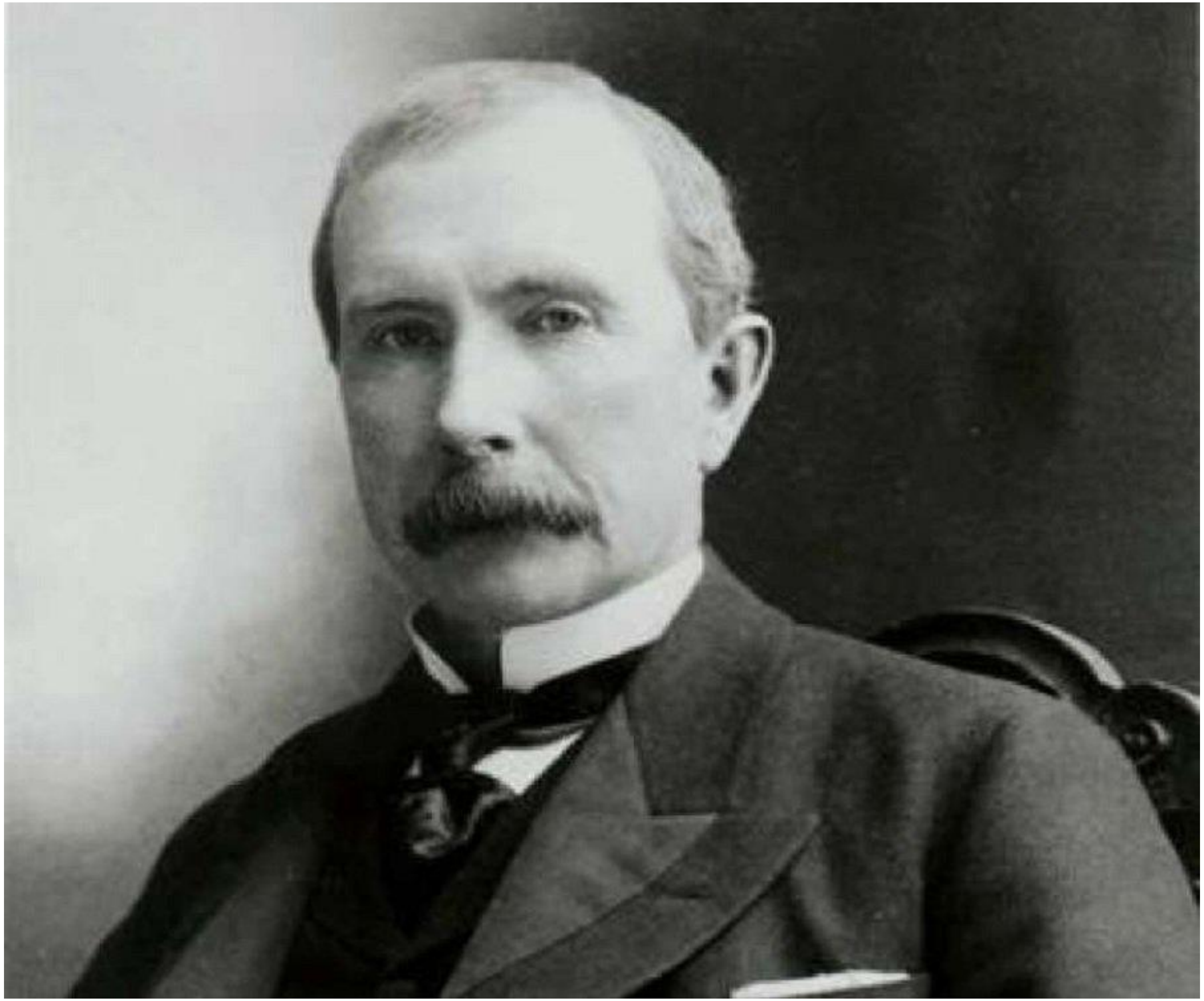
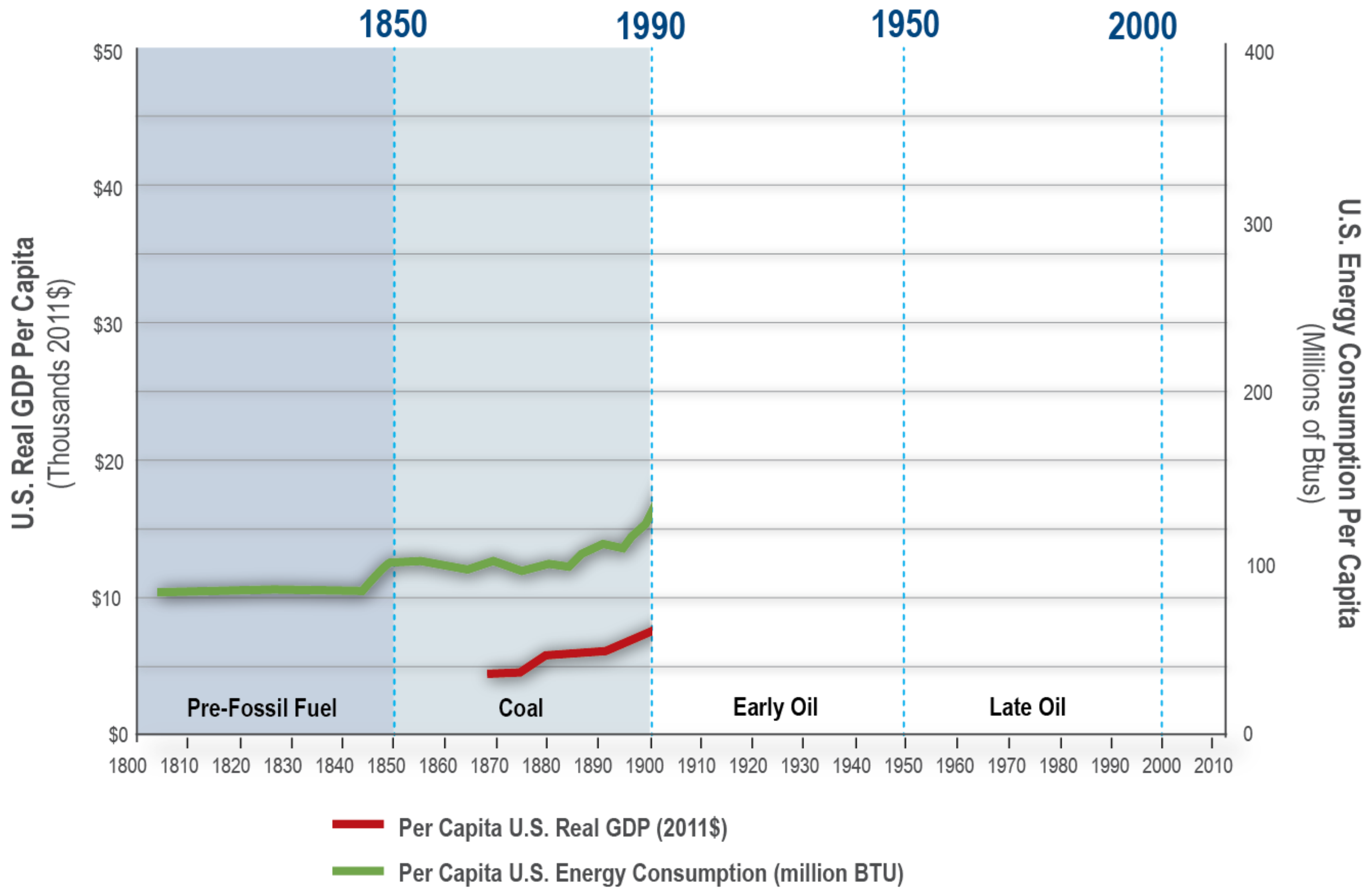




Energy Use and Prosperity (US, 1800-1900)

