APPLIED BIOTECHNOLOGY FOR TRANSPORTATION FUELS

Meeting Today's Energy Needs by Maximizing Photon Capture & Conversion

www.arpa-e.energy.gov

DISCLAIMER

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INTRODUCTION

- Jonathan J. Burbaum, PhD MBA
  - Education
    - PhD, Chemistry (Harvard), under Jeremy Knowles
    - Postdoc, Biology (MIT), under Paul Schimmel
    - MBA (UCSD)
  - Professional Background
    - Merck Research Labs (Rahway)
    - Pharmacopeia
    - ActivX Biosciences
    - Azure Therapeutics/Gnosys Consulting (Sofinnova)
    - Program Director, ARPA-E since August 2010

AGENDA OVERVIEW

Thursday, December 2, 2010

8 :30 AM - 9 :00 AM	**Continental Breakfast**
9 :00 AM – 9 :15 AM	**Welcome and Opening Remarks** Mark Hartney, *ARPA-E*
9 :15 AM – 9 :30 AM	**Workshop Overview and Objectives** Jonathan Burbaum, *ARPA-E*
9 :30 AM – 10 :15 AM	**Technology Overviews**
– 9 :30 AM – 9 :45 AM	**"What is the Maximum Efficiency that Photosynthesis Can Convert Solar Energy into Biomass?"** Don Ort, *UIUC*
– 9 :45 AM – 10 :00 AM	**"Photosynthesis to Fuels" - Enhancing Fuel Production in Cyanobacteria and Microalgae** Tasios Melis, *UC Berkeley*
– 10 :00 AM – 10 :15 AM	**"What Does it Take to Feed and Fuel the World with Agriculture?"** Ganesh Kishore
10 :15 AM – 10 :30 AM	**Coffee Break**
10 :30 AM – 12 :00 PM	**BREAKOUT SESSIONS Technology Barriers and Opportunities**
12 :00 PM – 1 :00PM	**Working Lunch- Summary of Breakout Sessions by Section Leaders, Discussion**
1 :00 PM – 2 :45 PM	**EXERCISE: What Would You Do? Design the Ideal Fuel System.**
2 :45 PM – 3 :00 PM	**Coffee Break**
3 :00 PM – 3 :30 PM	**Short Presentations by Breakout Groups**
3 :30 PM – 4 :30 PM	**Group Discussion/debate on Presented Ideas**
4 :30 PM – 5 :30 PM	**Networking over Refreshments**

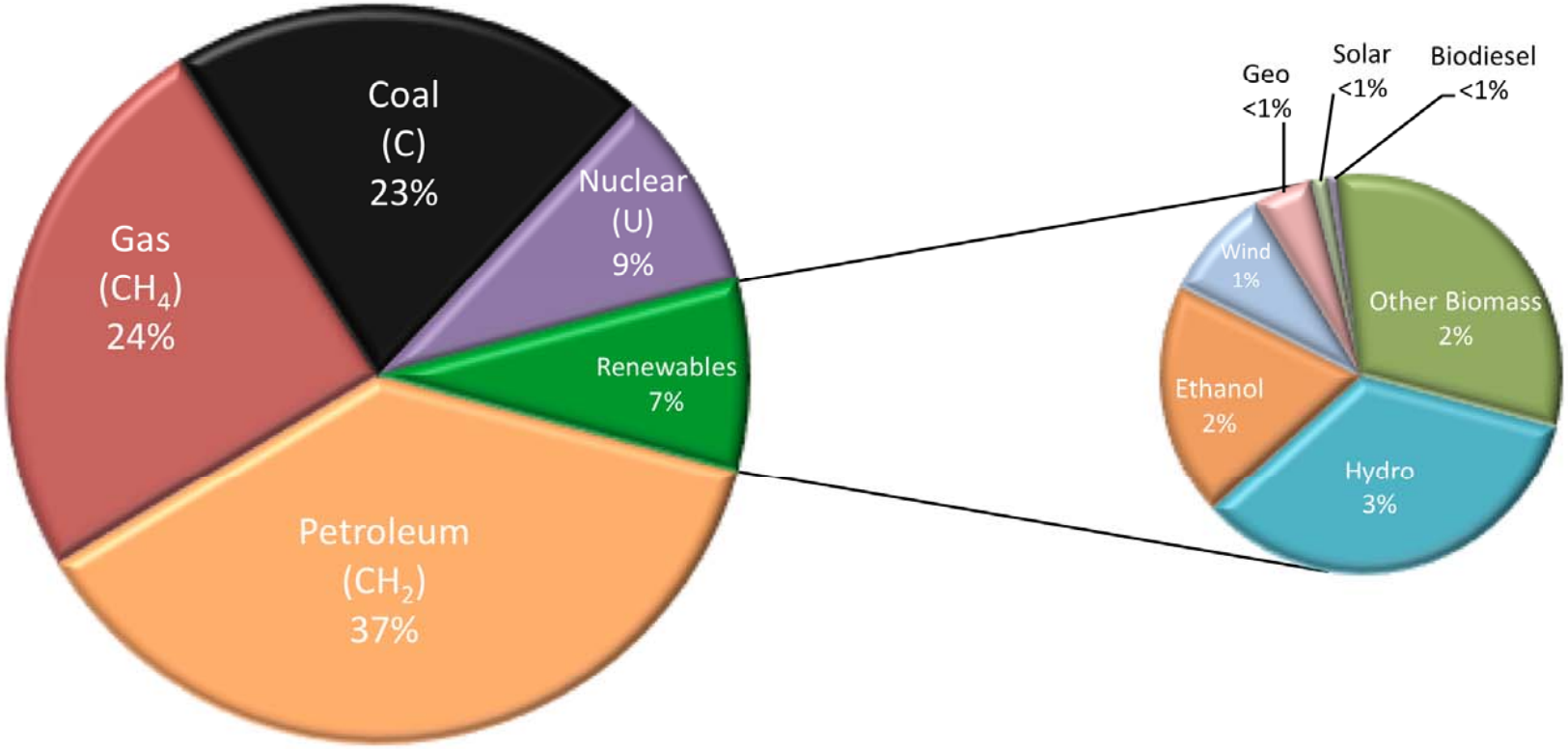
Dinner on your own

Friday, December 3, 2010 (Optional)

8 :00 AM – 8 :30 AM	**Continental Breakfast**
8 :30 AM – 10 :30 AM	**Preliminary Conclusions, Open Discussion**
	– What have we learned?
	– What is and is not possible?
	– What is "evolutionary" versus "revolutionary"?
	– What can we do now?
	– How will we tell that we've succeeded? (metrics)
10 :30 PM – 12 :00 PM	**Coffee and One-on-one Discussions**

