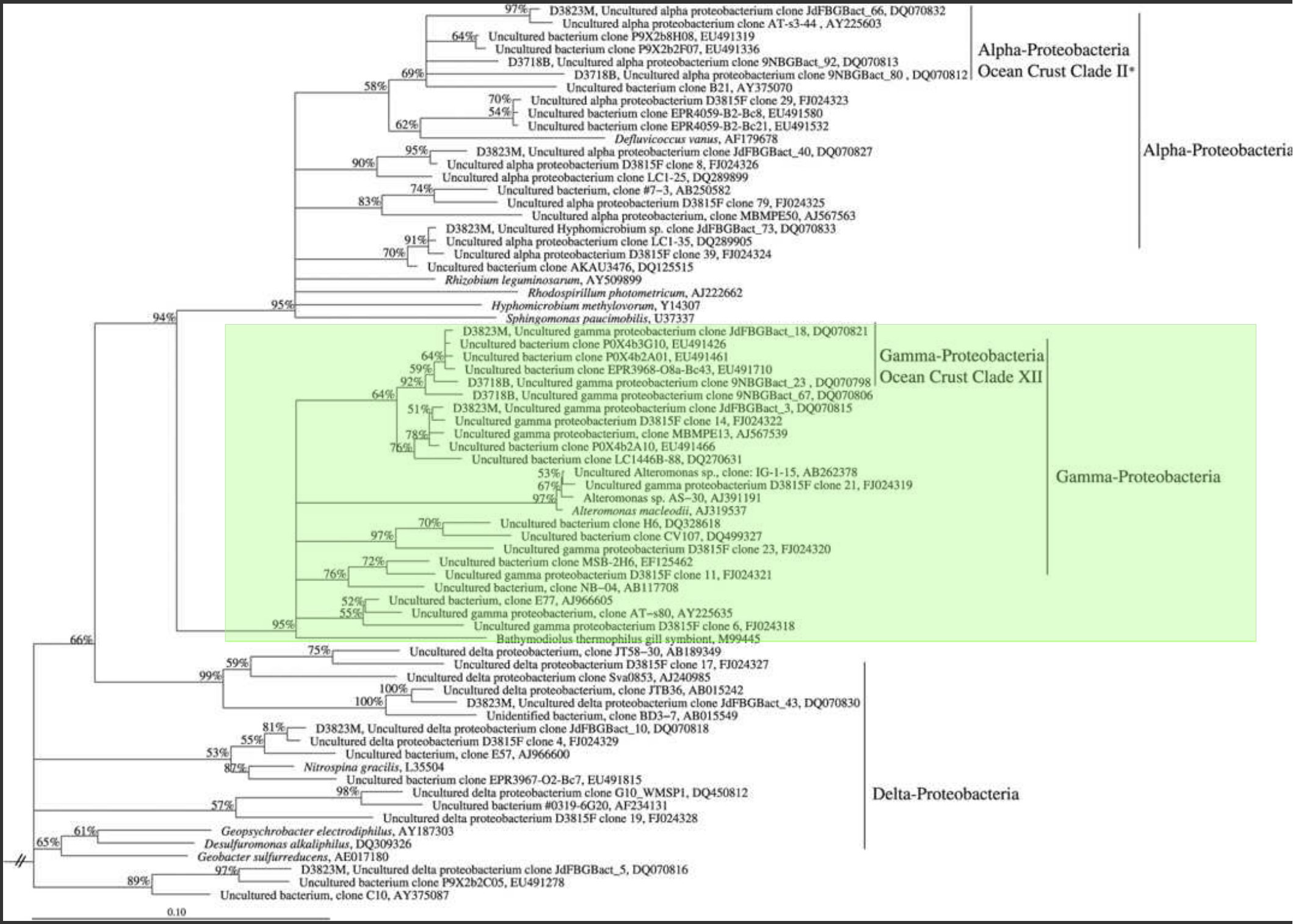
H_2O is reducing agent
What is product of photosynthesis?

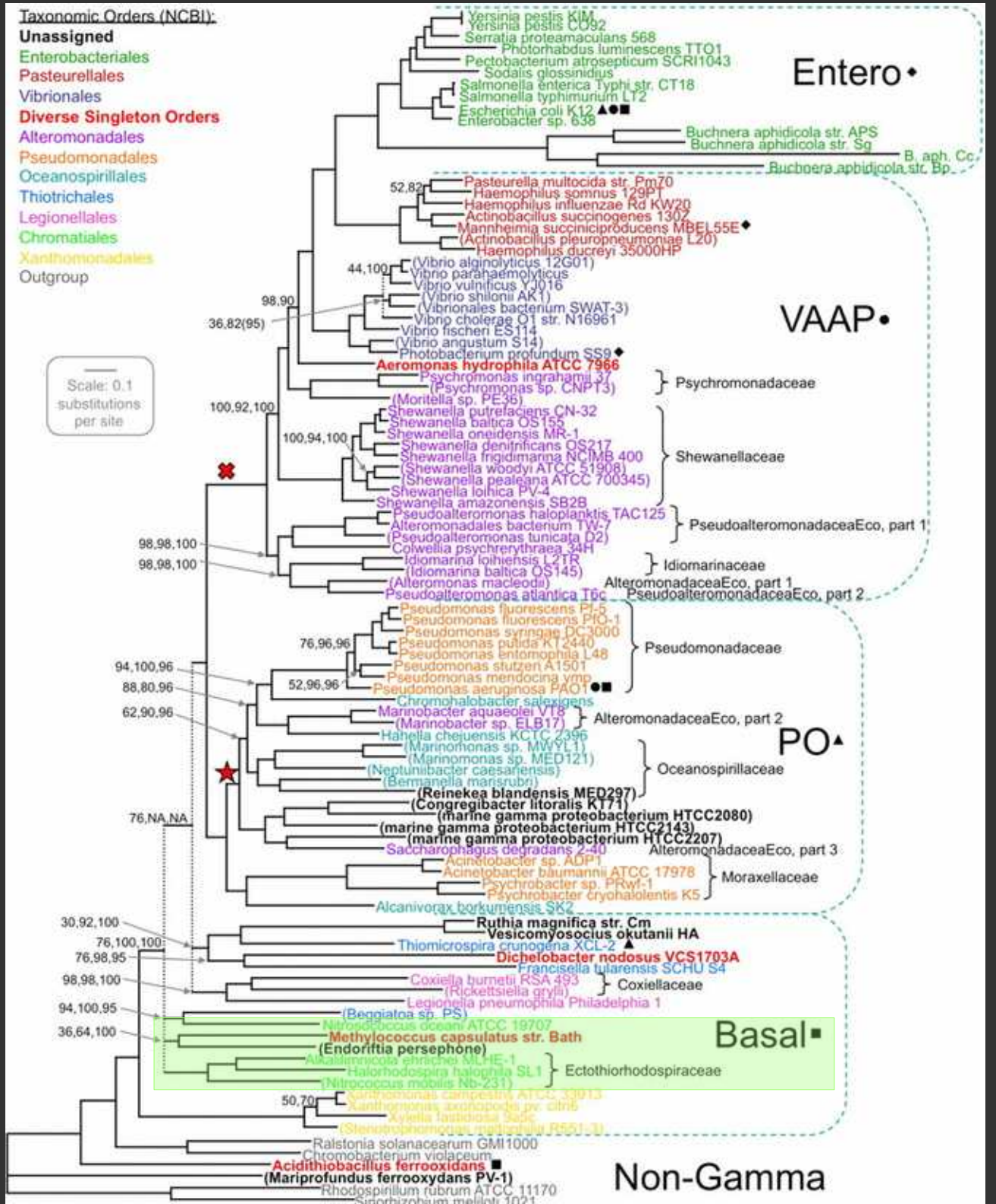
Can fix nitrogen in special cells

Carbon from CO_2

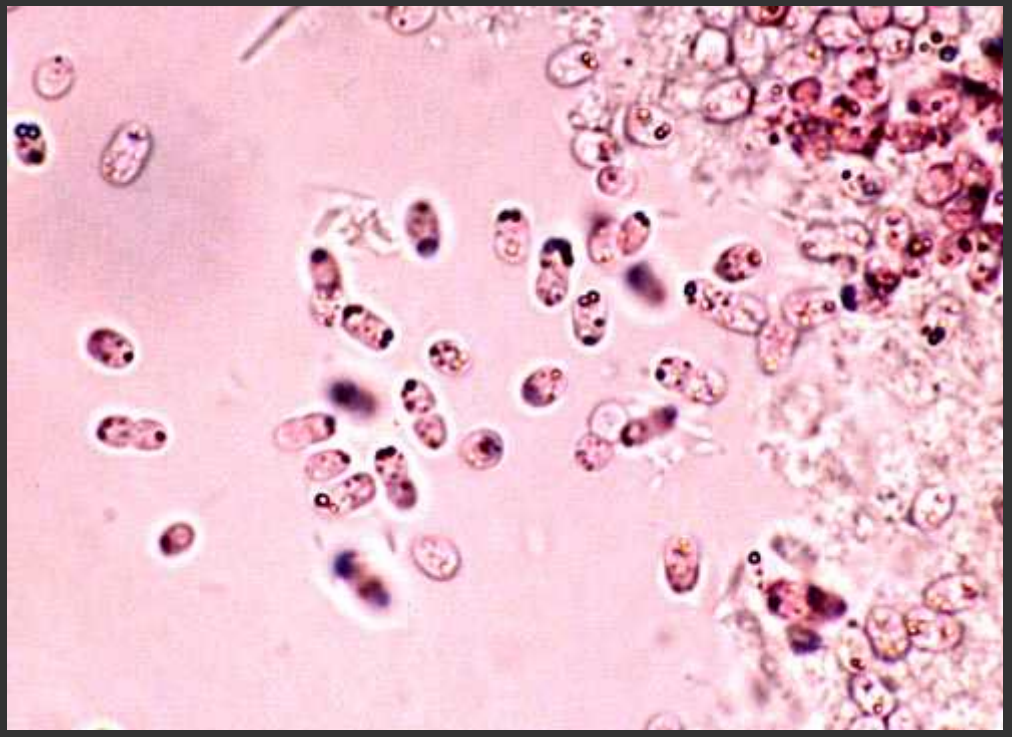
Photo-litho-auto-trophic

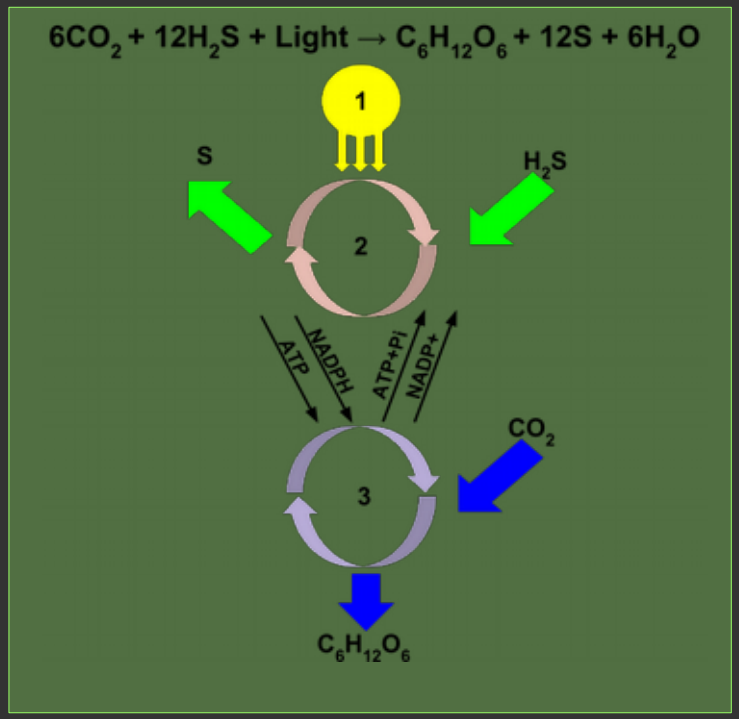

Phylogenetic Tree of Life
Bacteria
Archaea
Eucarya
Green
Filamentous
bacteria
Spirochetes
Gram
positives
Proteobacteria
Cyanobacteria
Planctomyces
Bacteroides
Cytophaga
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
T. celer
Thermoproteus
Pyrodicticum
Entamoebae
Slime
molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads


D3823M, Uncultured alpha proteobacterium clone JdFBGBact_66, DQ070832
Uncultured alpha proteobacterium clone AT-s3-44 , AY225603
Uncultured bacterium clone P9X2b8H08, EU491319
Uncultured bacterium clone P9X2b2F07, EU491336
D3718B, Uncultured alpha proteobacterium clone 9NBGBact_92, DQ070813
D3718B, Uncultured alpha proteobacterium clone 9NBGBact_80 , DQ070812
Uncultured bacterium clone B21, AY375070
Uncultured alpha proteobacterium D3815F clone 29, FJ024323
Uncultured bacterium clone EPR4059-B2-Bc8, EU491580
Uncultured bacterium clone EPR4059-B2-Bc21, EU491532
Defluvicoccus vanus, AF179678
D3823M, Uncultured alpha proteobacterium clone JdFBGBact_40, DQ070827
Uncultured alpha proteobacterium D3815F clone 8, FJ024326
Uncultured alpha proteobacterium clone LC1-25, DQ289899
Uncultured bacterium, clone #7-3, AB250582
Uncultured alpha proteobacterium D3815F clone 79, FJ024325
Uncultured alpha proteobacterium, clone MBMPE50, AJ567563
D3823M, Uncultured Hyphomicrobium sp. clone JdFBGBact_73, DQ070833
Uncultured alpha proteobacterium clone LC1-35, DQ289905
Uncultured alpha proteobacterium D3815F clone 39, FJ024324
Uncultured bacterium clone AKAU3476, DQ125515
Rhizobium leguminosarum, AY509899
Rhodospirillum photometricum, AJ222662
Hyphomicrobium methylovorum, Y14307
Sphingomonas paucimobilis, U37337
Alpha-Proteobacteria
Ocean Crust Clade II*
Alpha-Proteobacteria
D3823M, Uncultured gamma proteobacterium clone JdFBGBact_18, DQ070821
Uncultured bacterium clone P0X4b3G10, EU491426
Uncultured bacterium clone P0X4b2A01, EU491461
Uncultured bacterium clone EPR3968-O8a-Bc43, EU491710
D3718B, Uncultured gamma proteobacterium clone 9NBGBact_23 , DQ070798
D3718B, Uncultured gamma proteobacterium clone 9NBGBact_67, DQ070806
D3823M, Uncultured gamma proteobacterium clone JdFBGBact_3, DQ070815
Uncultured gamma proteobacterium D3815F clone 14, FJ024322
Uncultured gamma proteobacterium, clone MBMPE13, AJ567539
Uncultured bacterium clone P0X4b2A10, EU491466
Uncultured bacterium clone LC1446B-88, DQ270631
Uncultured Alteromonas sp., clone: IG-1-15, AB262378
Uncultured gamma proteobacterium D3815F clone 21, FJ024319
Alteromonas sp. AS-30, AJ391191
Alteromonas macleodii, AJ319537
Uncultured bacterium clone H6, DQ328618
Uncultured bacterium clone CV107, DQ499327
Uncultured gamma proteobacterium D3815F clone 23, FJ024320
Uncultured bacterium clone MSB-2H6, EF125462
Uncultured gamma proteobacterium D3815F clone 11, FJ024321
Uncultured bacterium, clone NB-04, AB117708
Uncultured bacterium, clone E77, AJ966605
Uncultured gamma proteobacterium, clone AT-s80, AY225635
Uncultured gamma proteobacterium D3815F clone 6, FJ024318
Bathymodiolus thermophilus gill symbiont, M99445
Gamma-Proteobacteria
Ocean Crust Clade XII
Gamma-Proteobacteria
Uncultured delta proteobacterium, clone JT58-30, AB189349
Uncultured delta proteobacterium D3815F clone 17, FJ024327
Uncultured delta proteobacterium clone Sva0853, AJ240985
Uncultured delta proteobacterium, clone JTB36, AB015242
D3823M, Uncultured delta proteobacterium clone JdFBGBact_43, DQ070830
Unidentified bacterium, clone BD3-7, AB015549
D3823M, Uncultured delta proteobacterium clone JdFBGBact_10, DQ070818
Uncultured delta proteobacterium D3815F clone 4, FJ024329
Uncultured bacterium, clone E57, AJ966600
Nitrospina gracilis, L35504
Uncultured bacterium clone EPR3967-O2-Bc7, EU491815
Uncultured delta proteobacterium clone G10_WMSP1, DQ450812
Uncultured bacterium #0319-6G20, AF234131
Uncultured delta proteobacterium D3815F clone 19, FJ024328
Geopsychrobacter electrodiphilus, AY187303
Desulfuromonas alkaliphilus, DQ309326
Geobacter sulfurreducens, AE017180
Delta-Proteobacteria
D3823M, Uncultured delta proteobacterium clone JdFBGBact_5, DQ070816
Uncultured bacterium clone P9X2b2C05, EU491278
Uncultured bacterium, clone C10, AY375087
0.10


Taxonomic Orders (NCBI):
Unassigned
Enterobacteriales
Pasteurellales
Vibrionales
Diverse Singleton Orders
Alteromonadales
Pseudomonadales
Oceanospirillales
Thiotrichales
Legionellales
Chromatiales
Xanthomonadales
Outgroup
Scale: 0.1 substitutions per site
Yersinia pestis KIM
Yersinia pestis CO92
Serratia proteamaculans 568
Photorhabdus luminescens TTO1
Pectobacterium atrosepticum SCRI1043
Sodalis glossinidius
Salmonella enterica Typhi str. CT18
Salmonella typhimurium LT2
Escherichia coli K12
Enterobacter sp. 638
Entero
Buchnera aphidicola str. APS
Buchnera aphidicola str. Sg
B. aph. Cc
Buchnera aphidicola str. Bp
52,82
Pasteurella multocida str. Pm70
Haemophilus somnus 129PT
Haemophilus influenzae Rd KW20
Actinobacillus succinogenes 130Z
Mannheimia succiniciproducens MBEL55E
(Actinobacillus pleuropneumoniae L20)
Haemophilus ducreyi 35000HP
44,100
(Vibrio alginolyticus 12G01)
Vibrio parahaemolyticus
Vibrio vulnificus YJ016
98,90
(Vibrio shilonii AK1)
(Vibrionales bacterium SWAT-3)
36,82(95)
Vibrio cholerae O1 str. N16961
Vibrio fischeri ES114
(Vibrio angustum S14)
Photobacterium profundum SS9
VAAP
Aeromonas hydrophila ATCC 7966
Psychromonas ingrahamii 37
(Psychromonas sp. CNPT3)
Psychromonadaceae
(Moritella sp. PE36)
100,92,100
Shewanella putrefaciens CN-32
Shewanella baltica OS155
Shewanella oneidensis MR-1
100,94,100
Shewanella denitrificans OS217
Shewanella frigidimarina NCIMB 400
(Shewanella woodyi ATCC 51908)
(Shewanella pealeana ATCC 700345)
Shewanella loihica PV-4
Shewanella amazonensis SB2B
Shewanella
Pseudoalteromonas haloplanktis TAC125
Alteromonadales bacterium TW-7
(Pseudoalteromonas tunicata D2)
PseudoalteromonadaceaEco, part 1
Colwellia psychrerythraea 34H
98,98,100
Idiomarina loihiensis L2TR
98,98,100
(Idiomarina baltica OS145)
Idiomarinaceae
(Alteromonas macleodii)
AlteromonadaceaEco, part 1
Pseudoalteromonas atlantica T6c
PseudoalteromonadaceaEco, part 2
Pseudomonas fluorescens Pf-5
Pseudomonas fluorescens Pf0-1
76,96,96
Pseudomonas syringae DC3000
Pseudomonas putida KT2440
Pseudomonas entomophila L48
Pseudomonas stutzeri A1501
Pseudomonas
94,100,96
Pseudomonas mendocina ymp
52,96,96
Pseudomonas aeruginosa PAO1
88,80,96
Chromohalobacter salexigens
62,90,96
Marinobacter aquaeolei VT8
(Marinobacter sp. ELB17)
AlteromonadaceaEco, part 2
Hahella chejuensis KCTC 2396
PO
(Marinomonas sp. MWYL1)
(Marinomonas sp. MED121)
(Neptuniibacter caesariensis)
(Bermanella marisrubri)
Oceanospirillaceae
(Reinekea blandensis MED297)
(Congregibacter litoralis KT71)
76,NA,NA
(marine gamma proteobacterium HTCC2080)
(marine gamma proteobacterium HTCC2143)
(marine gamma proteobacterium HTCC2207)
Saccharophagus degradans 2-40
AlteromonadaceaEco, part 3
Acinetobacter sp. ADP1
Acinetobacter baumannii ATCC 17978
Psychrobacter sp. PRwf-1
Moraxellaceae
Psychrobacter cryohalolentis K5
Alcanivorax borkumensis SK2
30,92,100
Ruthia magnifica str. Cm
Vesicomyosocius okutanii HA
76,100,100
Thiomicrospira crunogena XCL-2
76,98,95
Dichelobacter nodosus VCS1703A
Francisella tularensis SCHU S4
98,98,100
Coxiella burnetii RSA 493
(Rickettsiella grylli)
Coxiellaceae
Legionella pneumophila Philadelphia 1
94,100,95
(Beggiatoa sp. PS)
36,64,100
Nitrosococcus oceani ATCC 19707
Methylococcus capsulatus str. Bath
Basal
(Endoriftia persephone)
Alkalilimnicola ehrlichei MLHE-1
Halorhodospira halophila SL1
Ectothiorhodospiraceae
(Nitrococcus mobilis Nb-231)
50,70
Xanthomonas campestris ATCC 33913
Xanthomonas axonopodis pv. citri
Xylella fastidiosa 9a5c
(Stenotrophomonas maltophilia R551-3)
Ralstonia solanacearum GMI1000
Chromobacterium violaceum
Acidithiobacillus ferrooxidans
(Mariprofundus ferrooxydans PV-1)
Rhodospirillum rubrum ATCC 11170
Non-Gamma

Purple Sulfur Bacteria (Chromatiales)