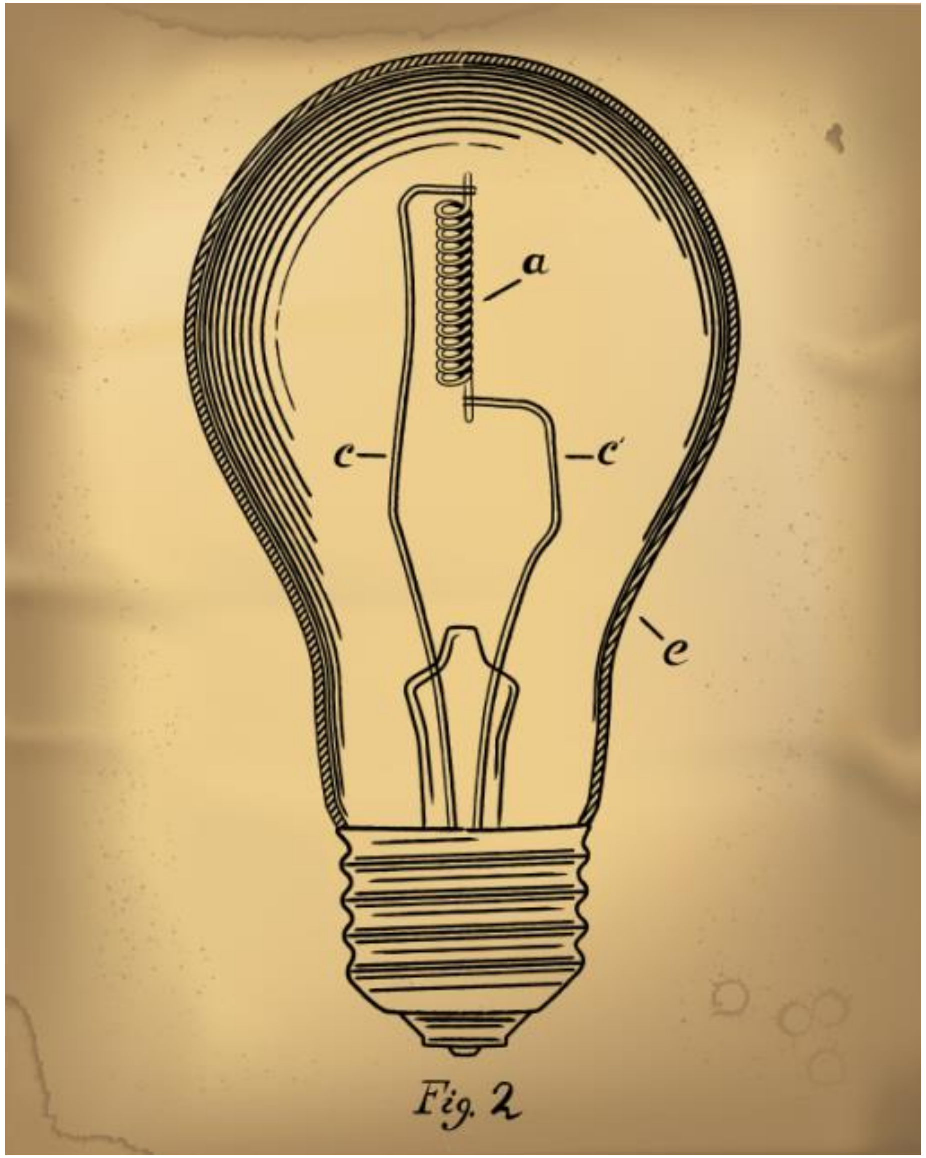
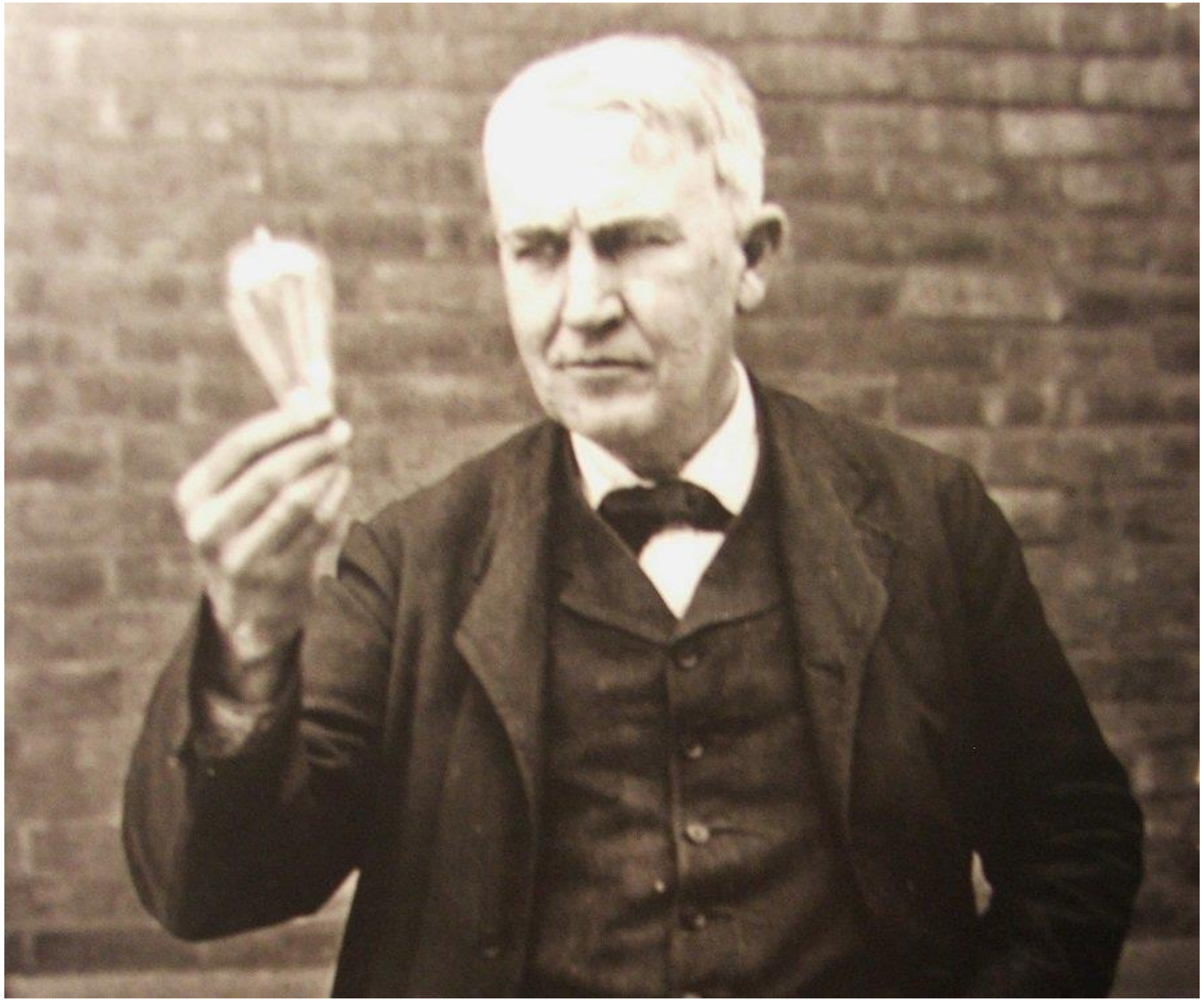