Please contact the organizers to schedule one-on-one time with program directors

ENERGY SOURCES IN THE US



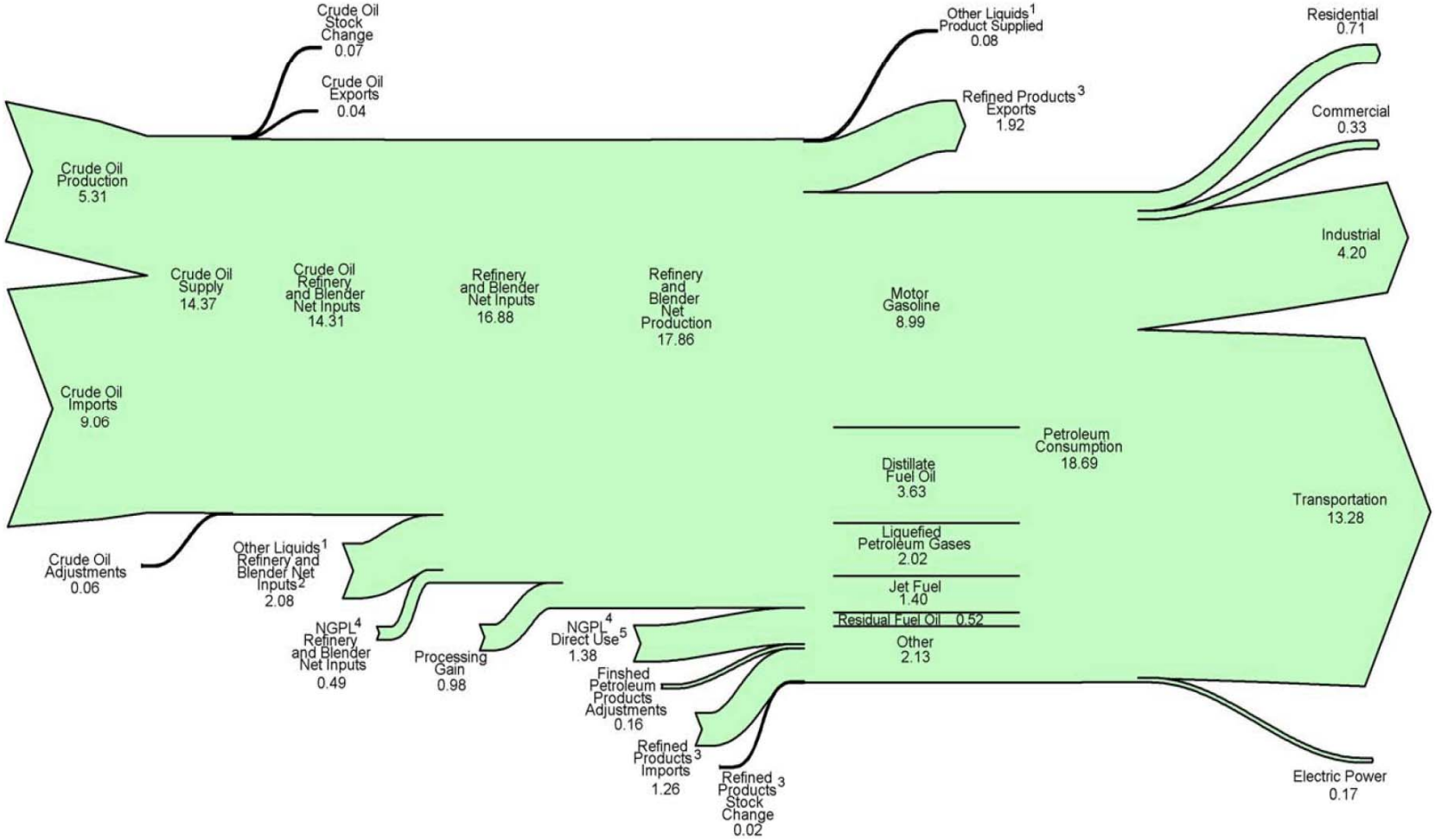
Total Energy Sources

Renewables

Source: DoE EIA Annual Review, 2009

PETROLEUM FLOW IN THE US

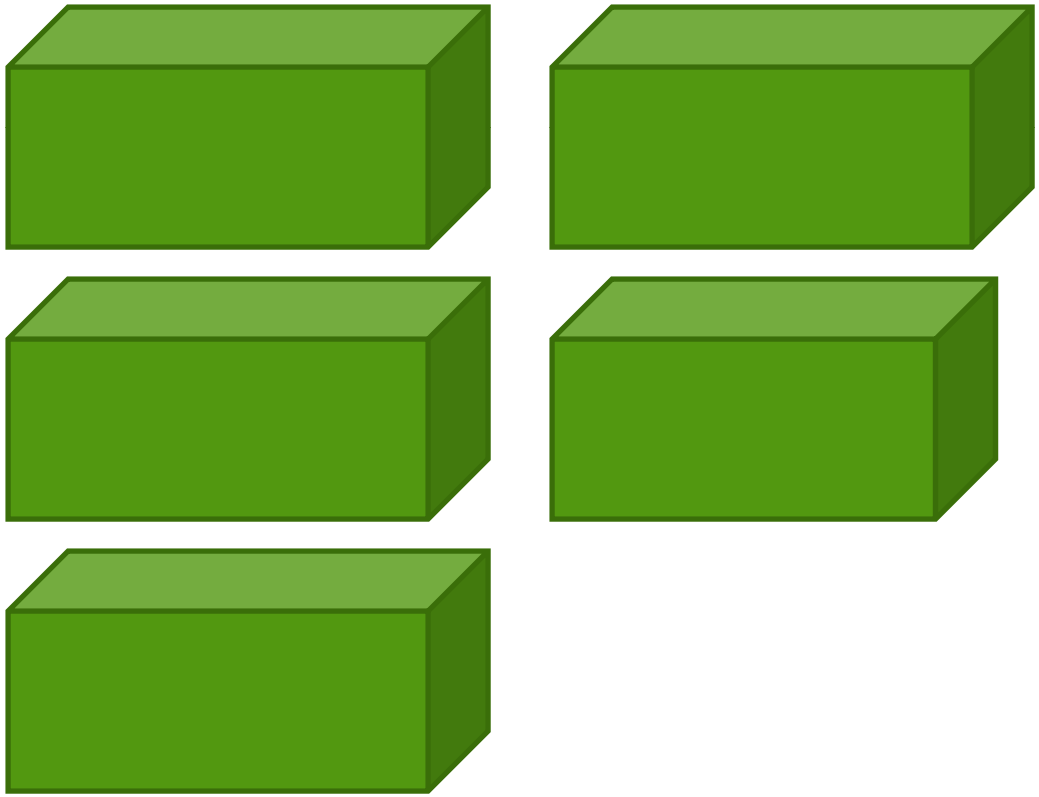
Figure 5.0. Petroleum Flow, 2009
(Million Barrels per Day)



Source: DoE EIA Annual Review, 2009

WHAT IS “1 MILLION BARRELS”?

4.9 Booz Allen VASQ Buildings (24,000 m^3 each)



WHITHER BIOFUELS?

- "Biofuels": Civilization's original energy
- Since then, though, a disappointment!
  - Today, transportation fuels ~ ethanol
  - Modern biotechnology has had ***NO impact*** on biofuels used for transportation

"MODERN" BIOTECHNOLOGY

FORD PREDICTS FUEL FROM VEGETATION

He Says Electricity Will Heat Cities in the Future—Tells of Testing a New Flour.

BOSTON, Sept. 19 (AP).—The time is coming when Americans will grow their own fuel and American cities will be heated by electricity, Henry Ford is quoted as saying during his stay at his Wayside Inn in Sudbury, in an interview published by The Christian Science Monitor today.

Patented Jan. 30, 1923. 1,443,881

UNITED STATES PATENT OFFICE.

HERBERT LANGWELL, OF STOCKTON-ON-TEES, ENGLAND.

FERMENTATION OF CELLULOSE.

No Drawing. Application filed September 29, 1919. Serial No. 327,265.

Vital Force Found in Plants May Increase World's Food

Dr. Dean Burk (left) and Prof. Otto Warburg examining their notes on photosynthesis.

Scientists, Reporting Efficiency Up to 87% in Using Energy of Sunlight, Visualize 100-Fold Rise in Yield of Algae

By WILLIAM L. LAURENCE

7 Claims. (Cl. 47—58)

Dr. Dean Burk (left) and Prof. Otto Warburg examining their notes on photosynthesis.

Scientists, Reporting Efficiency Up to 87% in Using Energy of Sunlight, Visualize 100-Fold Rise in Yield of Algae

By WILLIAM L. LAURENCE

The ideas aren't *new*.

They're just not *economical.*

NOBODY KNOWS THE FUTURE, BUT…

"Crude oil output [worldwide] reaches an undulating plateau of around 68-69 mb/d by 2020, but never regains its all-time peak of 70 mb/d reached in 2006…"

IEA, World Energy Outlook, 2010

"[T]otal oil demand will be 138 mb/d in 2030—about 30 mb/d greater than what is projected by DOE, IEA, and OPEC."