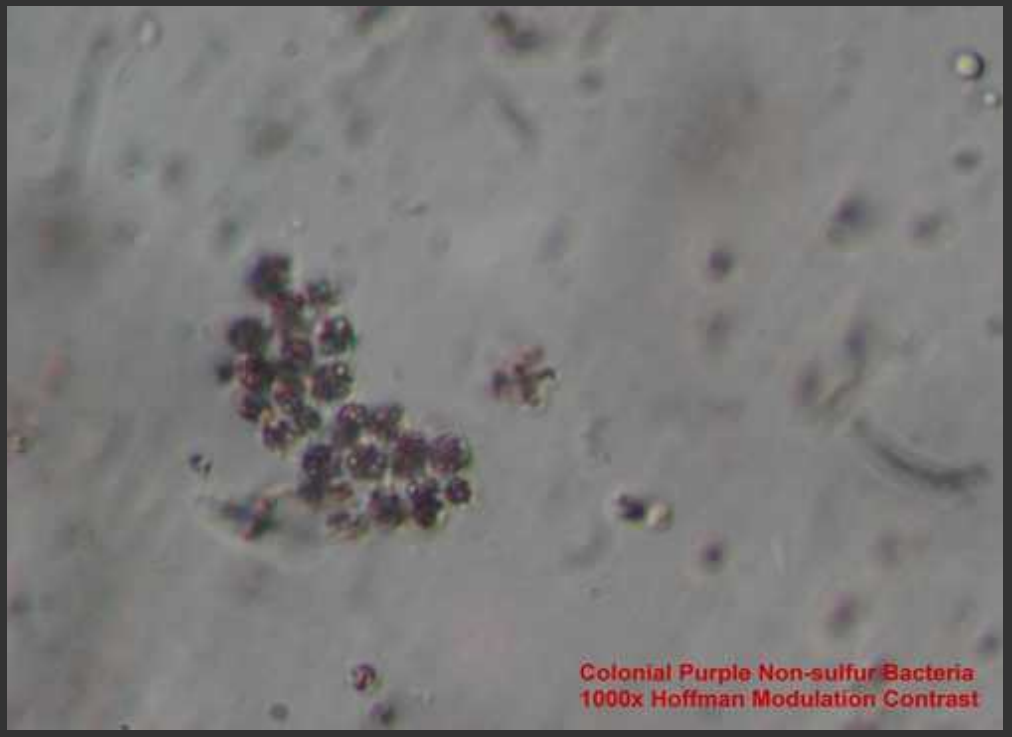




Where should I look for these?

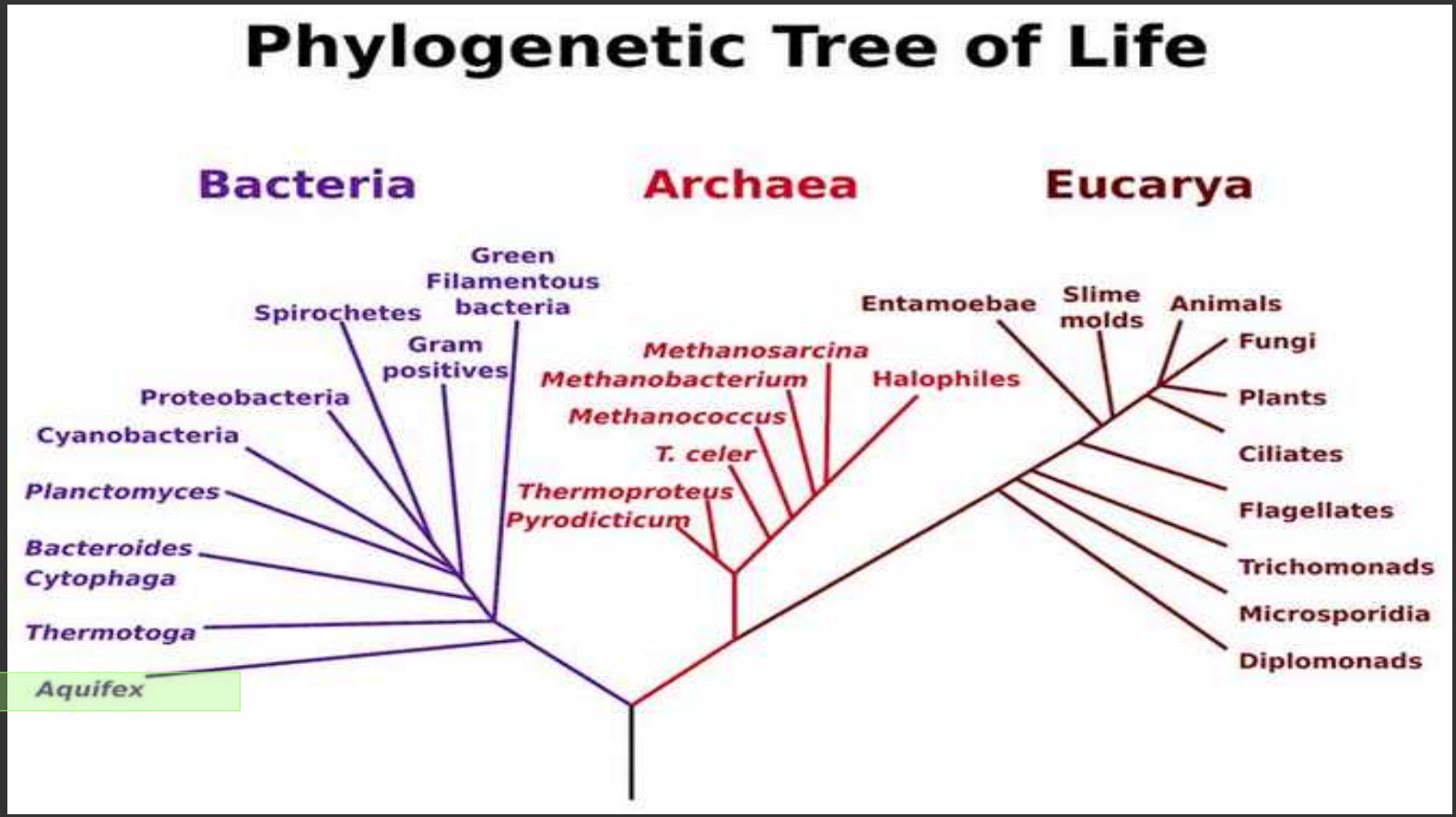
Not oxygen tolerant!
Energy from light (Phototrophic)
Reducing agent is H_2S, not H_2O (Lithotrophic)
Carbon source is $C0_2$ (Autotrophic)
Product of photosynthesis is …..

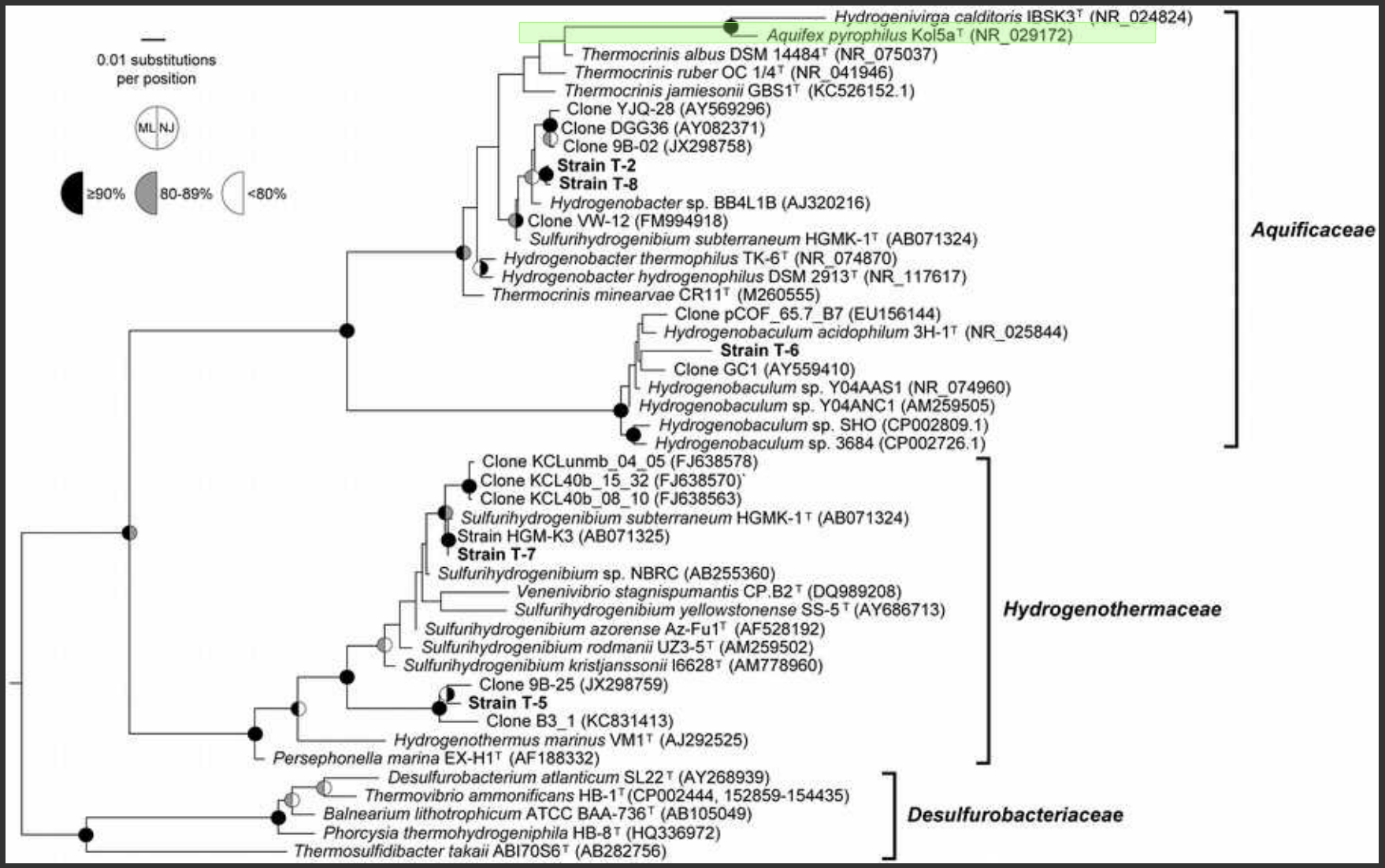
Purple Non-Sulfur Bacteria (Chromatiales)



How would I grow these in a lab?

Not oxygen tolerant! (usually)
Energy from light (Phototrophic) …. sometimes!
Reducing agents are organic, usually (Organotrophic)
Carbon source is $C0_2$ (Autotrophic)


Phylogenetic Tree of Life
Bacteria
Archaea
Eucarya
Green
Filamentous
bacteria
Spirochetes
Gram
positives
Proteobacteria
Cyanobacteria
Planctomyces
Bacteroides
Cytophaga
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
T. celer
Thermoproteus
Pyrodicticum
Entamoebae
Slime
molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads

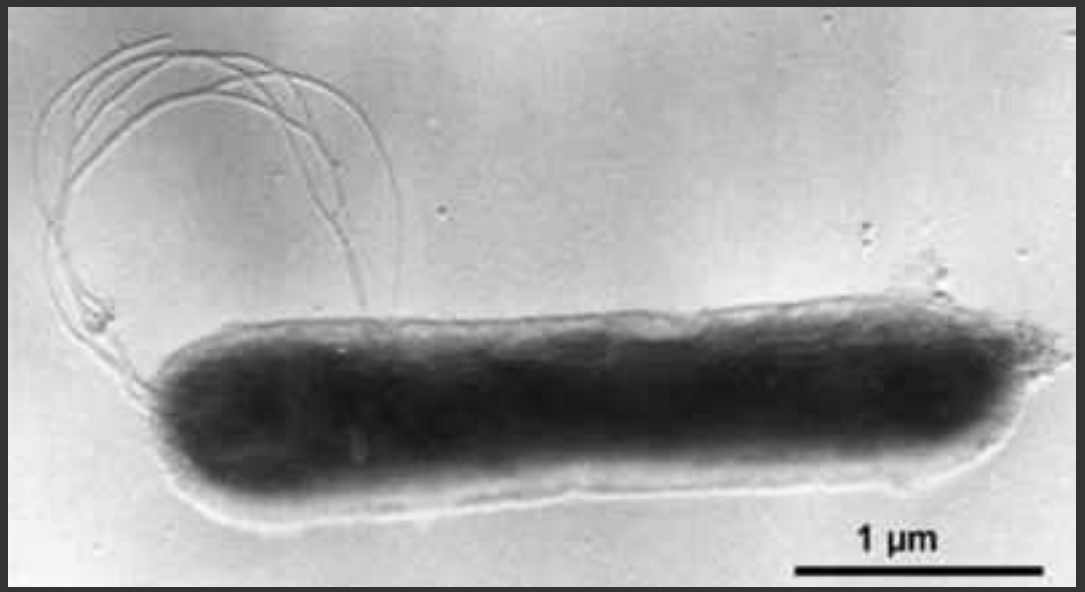

0.01 substitutions per position
ML NJ
≥90%
80-89%
<80%
Hydrogenivirga calditoris IBSK3T (NR_024824)
Aquifex pyrophilus Kol5aT (NR_029172)
Thermocrinis albus DSM 14484T (NR_075037)
Thermocrinis ruber OC 1/4T (NR_041946)
Thermocrinis jamiesonii GBS1T (KC526152.1)
Clone YJQ-28 (AY569296)
Clone DGG36 (AY082371)
Clone 9B-02 (JX298758)
Strain T-2
Strain T-8
Hydrogenobacter sp. BB4L1B (AJ320216)
Clone VW-12 (FM994918)
Sulfurihydrogenibium subterraneum HGMK-1T (AB071324)
Hydrogenobacter thermophilus TK-6T (NR_074870)
Hydrogenobacter hydrogenophilus DSM 2913T (NR_117617)
Thermocrinis minearvae CR11T (M260555)
Clone pCOF_65.7_B7 (EU156144)
Hydrogenobaculum acidophilum 3H-1T (NR_025844)
Strain T-6
Clone GC1 (AY559410)
Hydrogenobaculum sp. Y04AAS1 (NR_074960)
Hydrogenobaculum sp. Y04ANC1 (AM259505)
Hydrogenobaculum sp. SHO (CP002809.1)
Hydrogenobaculum sp. 3684 (CP002726.1)
Aquificaceae
Clone KCLunmb_04_05 (FJ638578)
Clone KCL40b_15_32 (FJ638570)
Clone KCL40b_08_10 (FJ638563)
Sulfurihydrogenibium subterraneum HGMK-1T (AB071324)
Strain HGM-K3 (AB071325)
Strain T-7
Sulfurihydrogenibium sp. NBRC (AB255360)
Venenivibrio stagnispumantis CP.B2T (DQ989208)
Sulfurihydrogenibium yellowstonense SS-5T (AY686713)
Sulfurihydrogenibium azorense Az-Fu1T (AF528192)
Sulfurihydrogenibium rodmanii UZ3-5T (AM259502)
Sulfurihydrogenibium kristjanssonii I6628T (AM778960)
Clone 9B-25 (JX298759)
Strain T-5
Clone B3_1 (KC831413)
Hydrogenothermus marinus VM1T (AJ292525)
Persephonella marina EX-H1T (AF188332)
Hydrogenothermaceae
Desulfurobacterium atlanticum SL22T (AY268939)
Thermovibrio ammonificans HB-1T (CP002444, 152859-154435)
Balnearium lithotrophicum ATCC BAA-736T (AB105049)
Phorcysia thermohydrogeniphila HB-8T (HQ336972)
Thermosulfidibacter takaii ABI70S6T (AB282756)
Desulfurobacteriaceae

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Very hyperthermic

Likes Oxygen

Doesn't like H_2S



Chemo-litho-heterotrophic

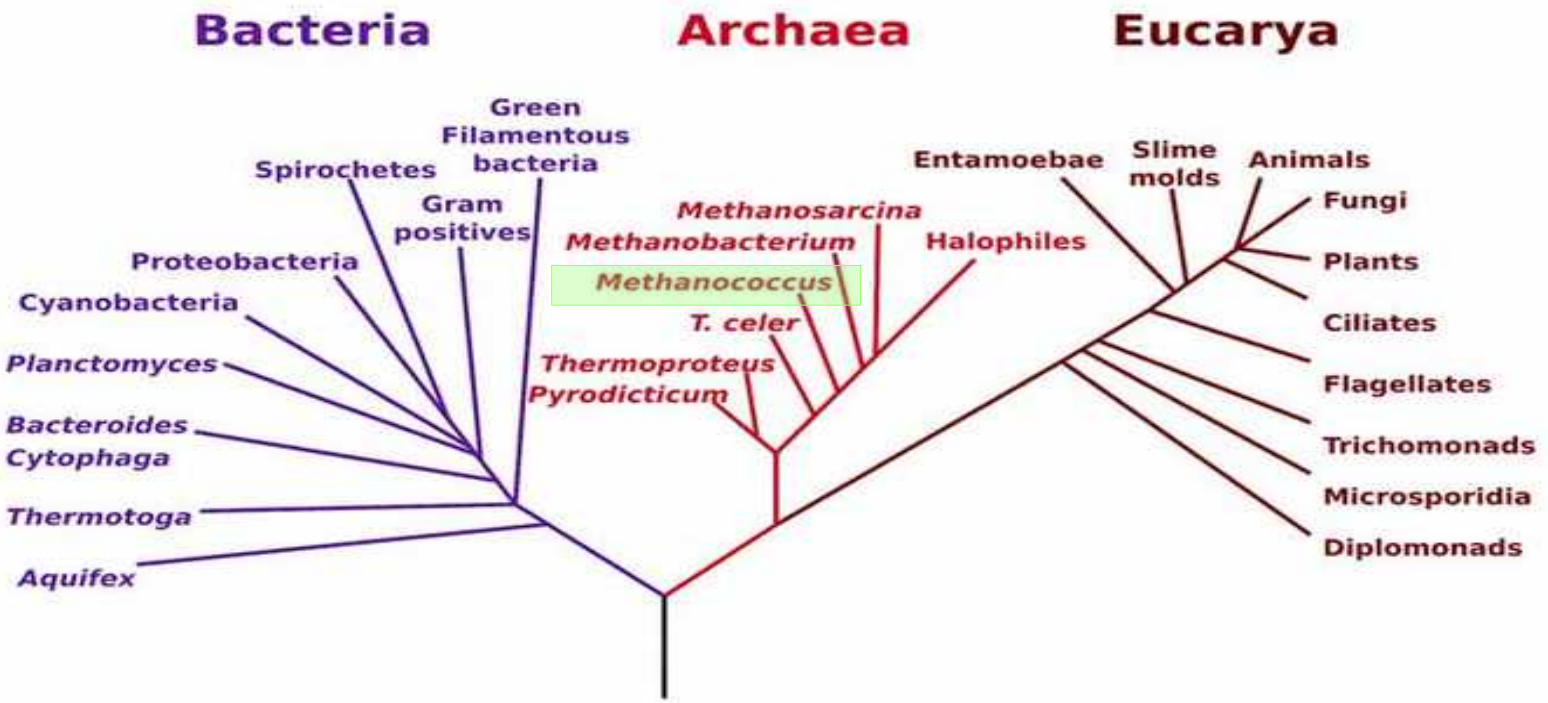
Energy

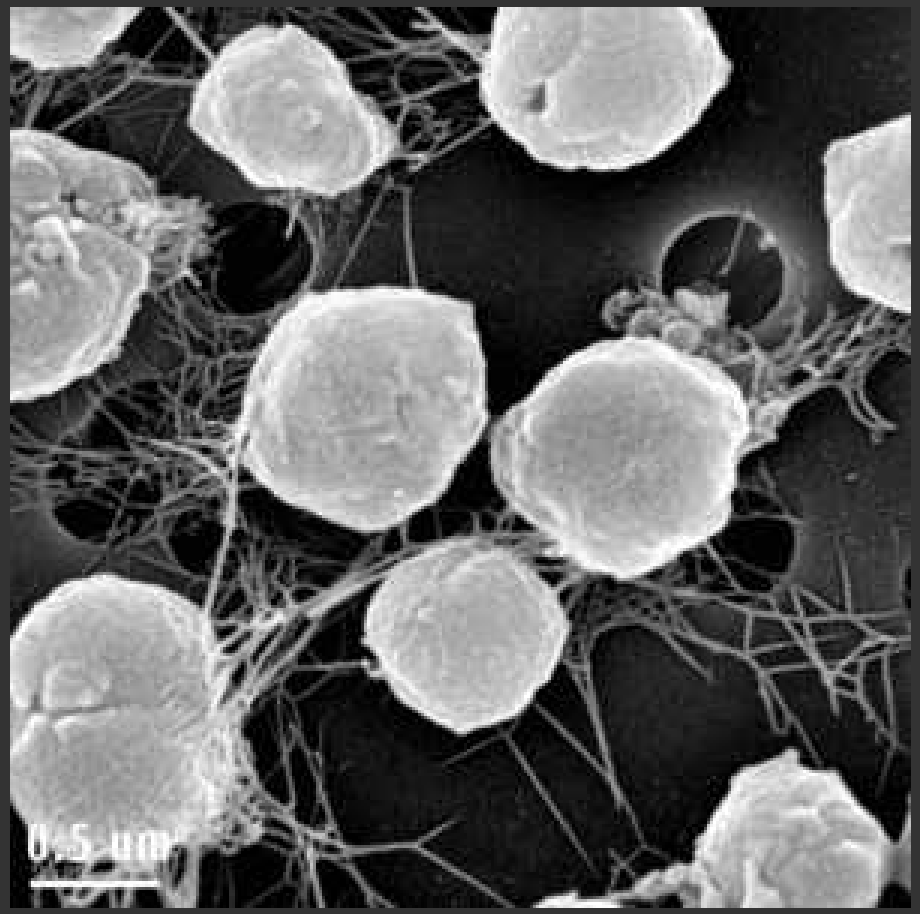
Electrons

Carbon

Aquifex sp.