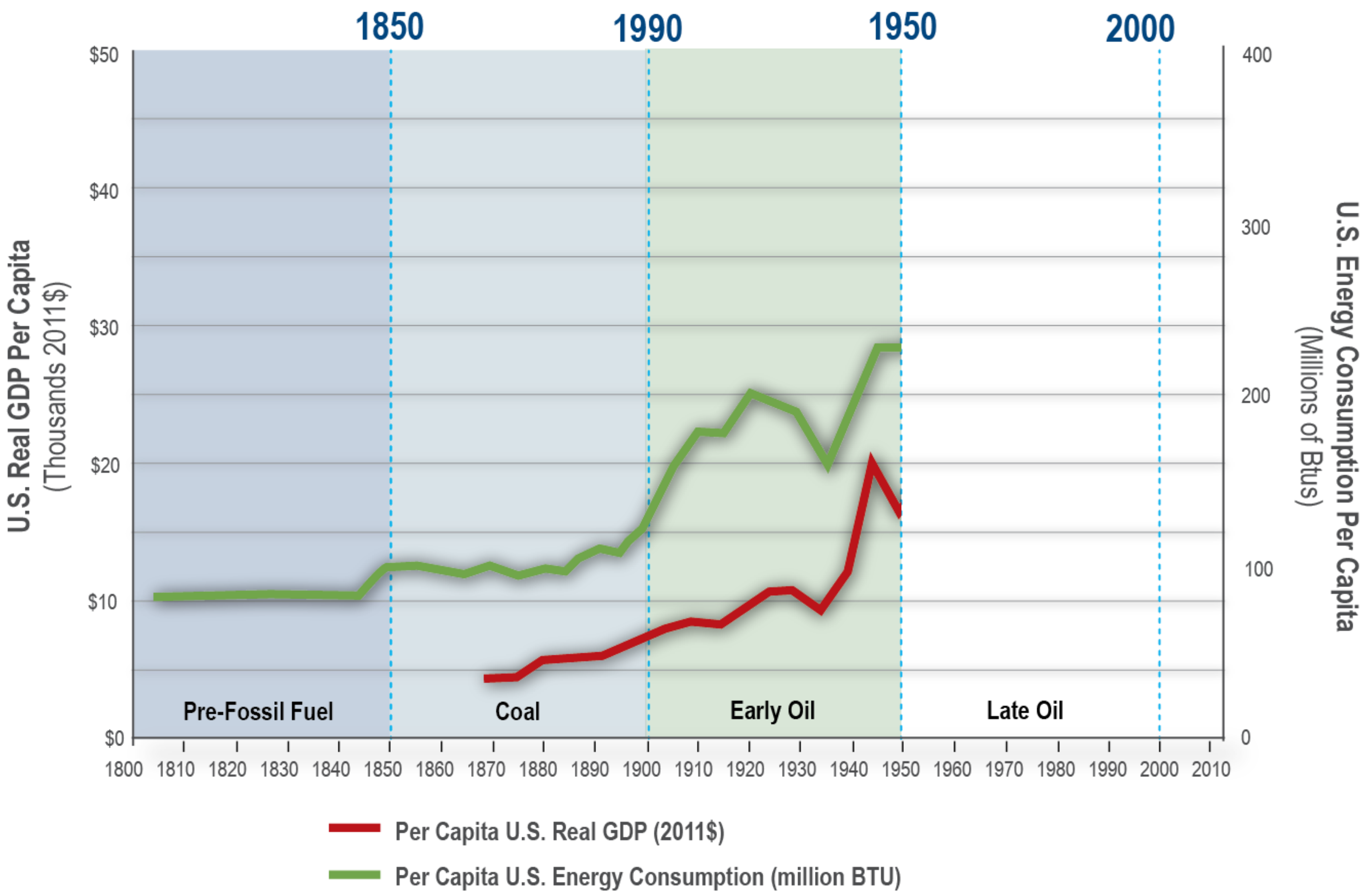
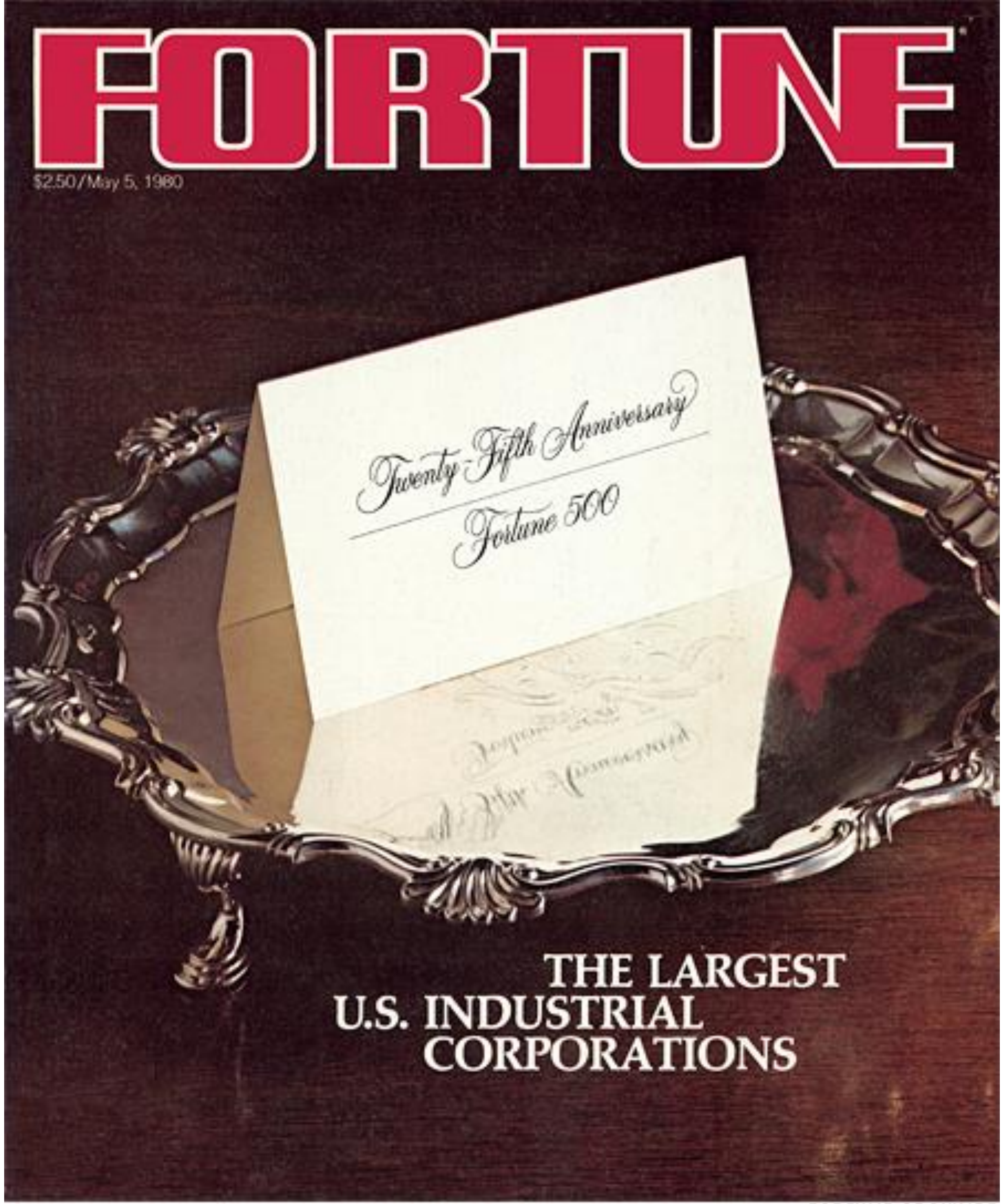