Dargay & Gately, 2010

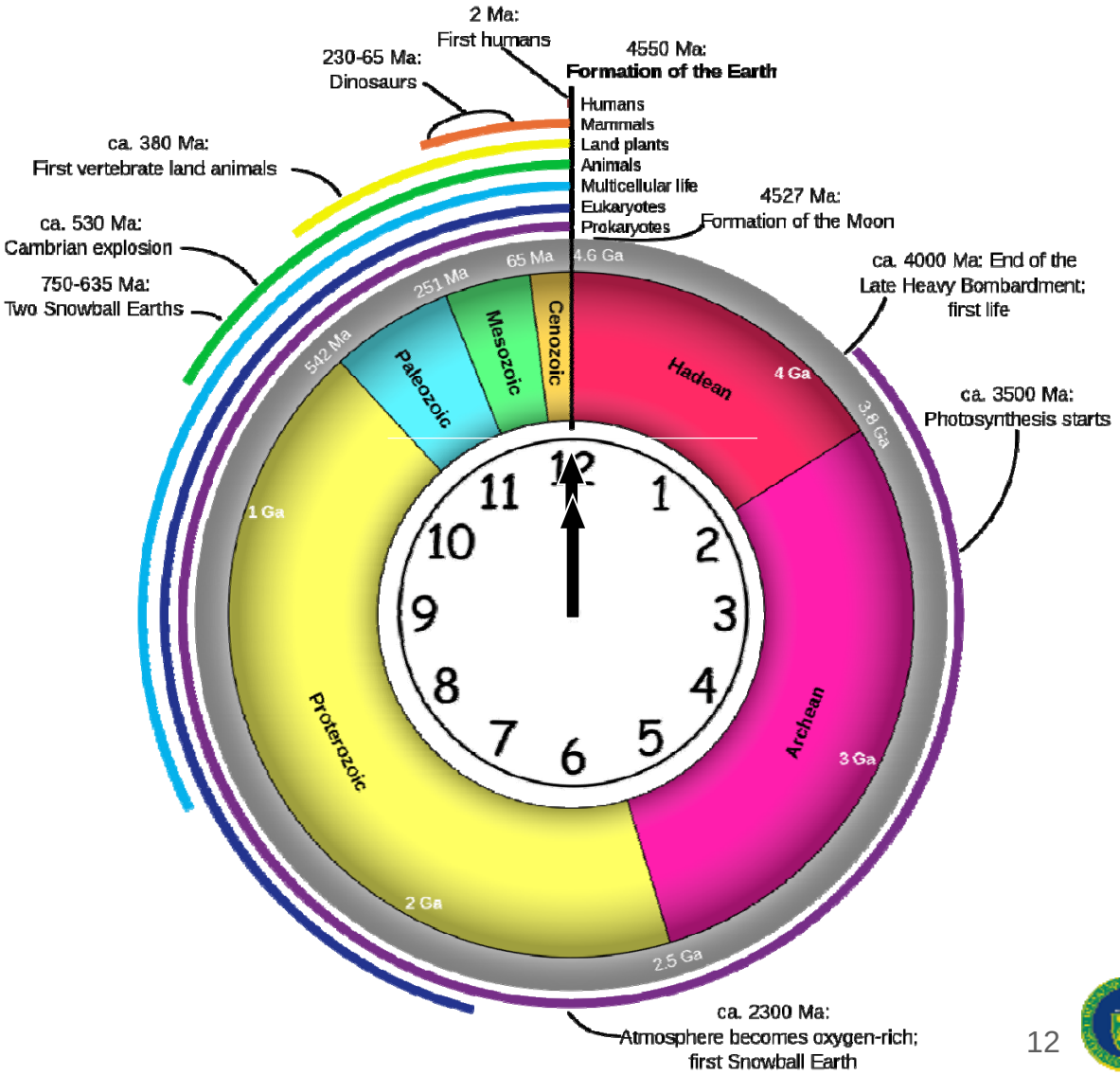
WHAT IS WRONG WITH THIS PICTURE?

HOW DID WE GET HERE?

- "Now, just follow my plan, and see how *easy*, how *simple,* how *free from care* everything will be." [Noted 20th Century energy entrepreneur, O. Hardy]
- "Replacing petroleum is not as easy as it looks." [Non-verbal commentary by S. Laurel]