Phylogenetic Tree of Life





Methanococcus jannaschii

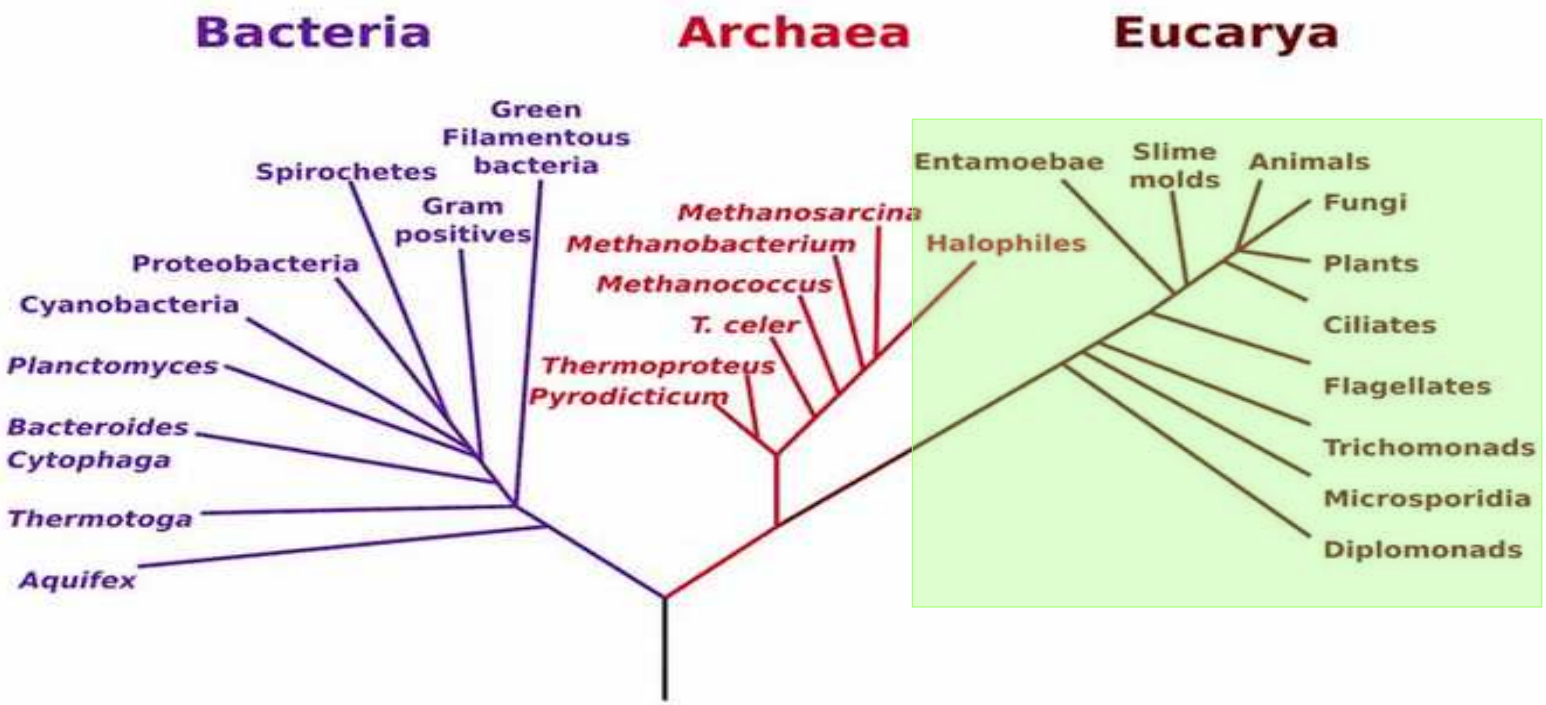
Cannot tolerate <u>any</u> oxygen

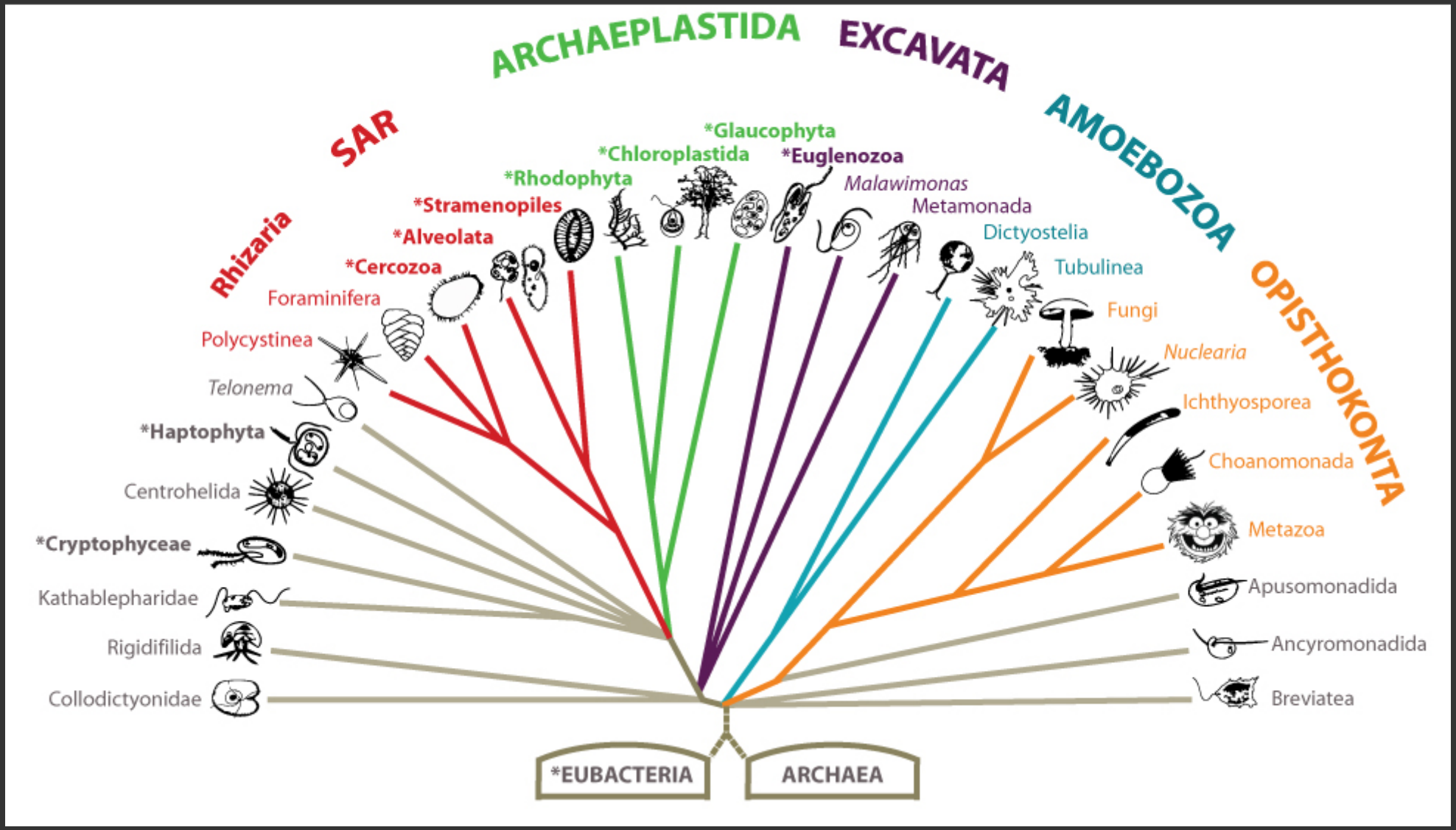
$2\ H_2 + CO_2 \rightarrow CH_4$ (methane)

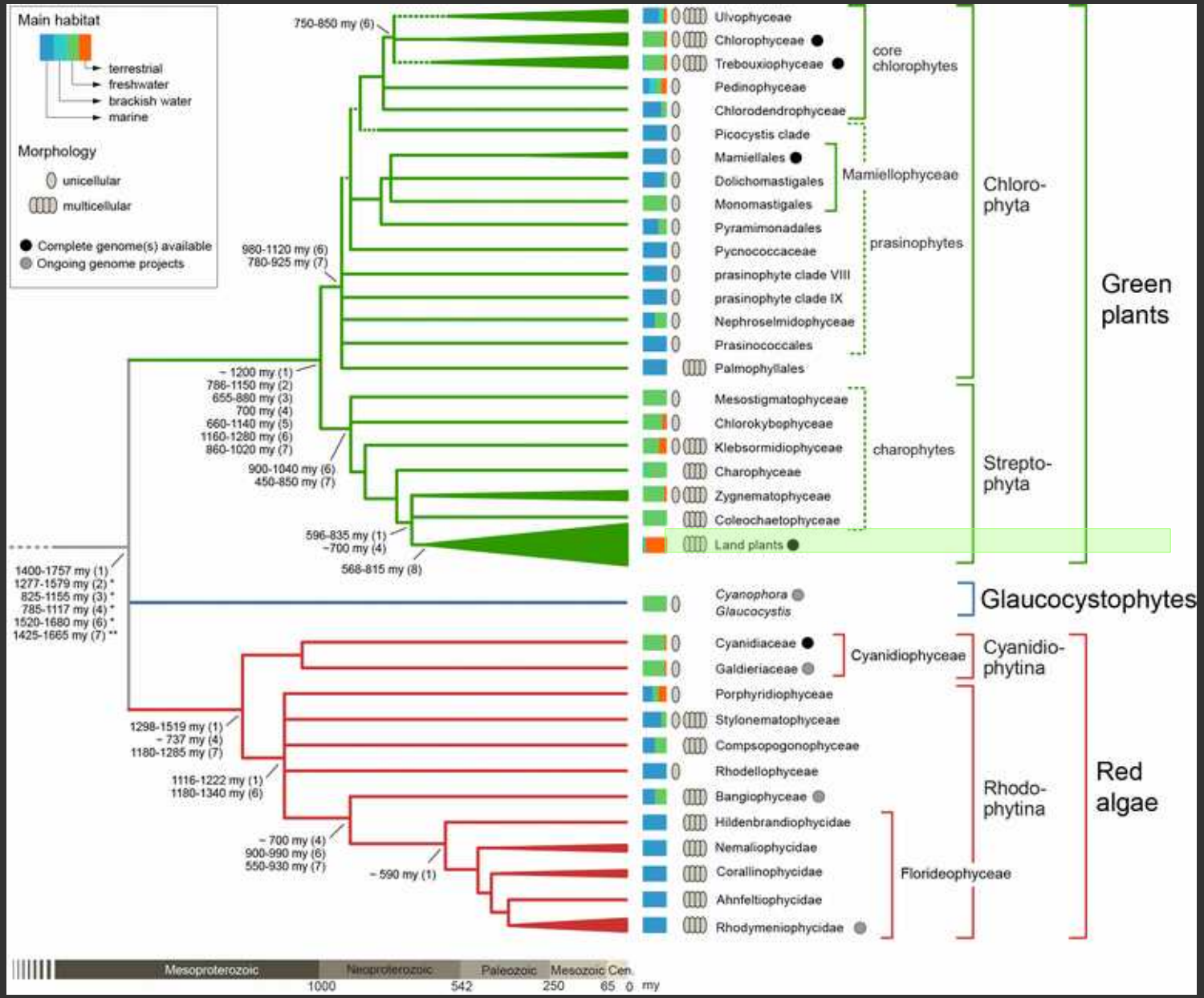
Energy from chemical sources, not light

Classify its metabolism → Energy:
Electron:
Carbon:

Phylogenetic Tree of Life




ARCHAEPLASTIDA
EXCAVATA
AMOEBOZOA
OPISTHOKONTA
SAR
Rhizaria
*Glaucophyta
*Chloroplastida
*Euglenozoa
*Rhodophyta
Malawimonas
*Stramenopiles
Metamonada
*Alveolata
Dictyostelia
*Cercozoa
Tubulinea
Foraminifera
Fungi
Polycystinea
Nucleariа
Telonema
Ichthyosporea
*Haptophyta
Choanomonada
Centrohelida
Metazoa
*Cryptophyceae
Apusomonadida
Kathablepharidae
Ancyromonadida
Rigidifilida
Breviatea
Collodictyonidae
*EUBACTERIA
ARCHAEA