Fig. 2





Energy Use and Prosperity (US, 1800-1900)



FORTUNE

$2.50 / May 5, 1980

Twenty-Fifth Anniversary

Fortune 500

THE LARGEST
U.S. INDUSTRIAL
CORPORATIONS

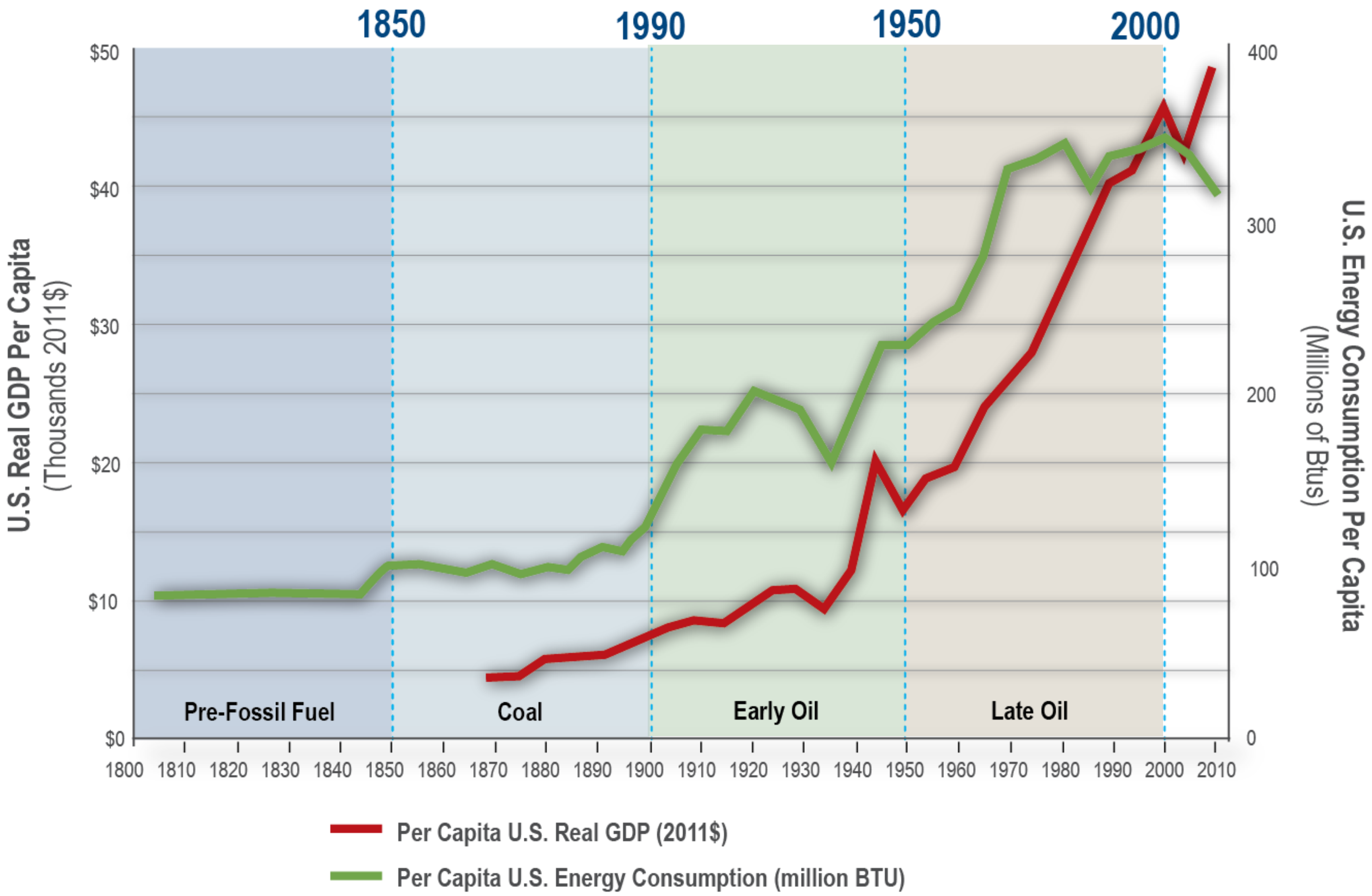
ExxonMobil

Mobil

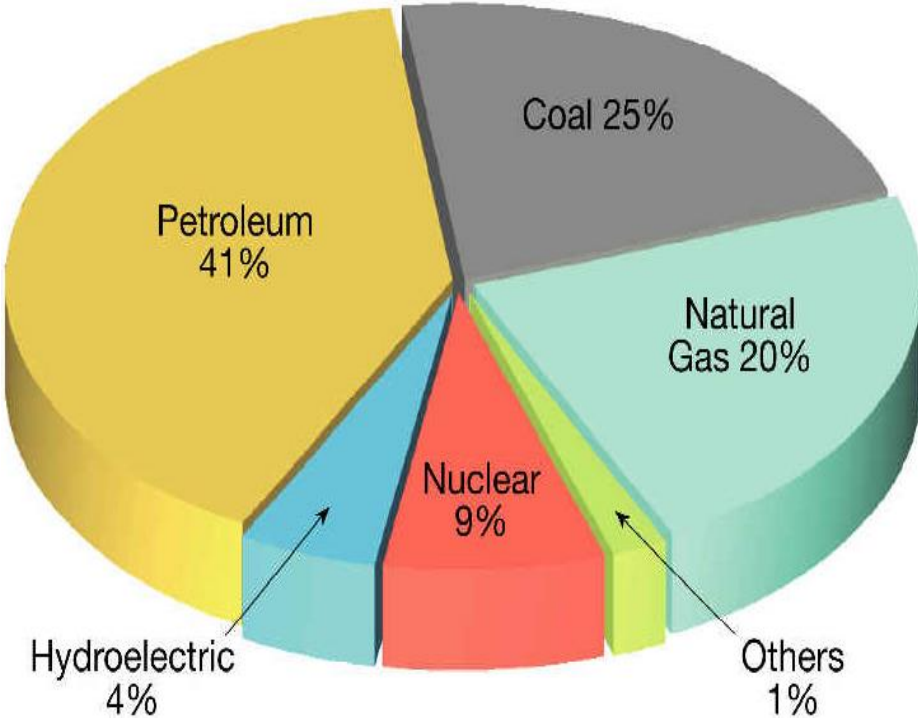
Chevron

Gulf

AMOCO



Energy Use and Prosperity (US, 1800-2000)


Coal 25%
Petroleum 41%
Natural Gas 20%
Nuclear 9%
Hydroelectric 4%
Others 1%


Access to Energy

The Origin of Breakthrough Energy

Breakthrough Energy VENTURES

01

CLIMATE IMPACT

We will invest in technologies that have the potential to reduce greenhouse gas emissions by at least half a gigaton.

02

OTHER INVESTMENTS

We will invest in companies with real potential to attract capital from sources outside of BEV and the broader Breakthrough Energy Coalition.

03

SCIENTIFIC POSSIBILITY

We will invest in technologies with an existing scientific proof of concept that can be meaningfully advanced.

04

FILLING THE GAPS

We will invest in companies that need the unique attributes of BEV capital, including patience, judgment by scientific milestones, flexible investment capabilities, and a significant global network.

Breakthrough Landscape of Innovation

ELECTRICITY TRANSPORTATION AGRICULTURE MANUFACTURING BUILDINGS

greenhouse gas emissions.

PUBLIC INVESTMENT

Governments around the world commit budget to scientific research into new energy solutions.

SCIENTIFIC INNOVATIONS

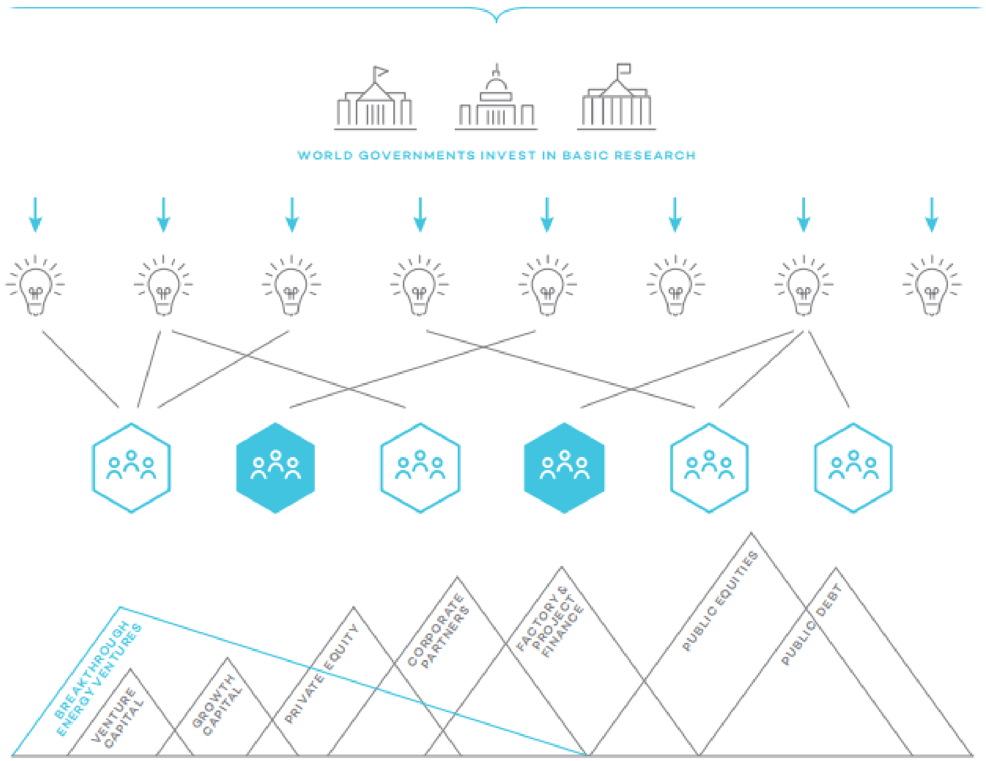
Leading research institutions, primarily funded by governments, working in collaboration will deliver new and exciting discoveries, with a variety of potential applications.

COMPANIES & PRODUCTS

New companies are formed around those innovations seeking capital from investors.

PRIVATE INVESTORS

Breakthrough Energy Coalition, BEV and other flexible capital is committed to investing in companies that will bring innovations from start-up to bankability.