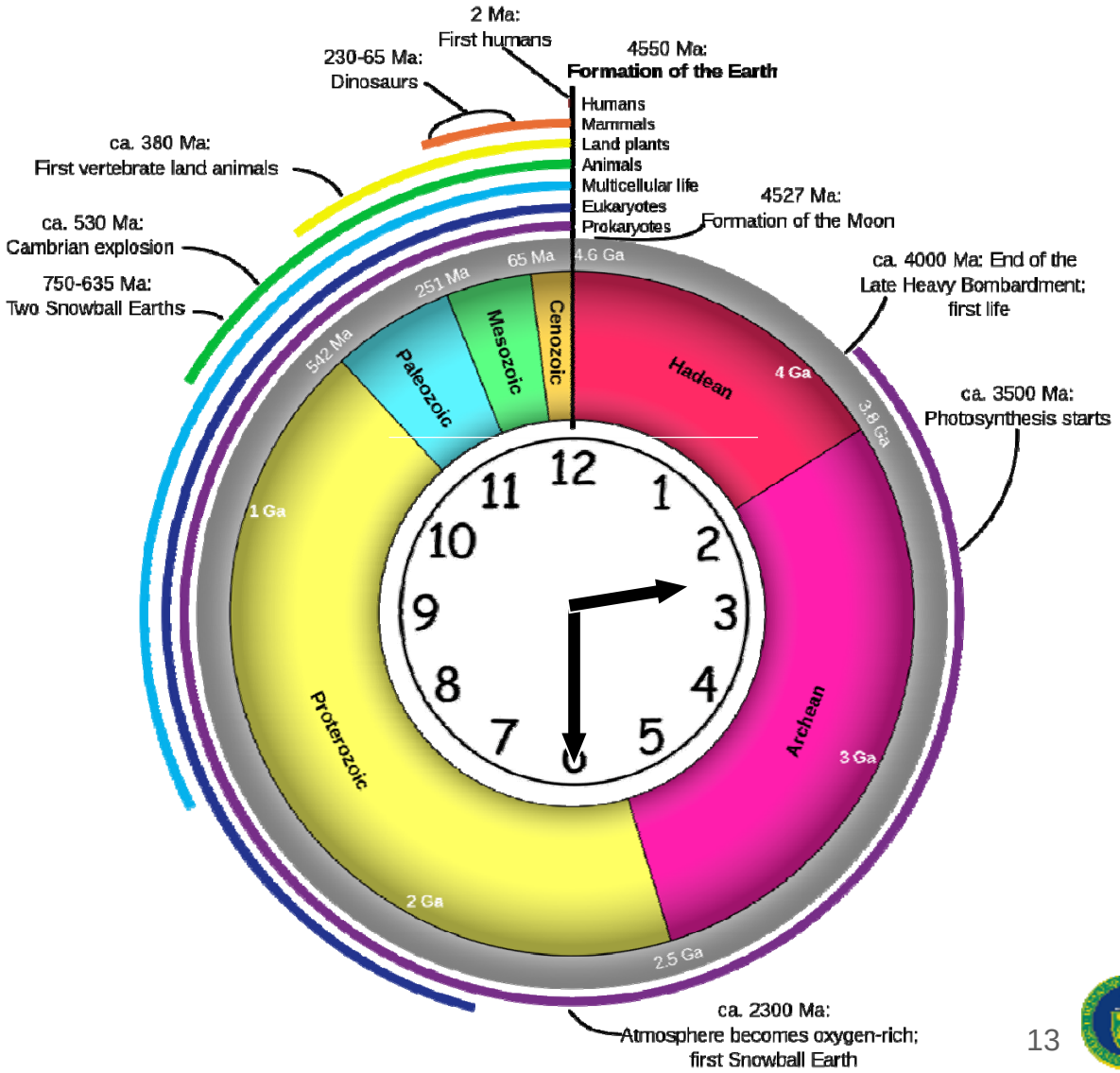
EVOLUTIONARY PERSPECTIVE

- Earth Forms



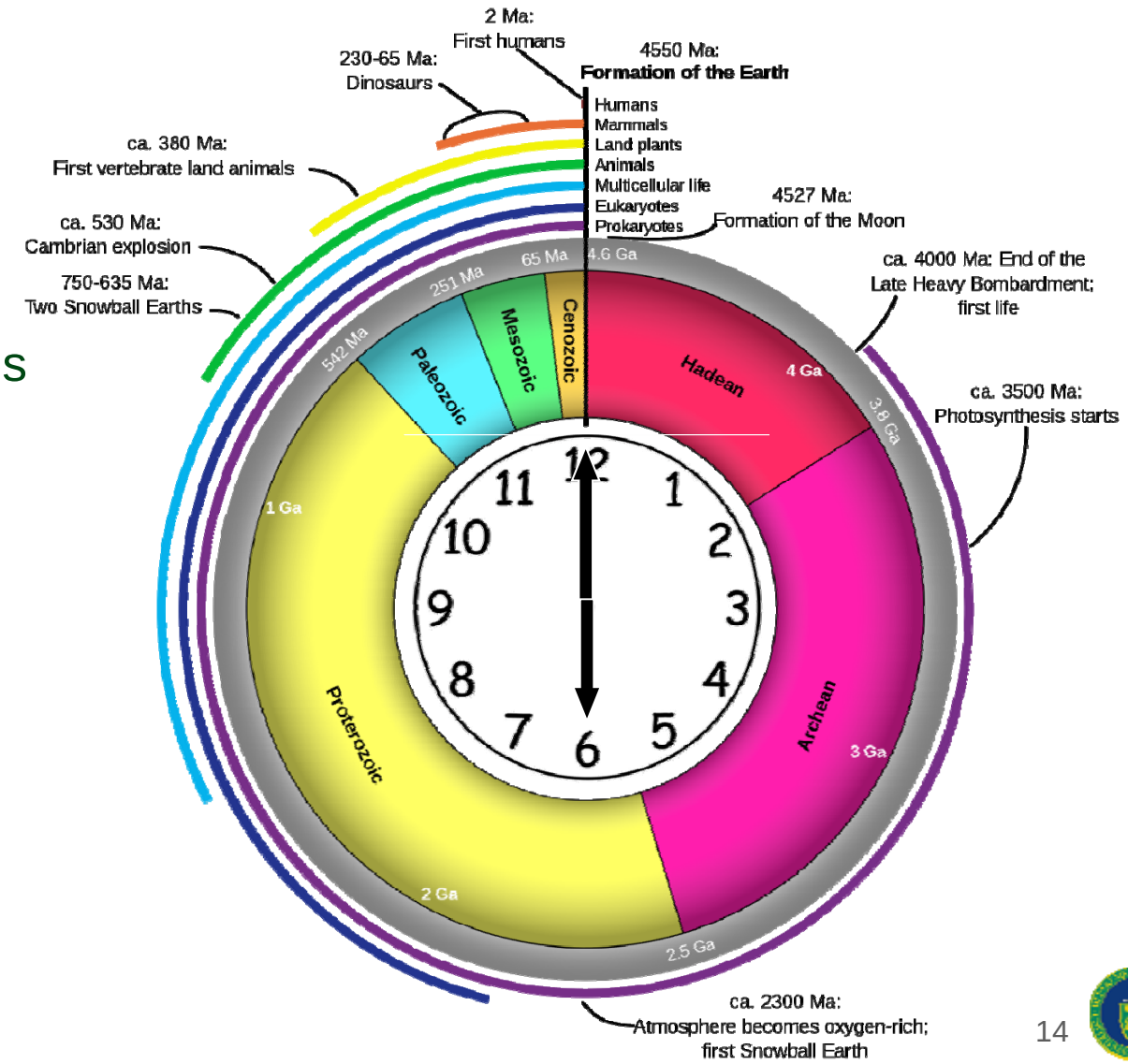
EVOLUTIONARY PERSPECTIVE

- Earth Forms
- Photosynthesis begins



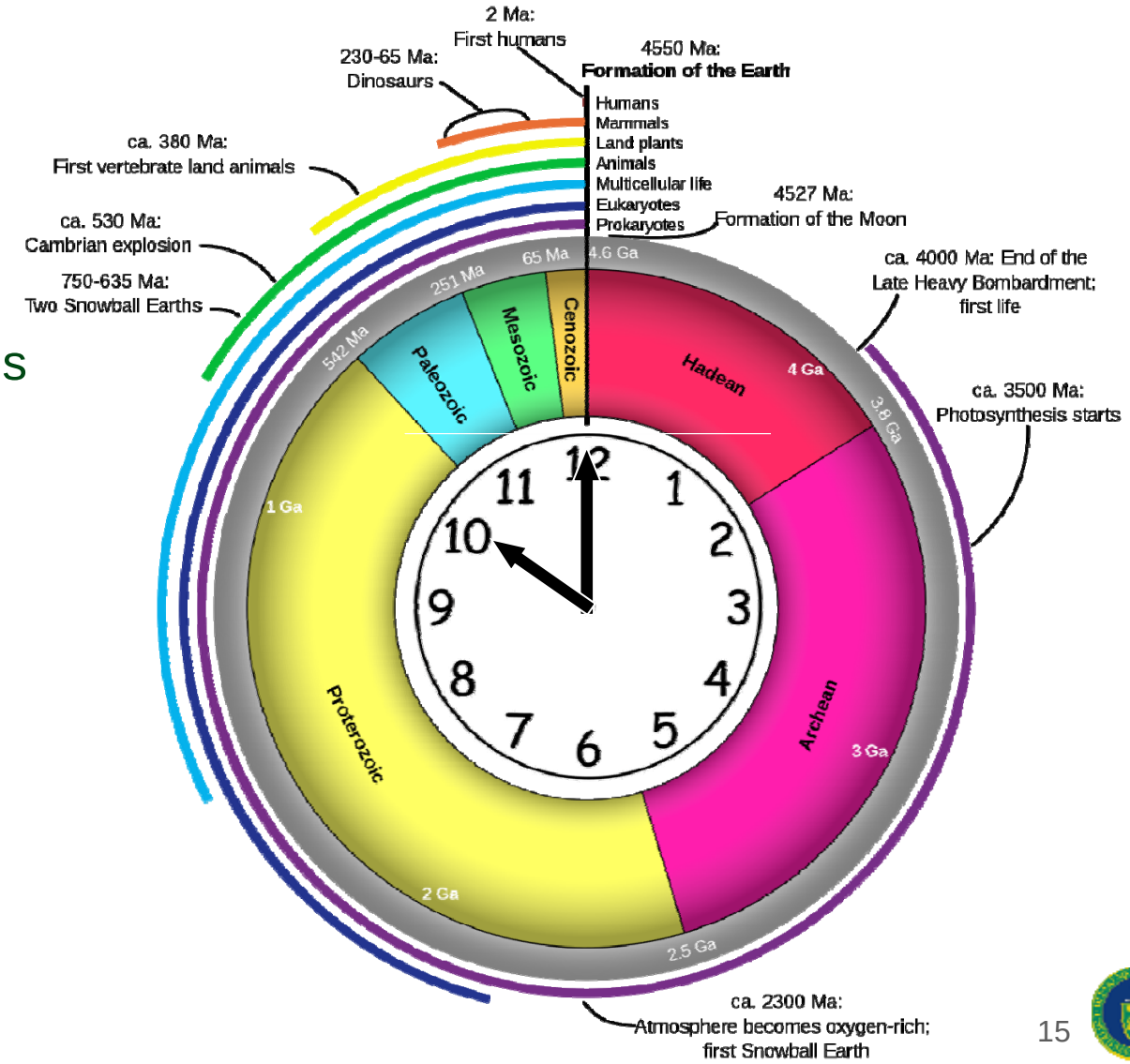
EVOLUTIONARY PERSPECTIVE

- Earth Forms
- Photosynthesis begins
- Oxygen dominates



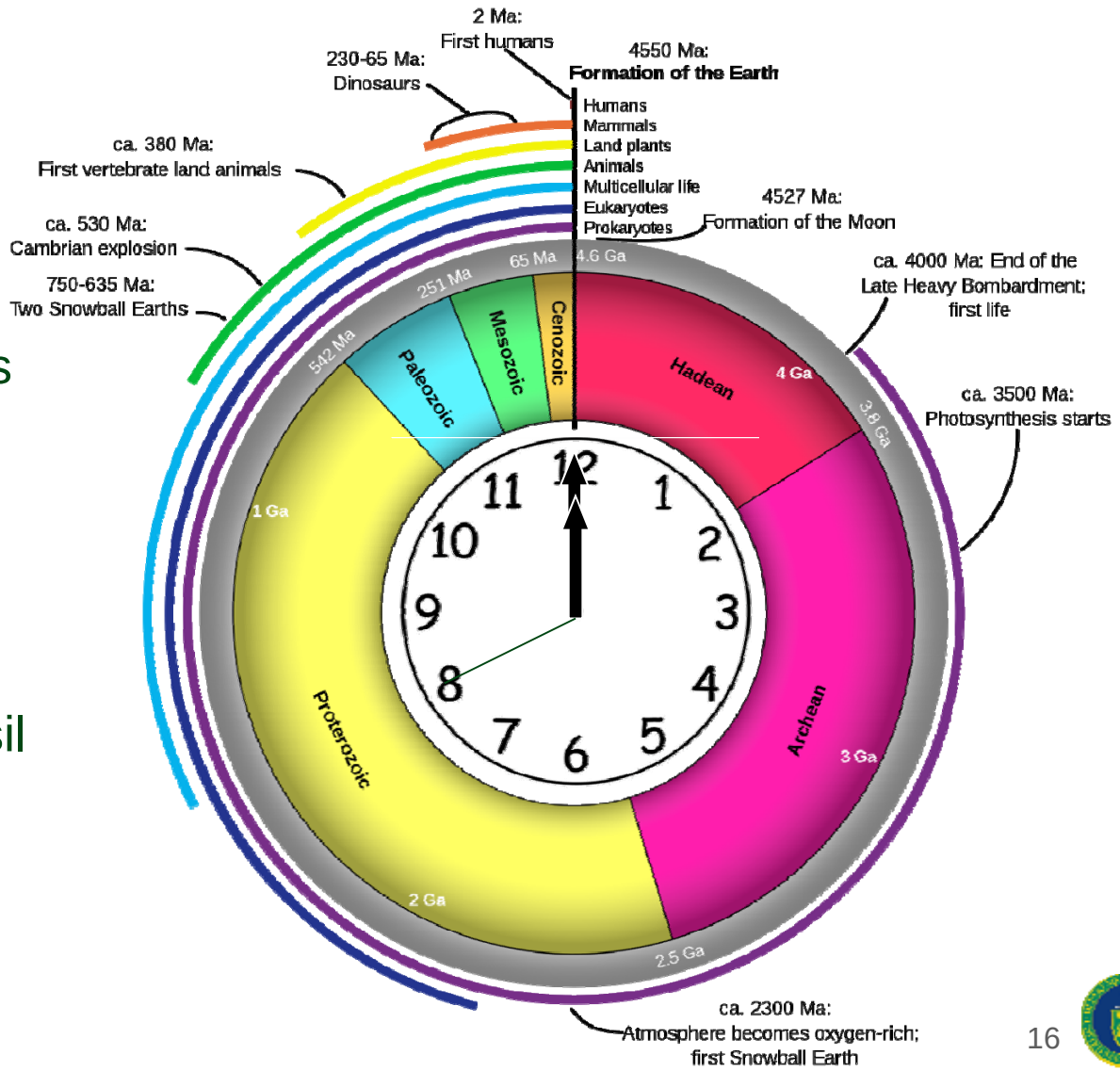
EVOLUTIONARY PERSPECTIVE