Main habitat
terrestrial
freshwater
brackish water
marine
Morphology
unicellular
multicellular
Complete genome(s) available
Ongoing genome projects
750-850 my (6)
980-1120 my (6)
780-925 my (7)
~ 1200 my (1)
786-1150 my (2)
655-880 my (3)
700 my (4)
660-1140 my (5)
1160-1280 my (6)
860-1020 my (7)
900-1040 my (6)
450-850 my (7)
596-835 my (1)
~700 my (4)
568-815 my (8)
1400-1757 my (1)
1277-1579 my (2) *
825-1155 my (3) *
785-1117 my (4) *
1520-1680 my (6) *
1425-1665 my (7) **
1298-1519 my (1)
~ 737 my (4)
1180-1285 my (7)
1116-1222 my (1)
1180-1340 my (6)
~ 700 my (4)
900-990 my (6)
550-930 my (7)
~ 590 my (1)
Ulvophyceae
Chlorophyceae
Trebouxiophyceae
Pedinophyceae
Chlorodendrophyceae
Picocystis clade
Mamiellales
Dolichomastigales
Monomastigales
Pyramimonadales
Pycnococcaceae
prasinophyte clade VIII
prasinophyte clade IX
Nephroselmidophyceae
Prasinococcales
Palmophyllales
Mesostigmatophyceae
Chlorokybophyceae
Klebsormidiophyceae
Charophyceae
Zygnematophyceae
Coleochaetophyceae
Land plants
Cyanophora
Glaucocystis
Cyanidiaceae
Galdieriaceae
Porphyridiophyceae
Stylonematophyceae
Compsopogonophyceae
Rhodellophyceae
Bangiophyceae
Hildenbrandiophycidae
Nemaliophycidae
Corallinophycidae
Ahnfeltiophycidae
Rhodymeniophycidae
core chlorophytes
Mamiellophyceae
prasinophytes
charophytes
Cyanidiophyceae
Florideophyceae
Chloro-phyta
Strepto-phyta
Green plants
Glaucocystophytes
Cyanidio-phytina
Rhodo-phytina
Red algae
Mesoproterozoic
Neoproterozoic
Paleozoic
Mesozoic
Cen.
1000
542
250
65
0
my

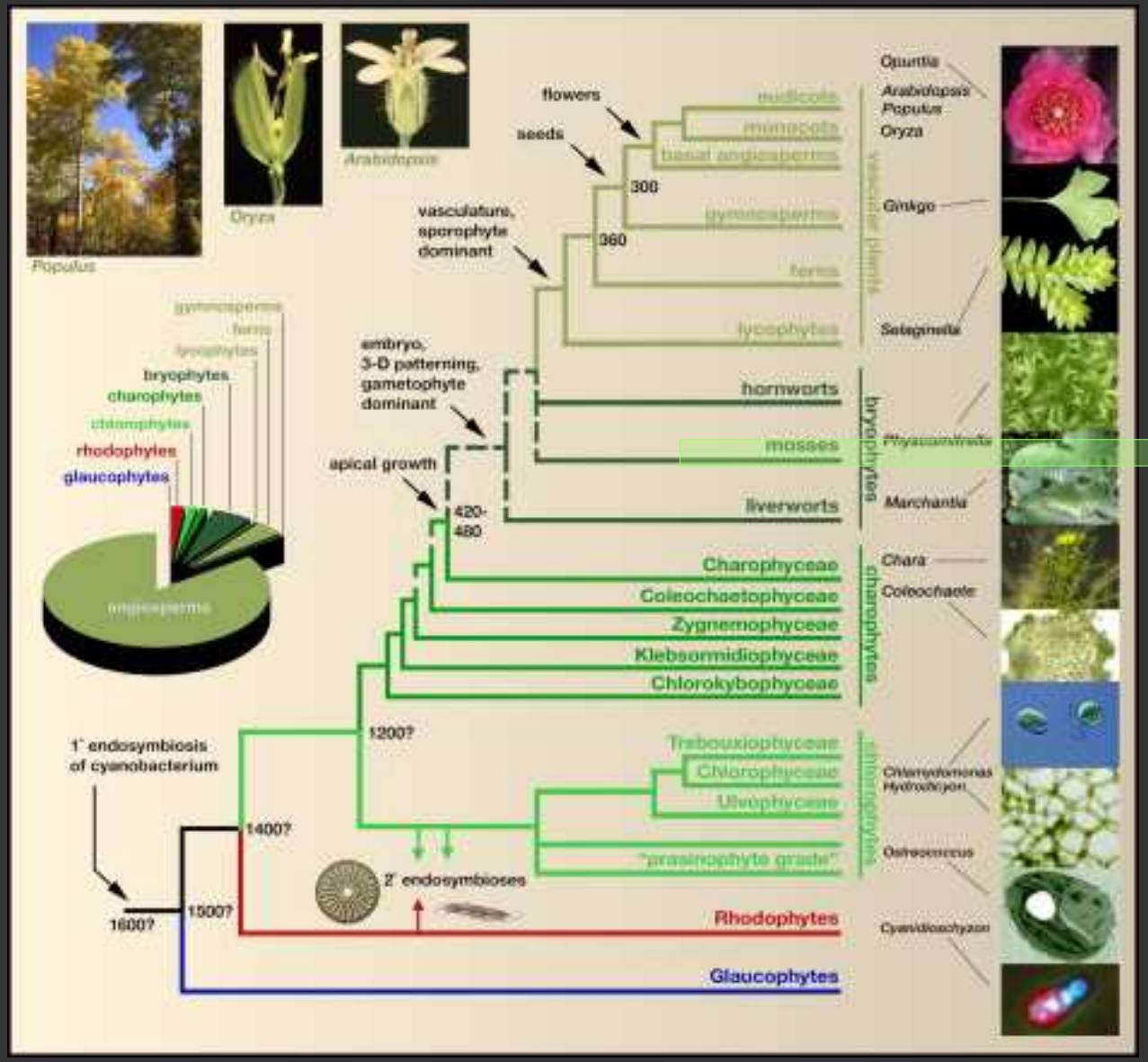

Populus
Oryza
Arabidopsis
flowers
seeds
eudicots
monocots
basal angiosperms
300
gymnosperms
vasculature, sporophyte dominant
360
ferns
lycophytes
embryo, 3-D patterning, gametophyte dominant
hornworts
mosses
apical growth
liverworts
420-480
Charophyceae
Coleochaetophyceae
Zygnemophyceae
Klebsormidiophyceae
Chlorokybophyceae
1200?
Trebouxiophyceae
Chlorophyceae
Ulvophyceae
"prasinophyte grade"
1° endosymbiosis of cyanobacterium
1400?
1500?
1600?
2° endosymbioses
Rhodophytes
Glaucophytes
gymnosperms
ferns
lycophytes
bryophytes
charophytes
chlorophytes
rhodophytes
glaucophytes
angiosperms
Oputtia
Arabidopsis
Populus
Oryza
Ginkgo
Selaginella
Physcomitrella
Marchantia
Chara
Coleochaete
Chlamydomonas
Hydrodictyon
Ostreococcus
Cyanidioschyzon
vascular plants
bryophytes
charophytes
chlorophytes

Photo-litho-auto-trophs

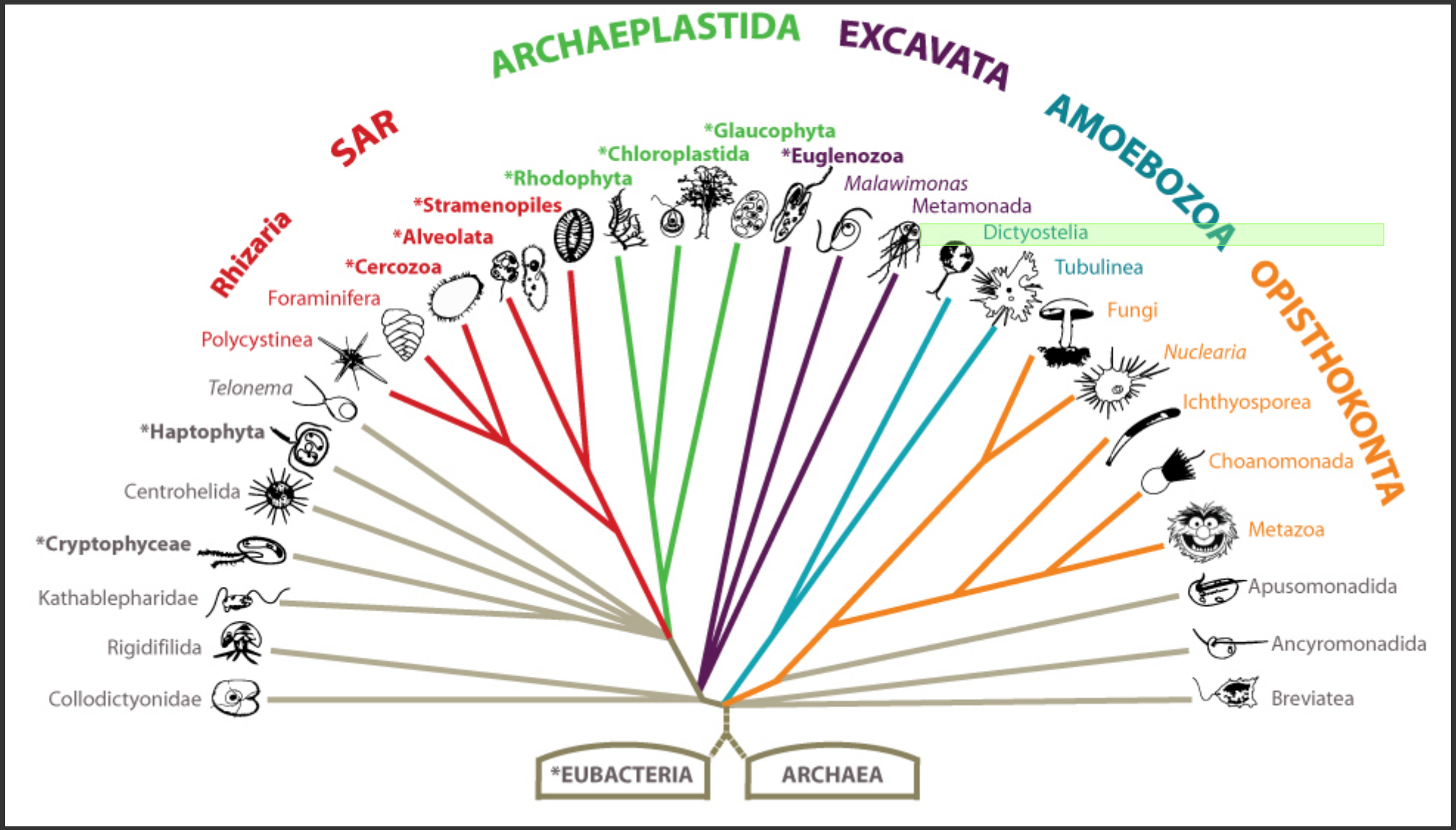
Moss – Bryophytes

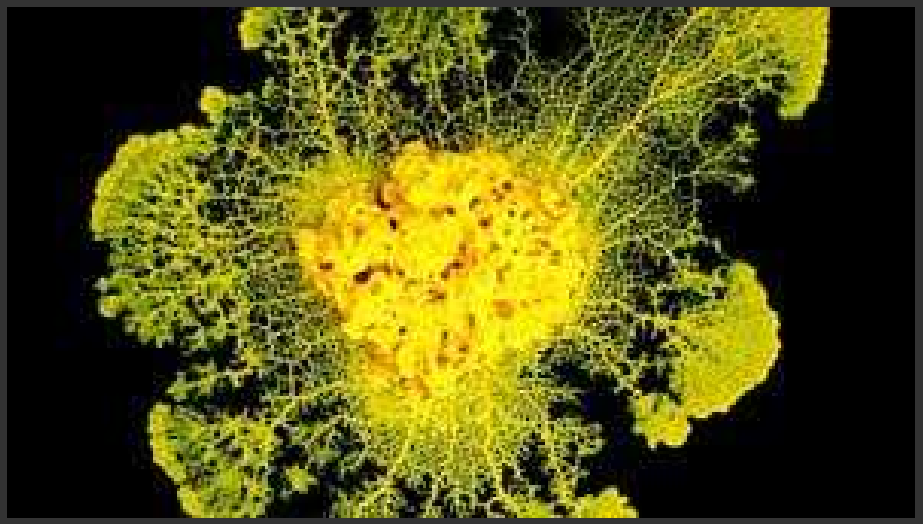
Energy source?