- Batteries for Gasoline Equivalent EVs
- Lightweight Materials and Structures
- Low-GHG Liquid-Fuels Production—Non-Biomass
- Low-GHG Gaseous Fuels Production—H_2, CH_4
- High-Energy-Density Gaseous Fuel Storage
- High-Efficiency Thermal Engines
- High-Efficiency, Low-Cost Electrochemical Engines
- Low-GHG Liquid Fuels Production—Biomass
- Transportation-System Efficiency Solutions
- Technology Solutions that Eliminate the Need for Travel
- Technology-Enabled Urban Planning and Design
- Low-GHG Air Transport
- Low-GHG Water-Borne-Goods Transportation

AGRICULTURE

- Reducing CH_4 and N_2O Emissions from Agriculture
- Zero-GHG Ammonia Production
- Reducing Methane Emissions from Ruminant Animals
- Developing Low-Cost, Low-GHG New Sources of Protein
- Eliminating Spoilage/Loss in the Food-Delivery Chain
- Soil-Management Solutions for GHG Reduction and CO_2 Storage
- Manure
- Agriculture-Related Deforestation

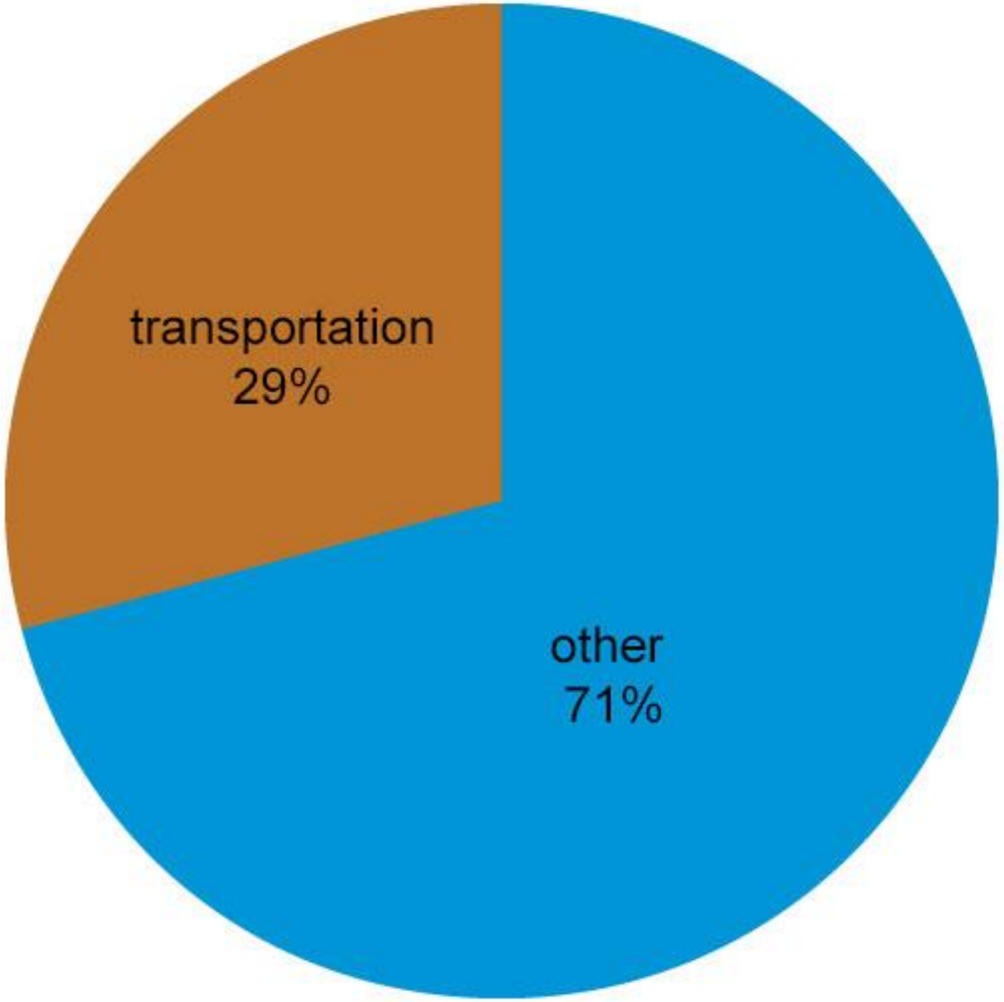
MANUFACTURING

- Low-GHG Chemicals
- Low-GHG Steel
- Low/Negative-GHG Cement
- Waste Heat Capture/Conversion
- Low-GHG Industrial Thermal Processing
- Low-GHG Paper Production
- Extreme Efficiency in IT/Data Centers
- Fugitive Methane Emissions from Industry
- Extreme Durability for Energy-Intensive Products and Materials
- Transformative Recycling Solutions for Energy-Intensive Products and Materials
- Increasing Biomass Uptake Rate of CO_2
- CO_2 Extraction from the Environment

BUILDINGS

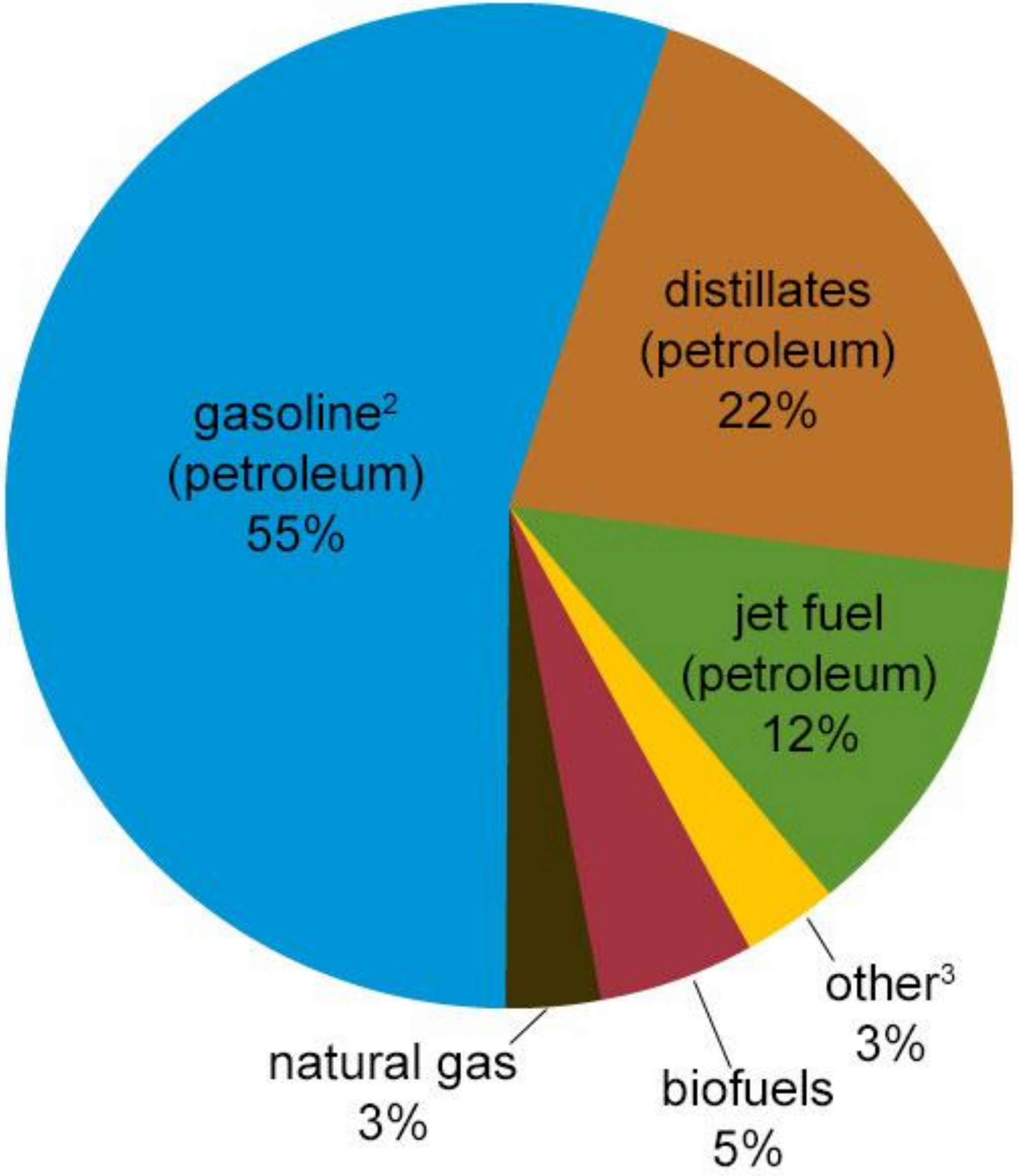
- High-Efficiency, Non-HFC Cooling & Refrigeration
- High-Efficiency Space/Water Heating
- Building-Level Electricity and Thermal Storage
- High-Efficiency Envelope: Windows and Insulation
- High Efficiency Lighting
- High-Efficiency Appliances and Plug-Loads
- Next-Generation Building Management
- Technology-Enabled Design of Efficient Buildings and Communities

Share of total U.S. energy used for transportation, 2017



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 2.1, April 2018, preliminary data

U.S. transportation energy sources/fuels, 2017[1]



Not. Happening.