- Earth Forms
- Photosynthesis begins
- Oxygen dominates
- “Fossil fuels” are formed

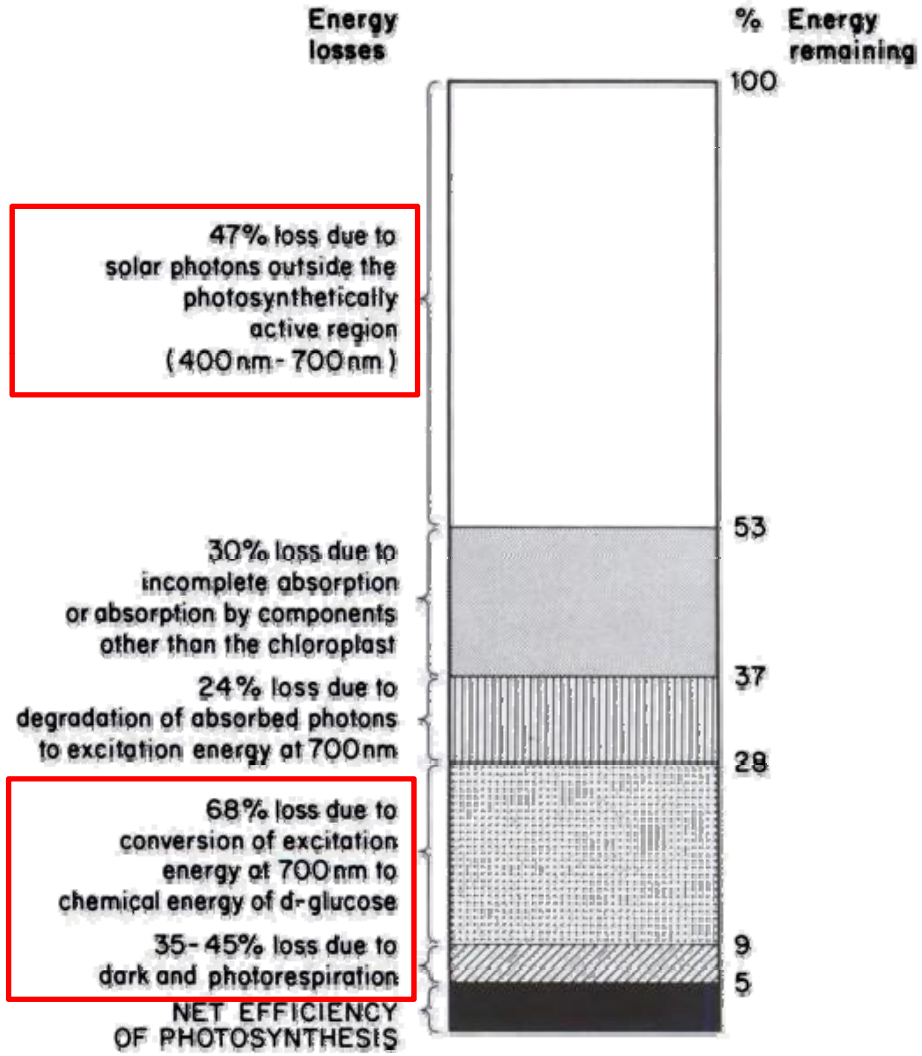


EVOLUTIONARY PERSPECTIVE

- Earth Forms
- Photosynthesis begins
- Oxygen dominates
- “Fossil fuels” are formed
- Humans appear
- On this scale, fossil fuels have been used for 2 ms



ENERGY LOSSES IN BIOFUELS



Hall & Rao, 1999

Photosynthesis:

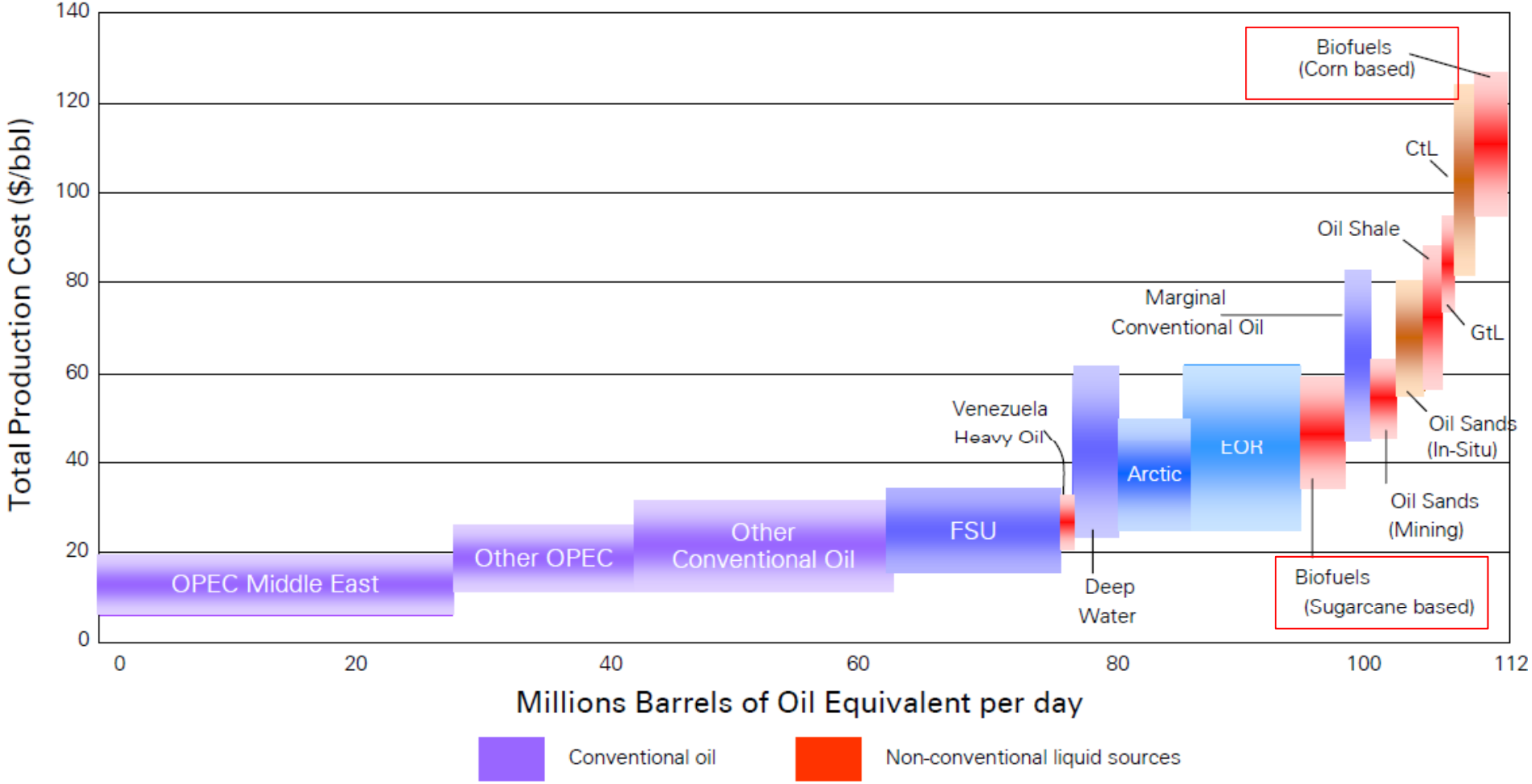
$$CO_2 + H_2O \rightarrow C_6H_{12}O_6$$

Fermentation:

$$C_6H_{12}O_6 \rightarrow 2CO_2 + 2\ C_2H_5OH$$

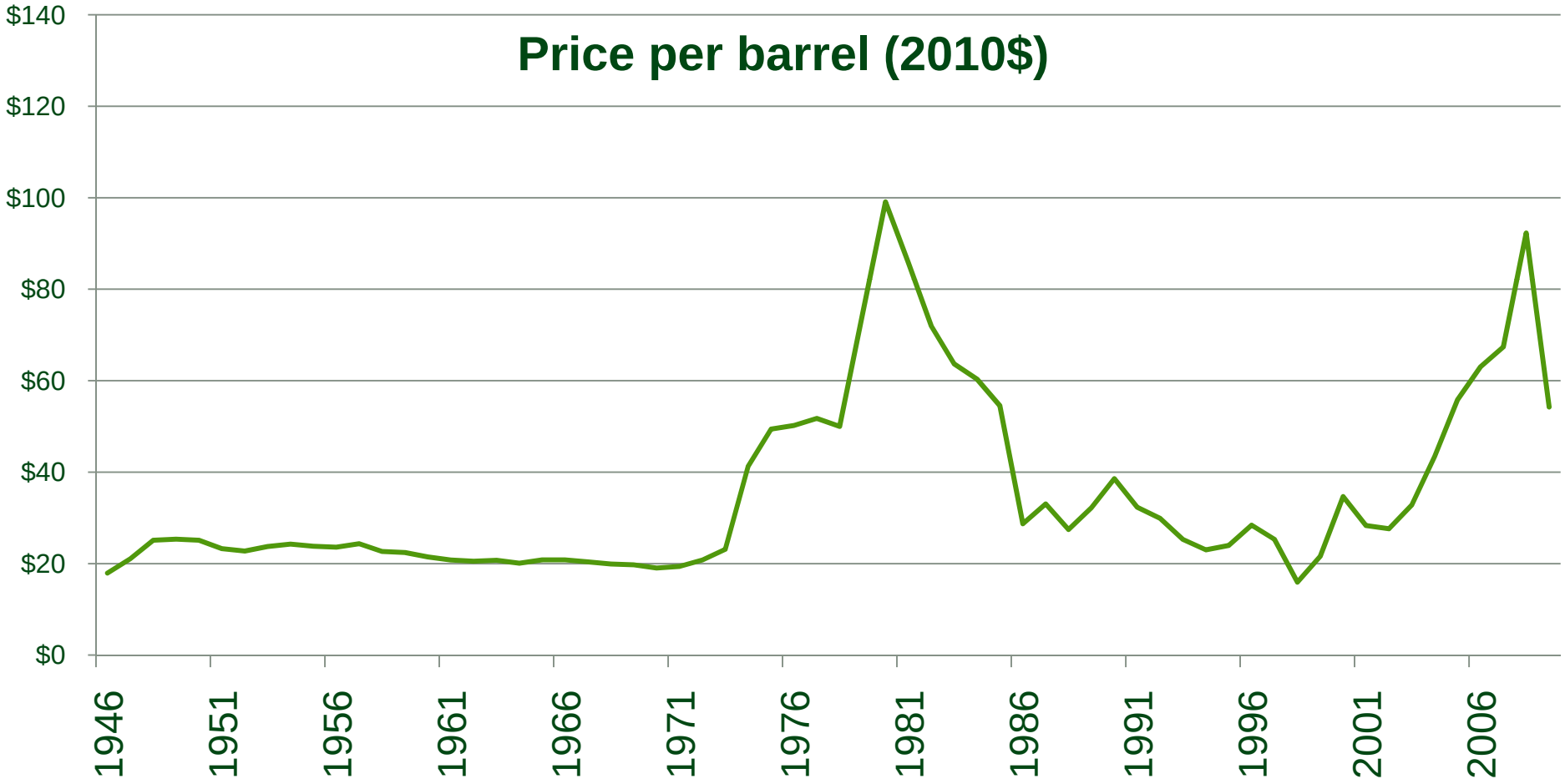
One third of the carbon captured is *not* converted into fuel.