Electron source?

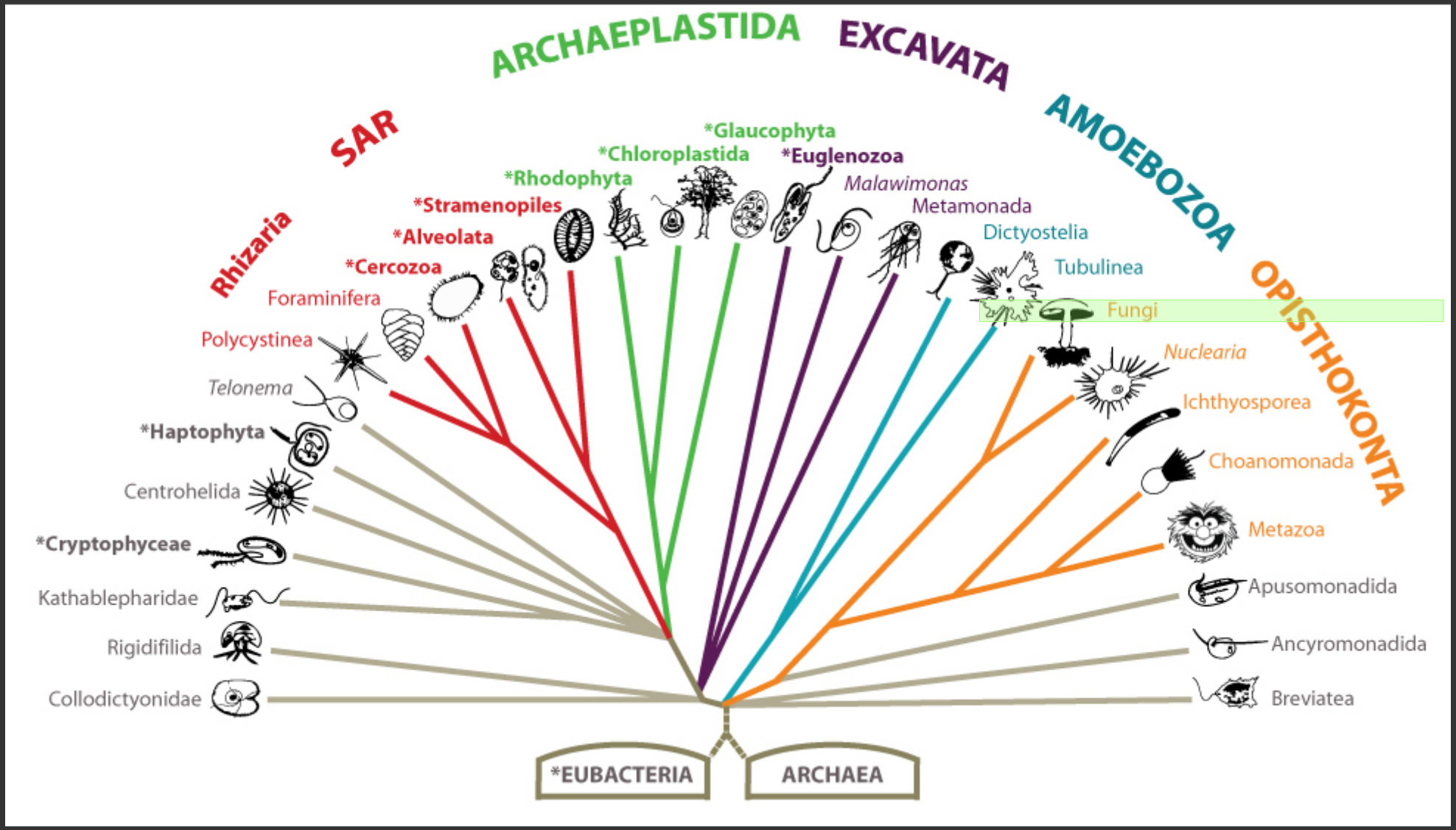
Carbon source?

Can plants undergo aerobic respiration?
Can they be chemoheterotrophic?


ARCHAEPLASTIDA
EXCAVATA
AMOEBOZOA
OPISTHOKONTA
SAR
Rhizaria
*Glaucophyta
*Chloroplastida
*Euglenozoa
*Rhodophyta
Malawimonas
*Stramenopiles
Metamonada
*Alveolata
Dictyostelia
*Cercozoa
Tubulinea
Foraminifera
Fungi
Polycystinea
Nucleariа
Telonema
Ichthyosporea
*Haptophyta
Choanomonada
Centrohelida
Metazoa
*Cryptophyceae
Apusomonadida
Kathablepharidae
Ancyromonadida
Rigidifilida
Breviatea
Collodictyonidae
*EUBACTERIA
ARCHAEA




BBC one

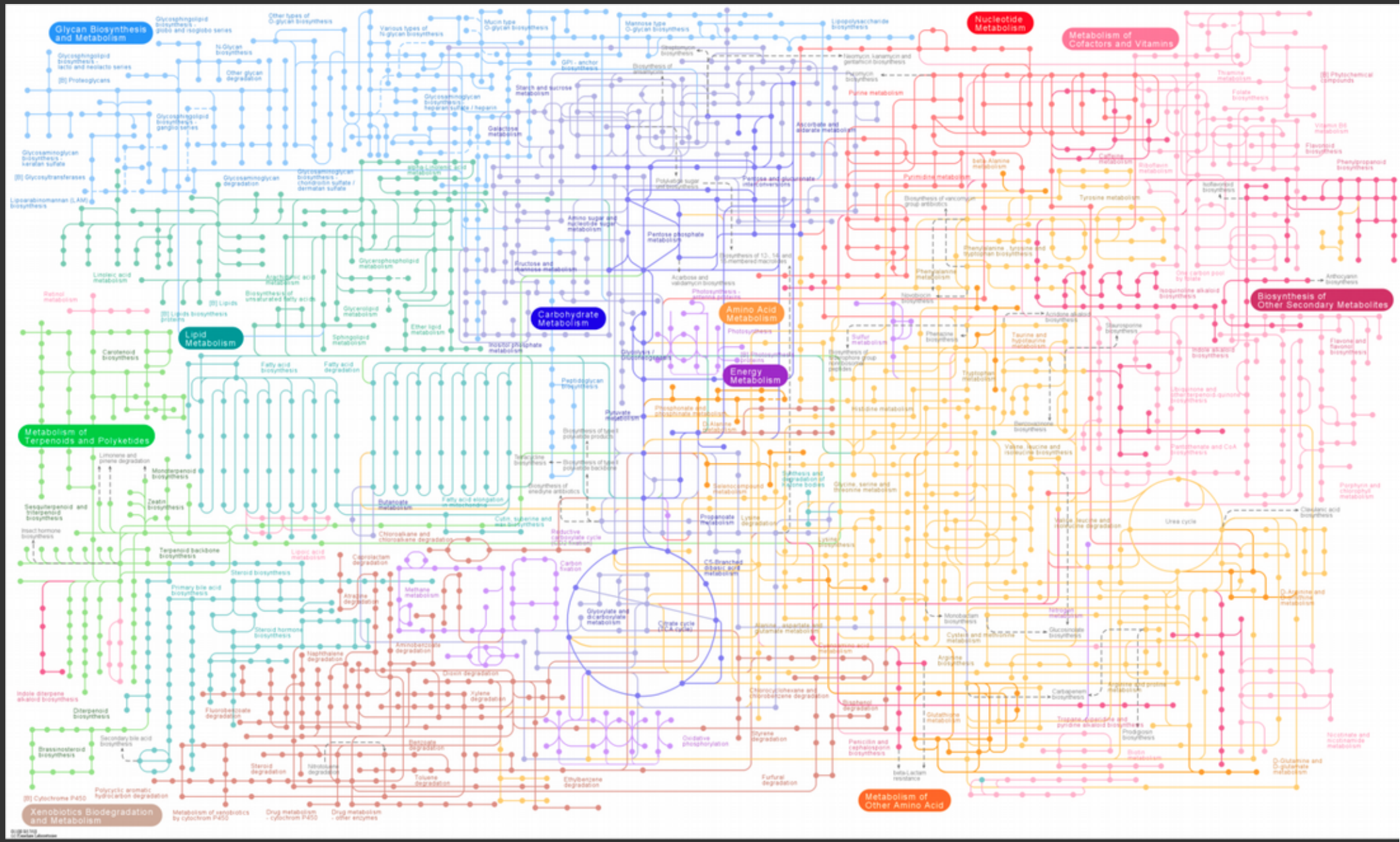

ARCHAEPLASTIDA
EXCAVATA
AMOEBOZOA
OPISTHOKONTA
SAR
Rhizaria
*Glaucophyta
*Chloroplastida
*Euglenozoa
*Rhodophyta
Malawimonas
*Stramenopiles
Metamonada
*Alveolata
Dictyostelia
*Cercozoa
Tubulinea
Foraminifera
Fungi
Polycystinea
Nucleariа
Telonema
Ichthyosporea
*Haptophyta
Choanomonada
Centrohelida
Metazoa
*Cryptophyceae
Apusomonadida
Kathablepharidae
Ancyromonadida
Rigidifilida
Breviatea
Collodictyonidae
*EUBACTERIA
ARCHAEA

Fungi

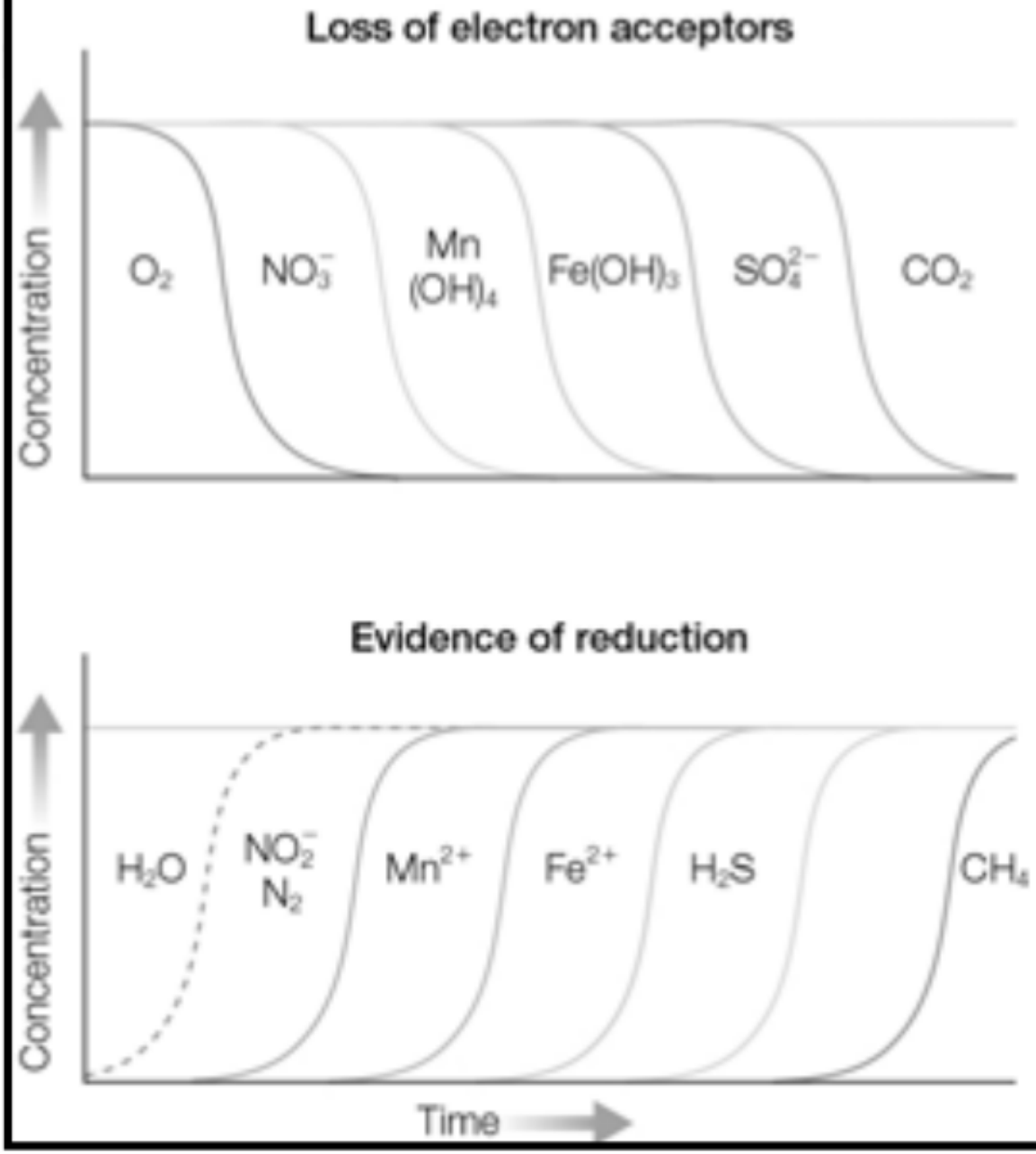
With oxygen:
$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$