Assumptions/Stipulations:

Liquid fuels for transportation will be highly persistent;

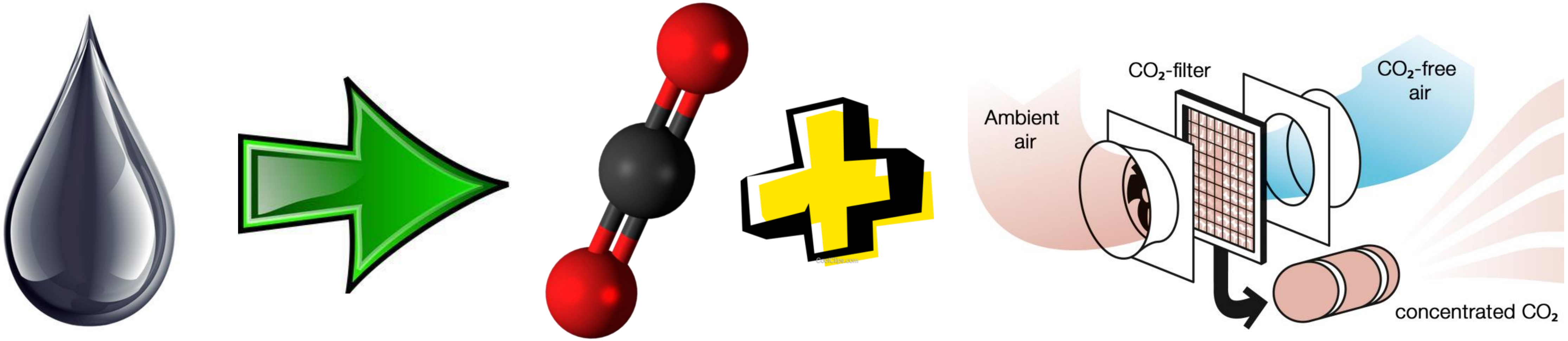
The planet will mandate zero-carbon fuels;

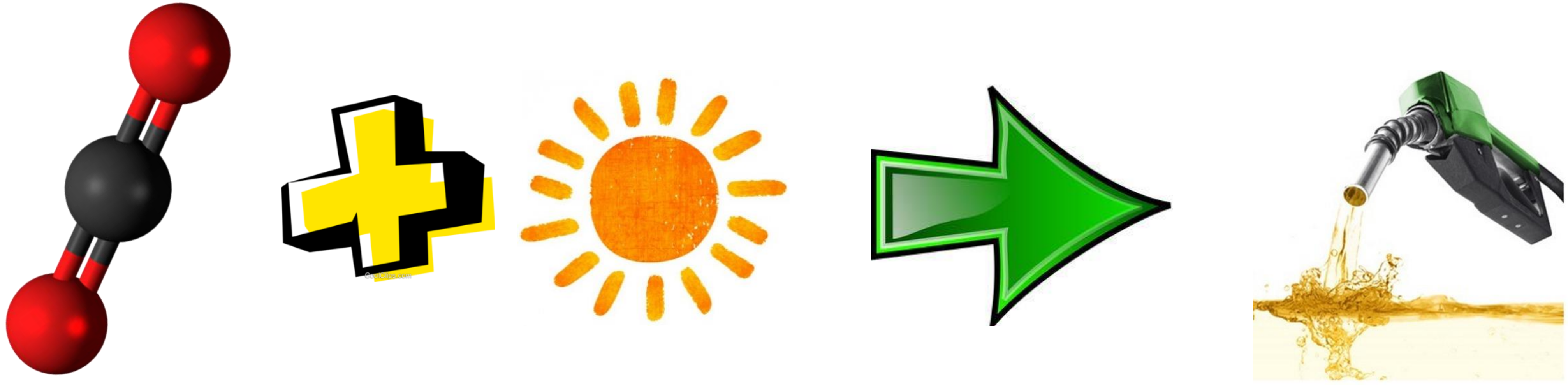
The planet will adopt the low-cost solution;

Subsidies at scale are not viable;

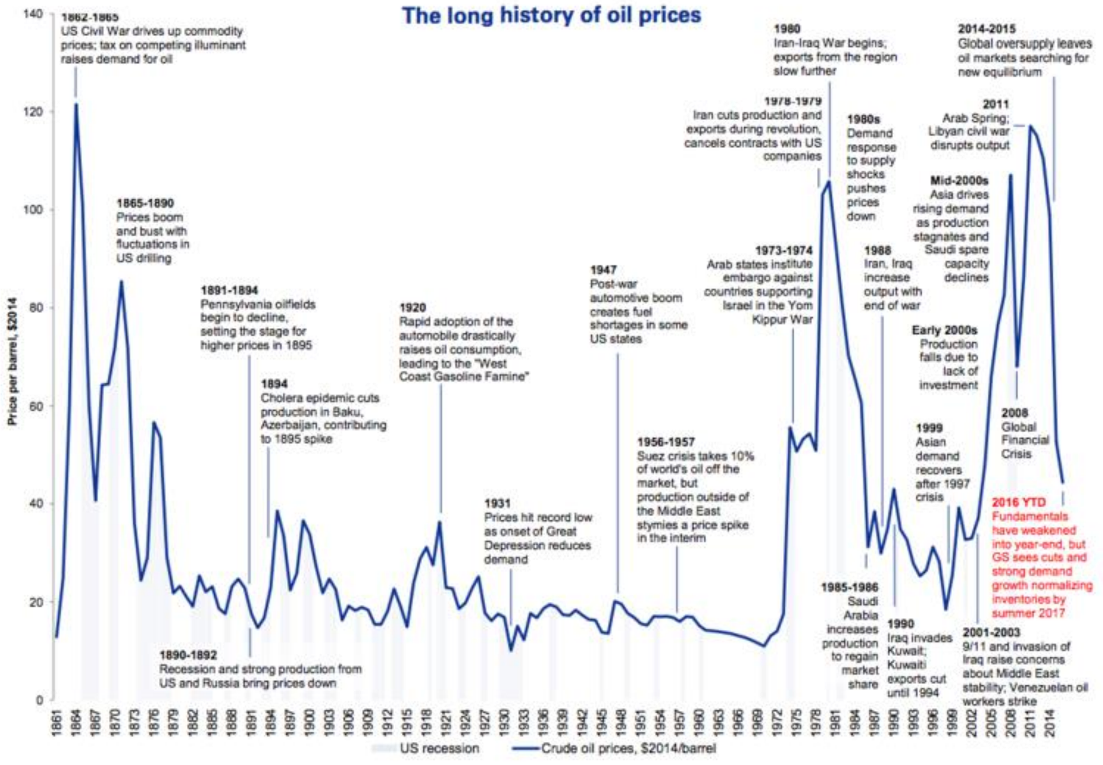
Infrastructure-compatible solutions are preferred.