BIOFUELS: ECONOMICS



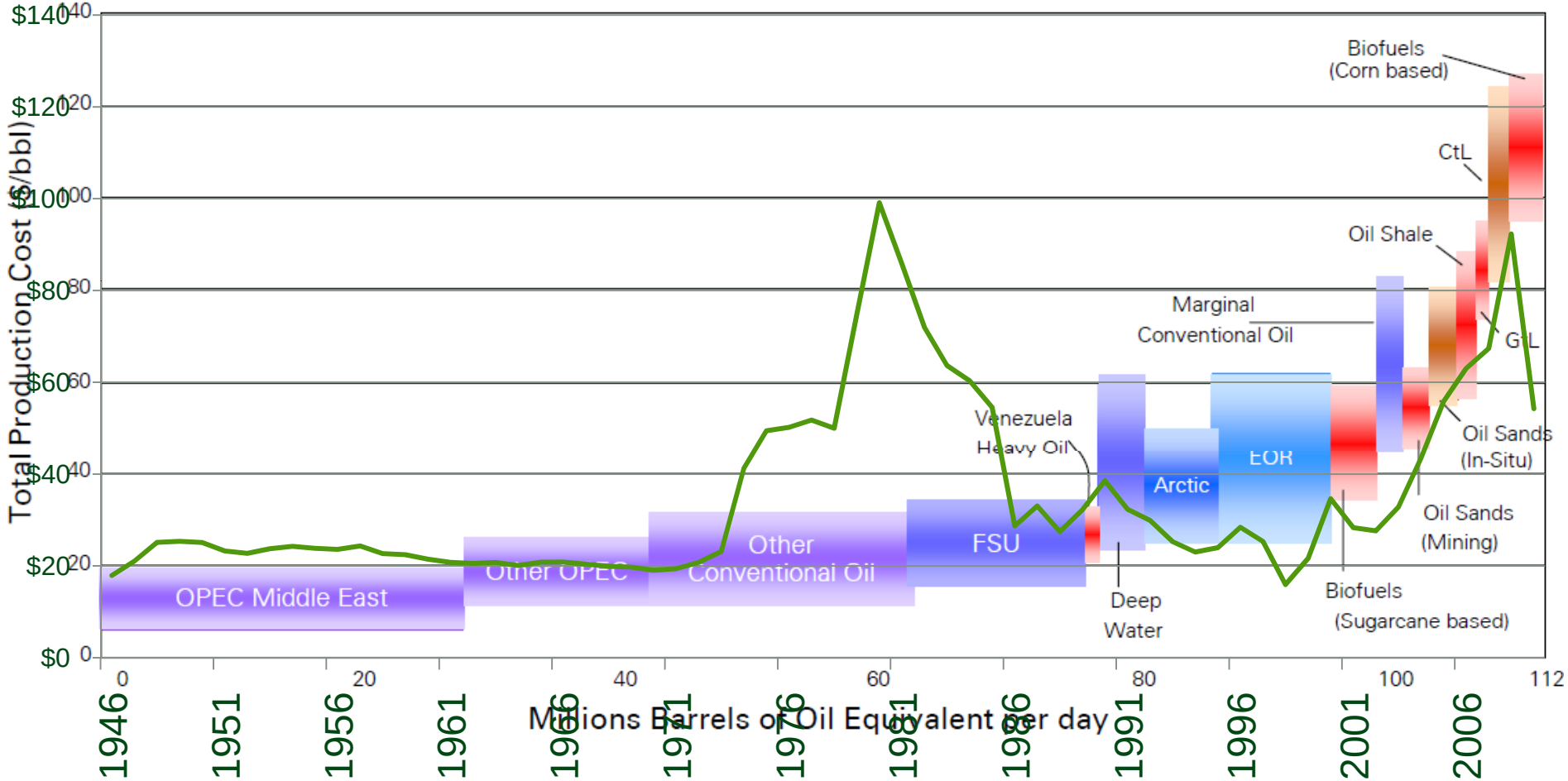
Source: Booz Allen Hamilton analysis based on information from IEA, DOE and interviews with super-majors