Without oxygen:
$C_6H_{12}O_6 \rightarrow CO_2 + C_3H_4O_3 + C_2H_5OH$

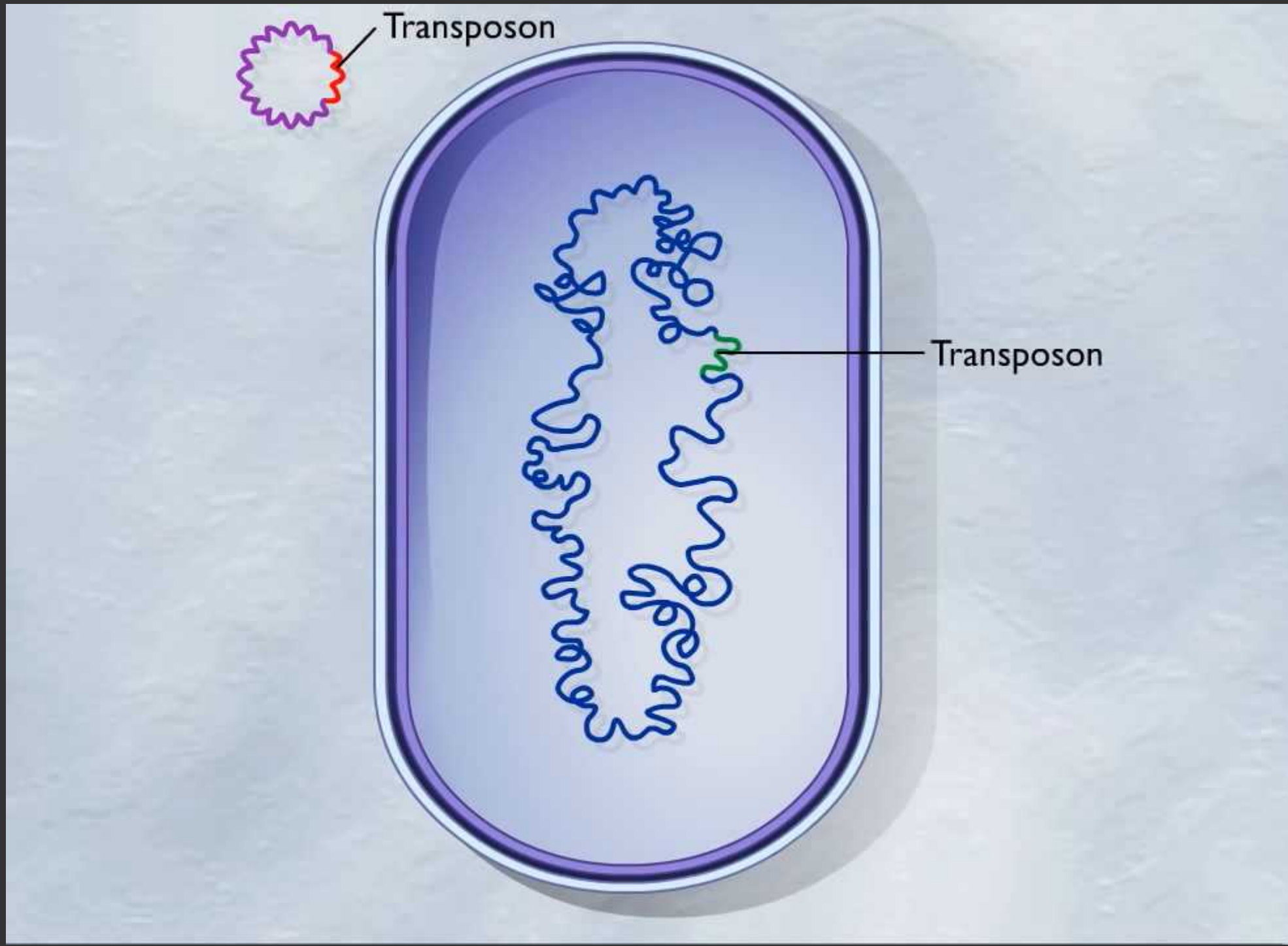
Some of the currently known metabolic pathways from the Kyoto Encyclopedia of Genomes and Genes (KEGG)



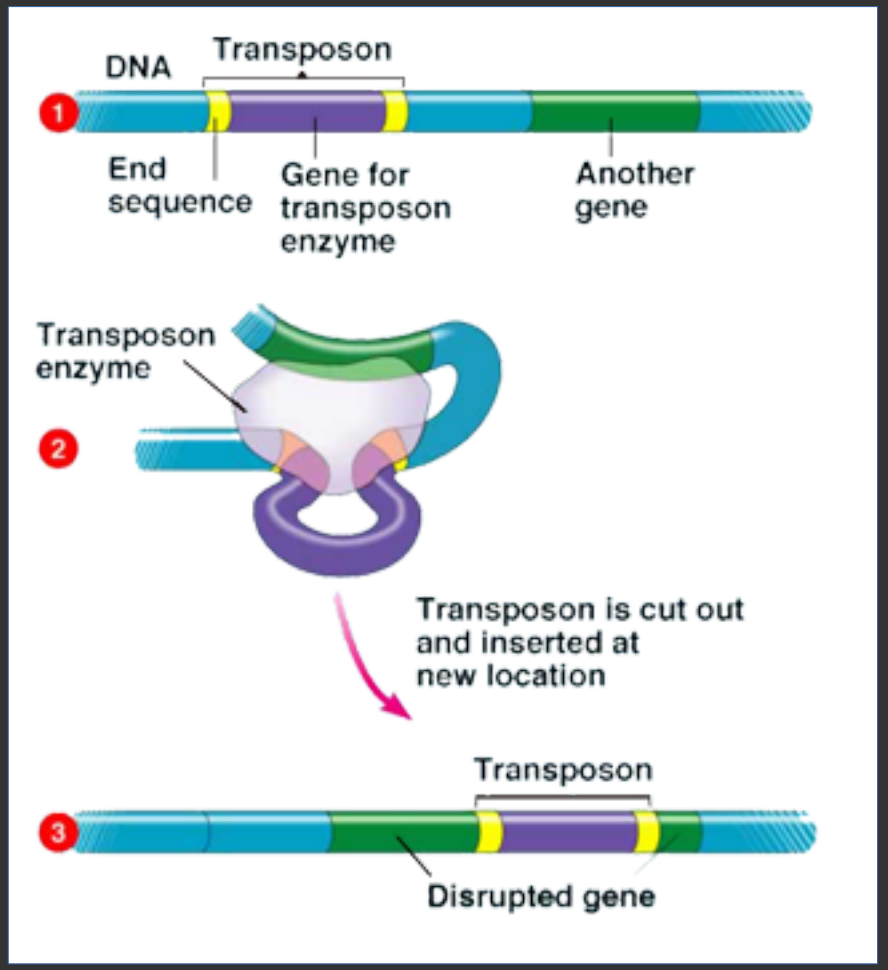
Anaerobic respiration

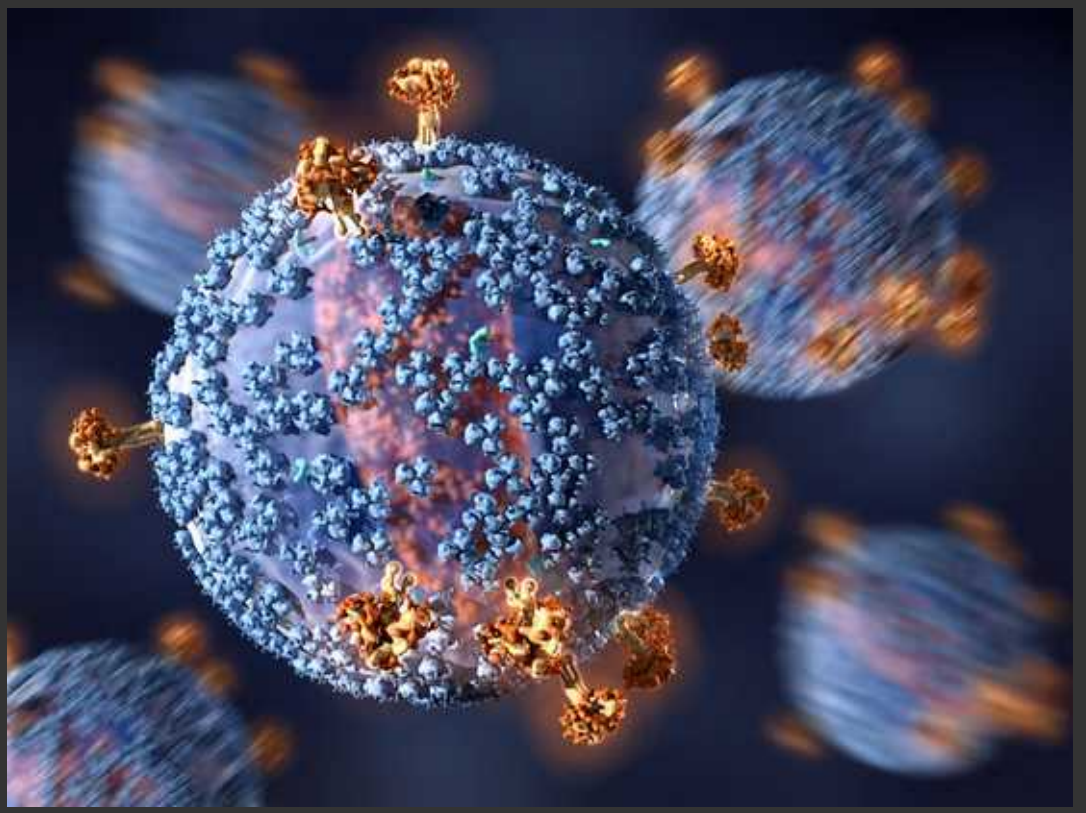


- As O_2 is used & environment becomes reduced, organisms that use other compounds become active


Transposon
Transposon

Transposons and other viruses





Transposons and other viruses