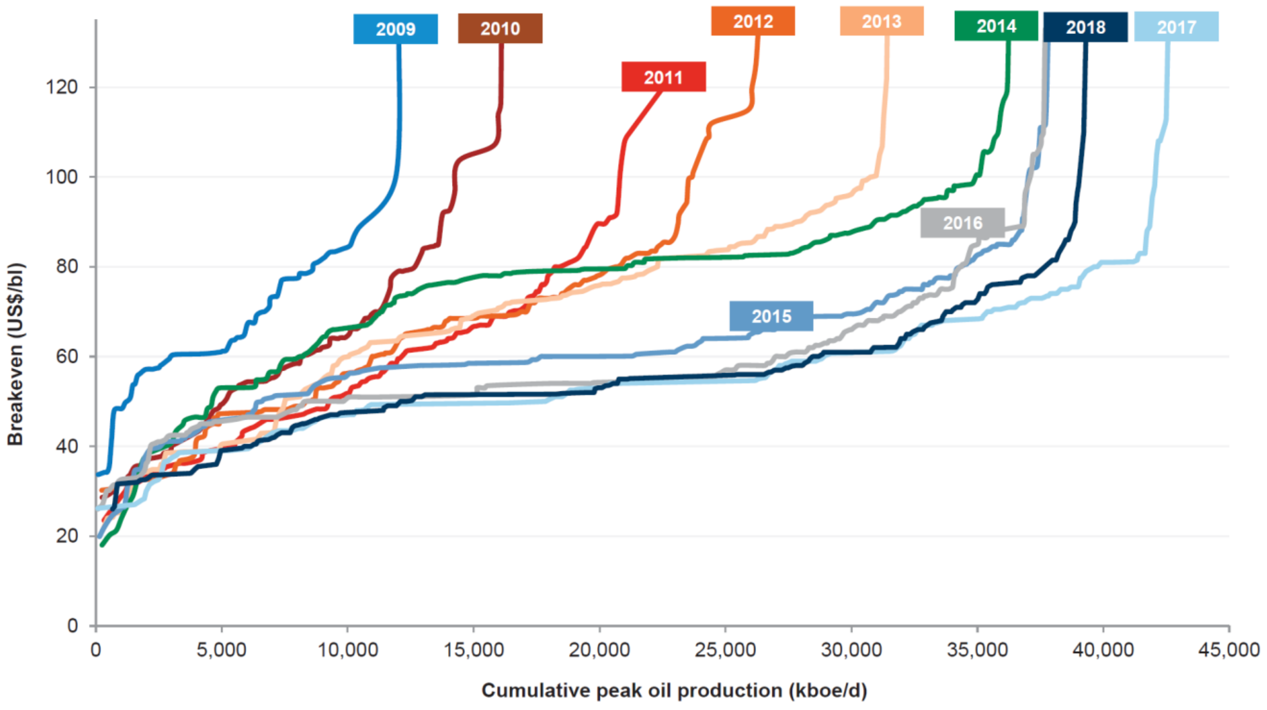
Zero-Carbon Liquid Fuels Means Air Capture





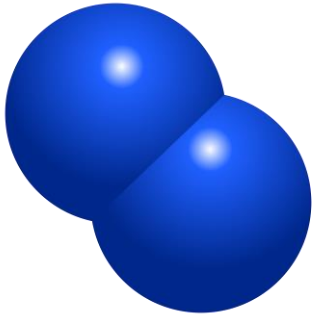
Guesstimating the Price of Oil





Avg 1972 – 2018 = $54/bbl

Strong price support at $60/bbl



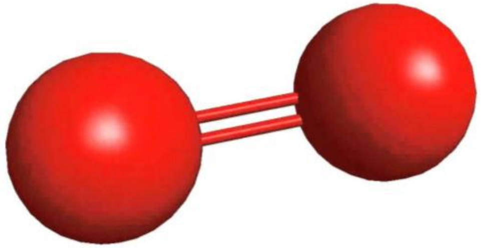
N_2

Concentration: 78.1%

Kinetic Diameter: 364 pM

Dipole moment: 0

Quadrupole moment: N



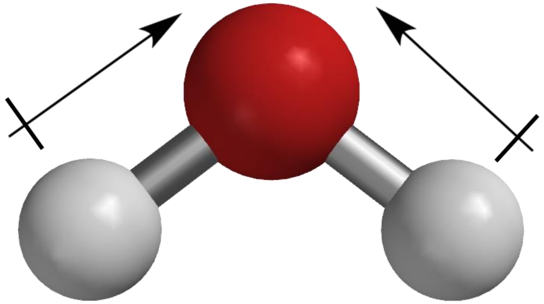
O_2

Concentration: 20.9%

Kinetic Diameter: 346 pM

Dipole Moment: 0

Quadrupole Moment: N



H_2O

Concentration: 0 - 5%

Kinetic Diameter: 265 pM

Dipole Moment: 1.8546 d

Quadrupole Moment: Y

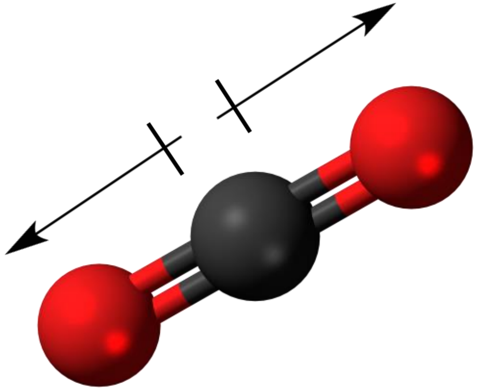
Ar

Concentration: 0.93%

Kinetic Diameter: 340 pM

Dipole Moment: 0

Quadrupole Moment: N



CO_2

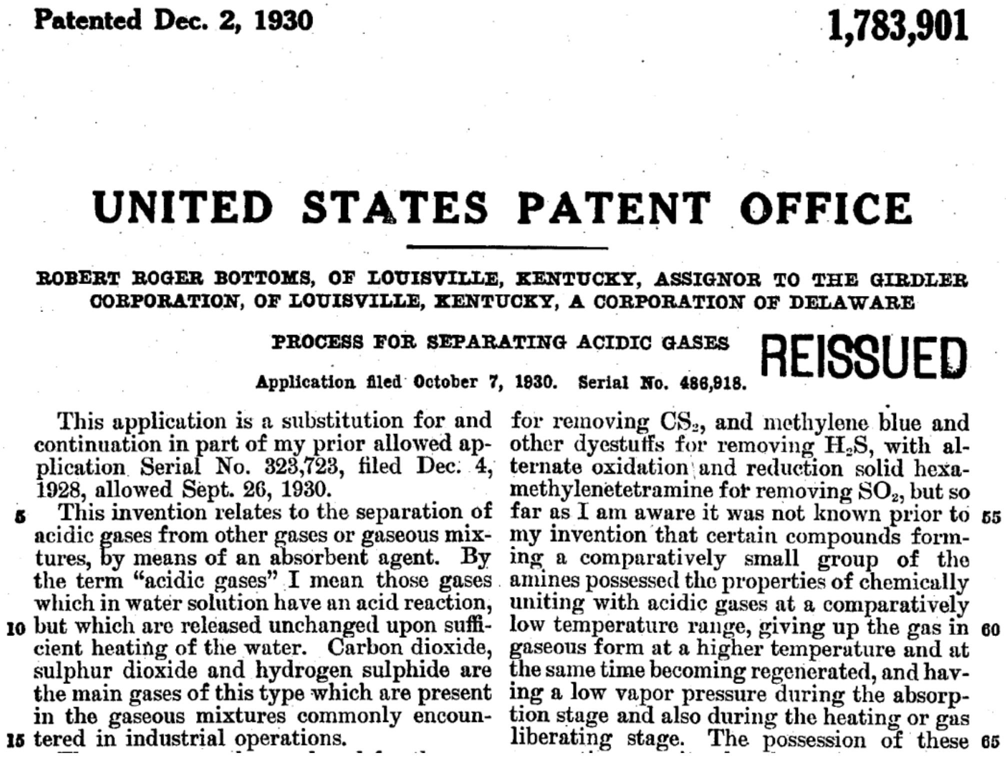
Concentration: 0.04%

Kinetic Diameter: 330 pM

Dipole Moment: 0

Quadrupole Moment: Y

Amines Long Known for CO_2 Capture



Patented Dec. 2, 1930 **1,783,901**

UNITED STATES PATENT OFFICE

ROBERT ROGER BOTTOMS, OF LOUISVILLE, KENTUCKY, ASSIGNOR TO THE GIRDLER CORPORATION, OF LOUISVILLE, KENTUCKY, A CORPORATION OF DELAWARE

PROCESS FOR SEPARATING ACIDIC GASES

REISSUED

Application filed October 7, 1930. Serial No. 486,918.

This application is a substitution for and continuation in part of my prior allowed application Serial No. 323,723, filed Dec. 4, 1928, allowed Sept. 26, 1930.