PETROFUEL ECONOMICS

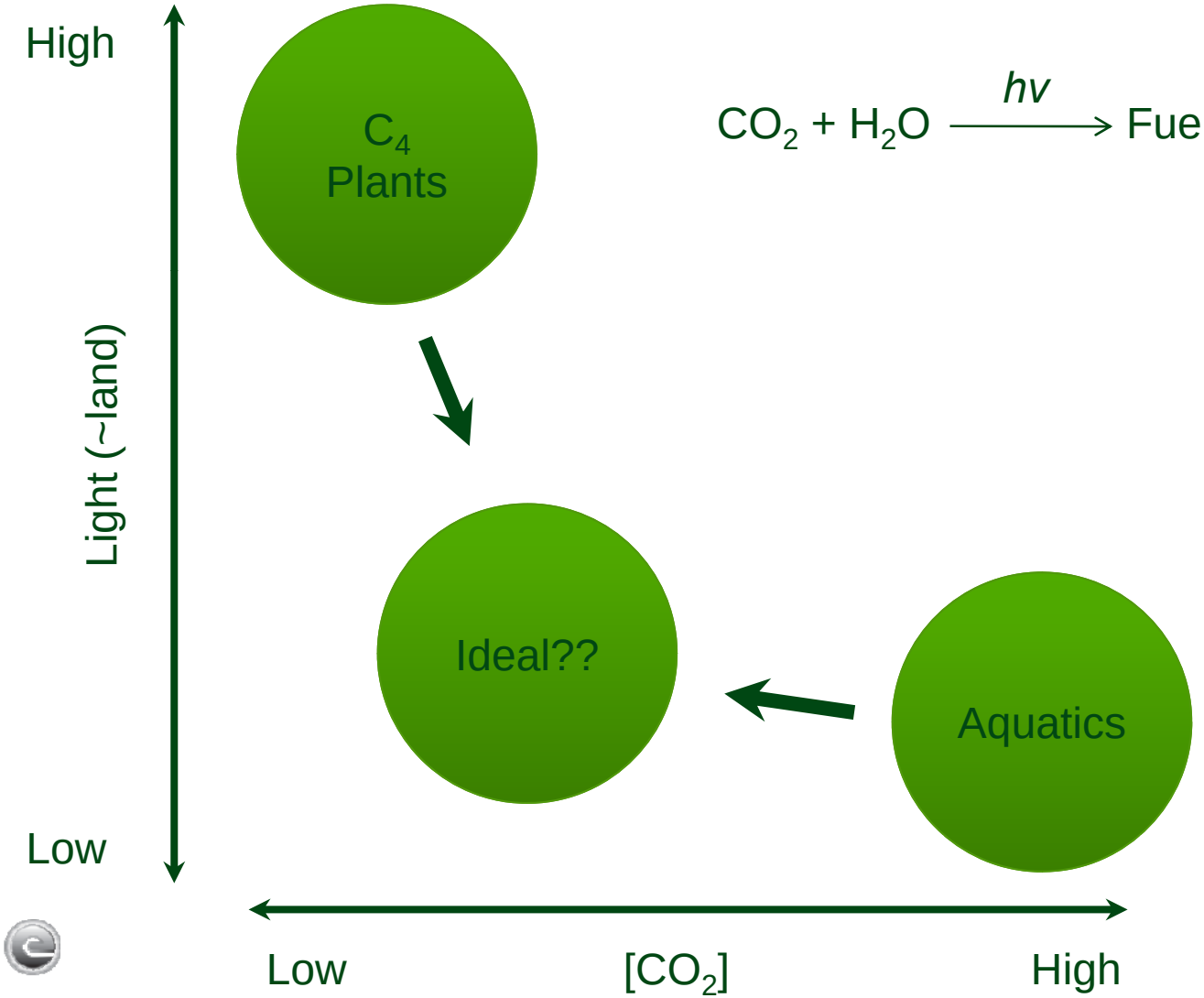


Source: InflationData.com; Annual average price

BIOFUELS: AN ECONOMIC CONTEXT



FRAMING THE ISSUES

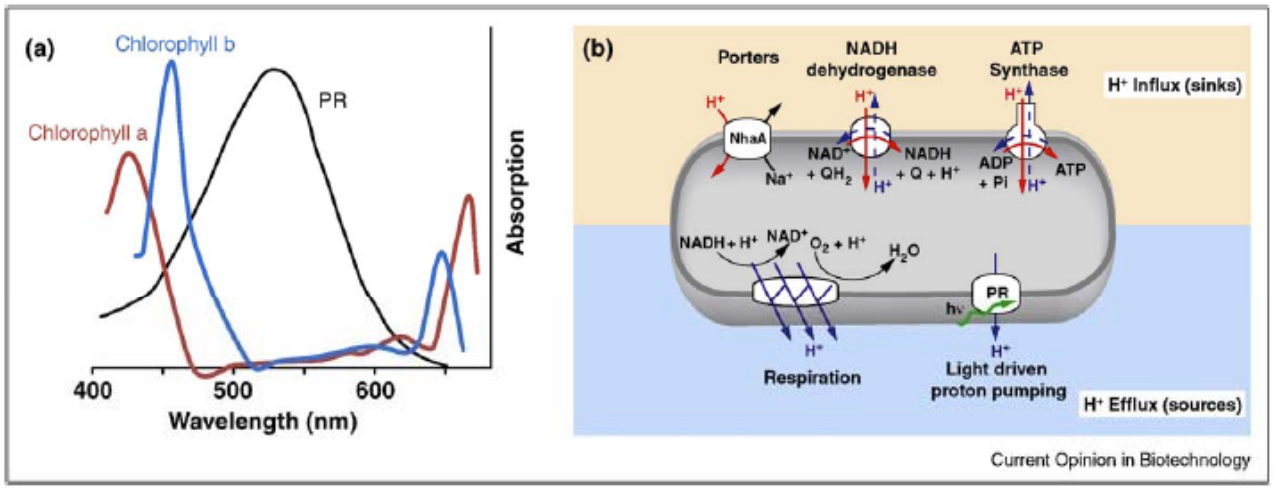


$$CO_2 + H_2O \xrightarrow{hv} \text{Fuel}$$

ABSORPTION ENGINEERING

- Proteorhodopsin

Figure 2

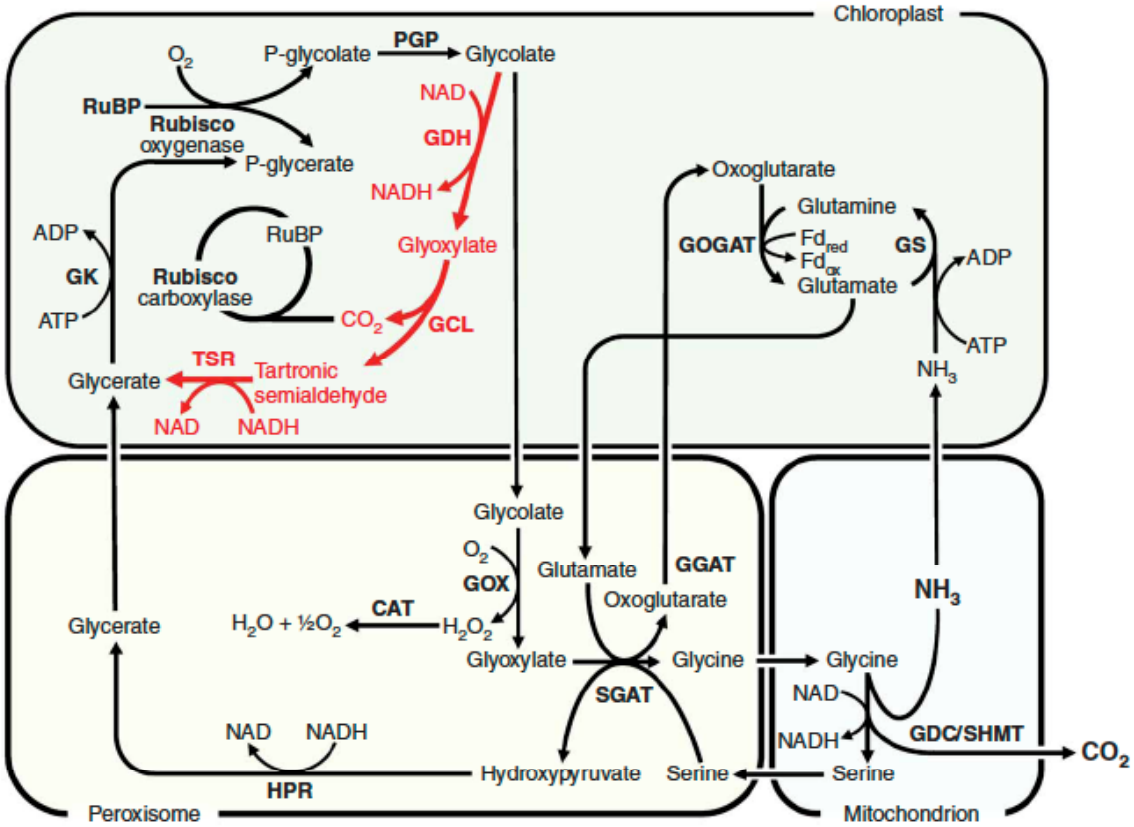


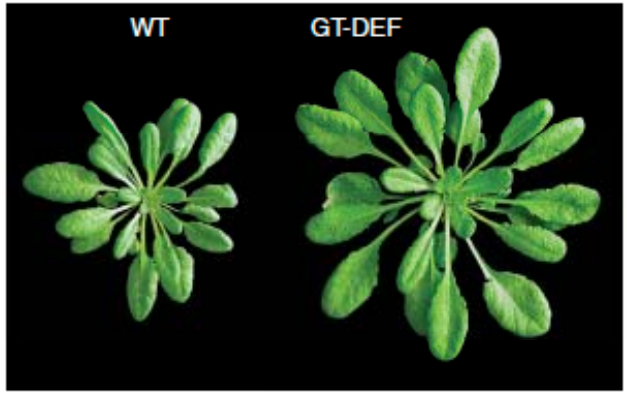
(a) Comparison of the absorption spectra of chlorophylls and proteorhodopsin (PR) shows that PR fills a gap in the chlorophyll absorption spectrum. Chlorophyll data from Mackinney [42]. **(b)** Schematic representation of enzymes and complexes generating and utilizing proton motive force. PR will be of particular use in conditions or processes where the pmf is low and key enzymatic reactions are ATP-limited or pmf-limited. Pmf can be supplied by oxidative phosphorylation or proton pumping by PR and drives many processes including ATP production, ion transport, and conversion of NAD^+ to NADH.

Walter et al., Current Opinion in Biotechnology 2010, 21:265–270

METABOLIC ENGINEERING

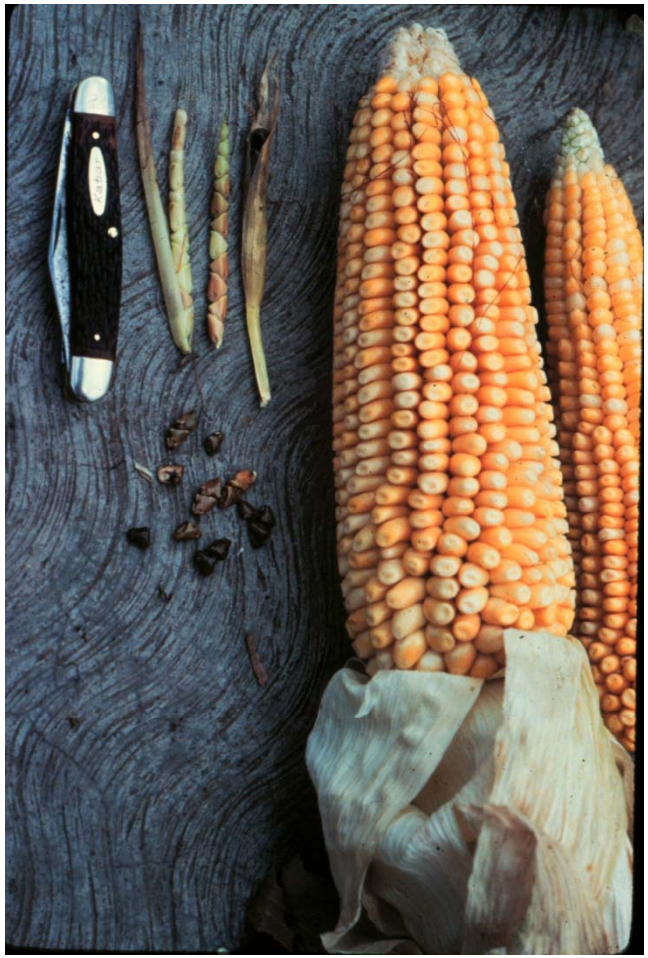
- Photorespiratory bypass





Kebeish et al., Nature Biotechnology 25, p593 (2007)

RAPID CONVENTIONAL GENETICS



Teosinte-to-maize

- Human-applied breeding
- 9,000 years, countless individual selection steps, but evidently successful

ARPA-E'S FUNDING CHOICES

- ARPA-E:
  - funds the development of disruptive new technologies rather than new scientific knowledge
  - focuses on high-risk, high-reward projects with significant commercial potential
  - chooses projects that that are generally unable to attract private sector financing because of the significant risks involved

- **break·through** [*breyk-throo*] –*noun*. **1.** A military movement or advance all the way through and beyond an enemy's front-line defense