This invention relates to the separation of acidic gases from other gases or gaseous mixtures, by means of an absorbent agent. By the term "acidic gases" I mean those gases which in water solution have an acid reaction, but which are released unchanged upon sufficient heating of the water. Carbon dioxide, sulphur dioxide and hydrogen sulphide are the main gases of this type which are present in the gaseous mixtures commonly encountered in industrial operations.

for removing CS_2, and methylene blue and other dyestuffs for removing H_2S, with alternate oxidation and reduction solid hexamethylenetetramine for removing SO_2, but so far as I am aware it was not known prior to my invention that certain compounds forming a comparatively small group of the amines possessed the properties of chemically uniting with acidic gases at a comparatively low temperature range, giving up the gas in gaseous form at a higher temperature and at the same time becoming regenerated, and having a low vapor pressure during the absorption stage and also during the heating or gas liberating stage. The possession of these

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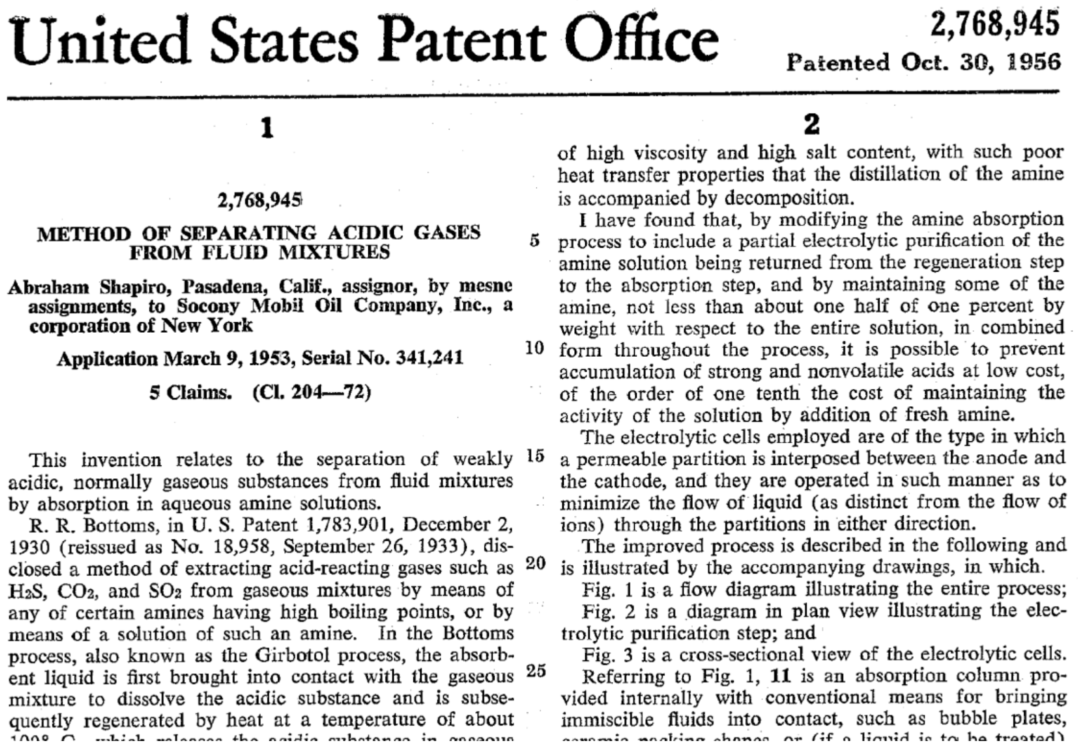


United States Patent Office

2,768,945
Patented Oct. 30, 1956

1

2,768,945

METHOD OF SEPARATING ACIDIC GASES FROM FLUID MIXTURES

Abraham Shapiro, Pasadena, Calif., assignor, by mesne assignments, to Socony Mobil Oil Company, Inc., a corporation of New York

Application March 9, 1953, Serial No. 341,241

5 Claims. (Cl. 204—72)

This invention relates to the separation of weakly acidic, normally gaseous substances from fluid mixtures by absorption in aqueous amine solutions.

R. R. Bottoms, in U. S. Patent 1,783,901, December 2, 1930 (reissued as No. 18,958, September 26, 1933), disclosed a method of extracting acid-reacting gases such as H_2S, CO_2, and SO_2 from gaseous mixtures by means of any of certain amines having high boiling points, or by means of a solution of such an amine. In the Bottoms process, also known as the Girbotol process, the absorbent liquid is first brought into contact with the gaseous mixture to dissolve the acidic substance and is subsequently regenerated by heat at a temperature of about

2

of high viscosity and high salt content, with such poor heat transfer properties that the distillation of the amine is accompanied by decomposition.

I have found that, by modifying the amine absorption process to include a partial electrolytic purification of the amine solution being returned from the regeneration step to the absorption step, and by maintaining some of the amine, not less than about one half of one percent by weight with respect to the entire solution, in combined form throughout the process, it is possible to prevent accumulation of strong and nonvolatile acids at low cost, of the order of one tenth the cost of maintaining the activity of the solution by addition of fresh amine.

The electrolytic cells employed are of the type in which a permeable partition is interposed between the anode and the cathode, and they are operated in such manner as to minimize the flow of liquid (as distinct from the flow of ions) through the partitions in either direction.

The improved process is described in the following and is illustrated by the accompanying drawings, in which.

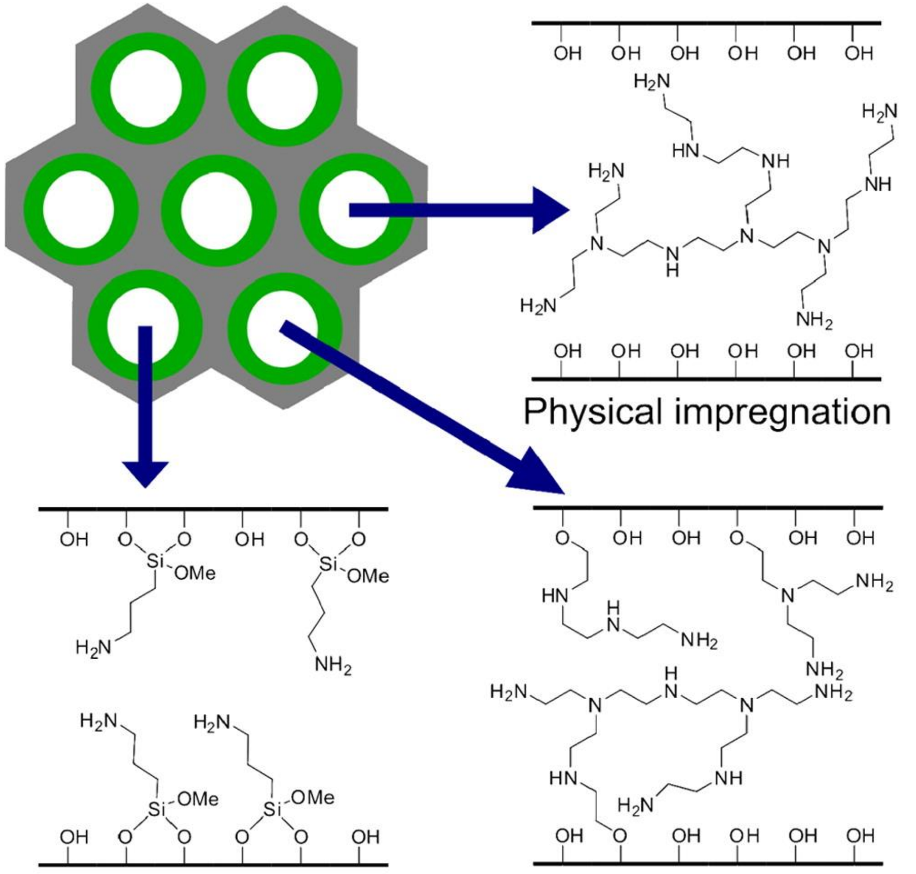
Fig. 1 is a flow diagram illustrating the entire process;

Fig. 2 is a diagram in plan view illustrating the electrolytic purification step; and

Fig. 3 is a cross-sectional view of the electrolytic cells.

Referring to Fig. 1, **11** is an absorption column provided internally with conventional means for bringing immiscible fluids into contact, such as bubble plates,

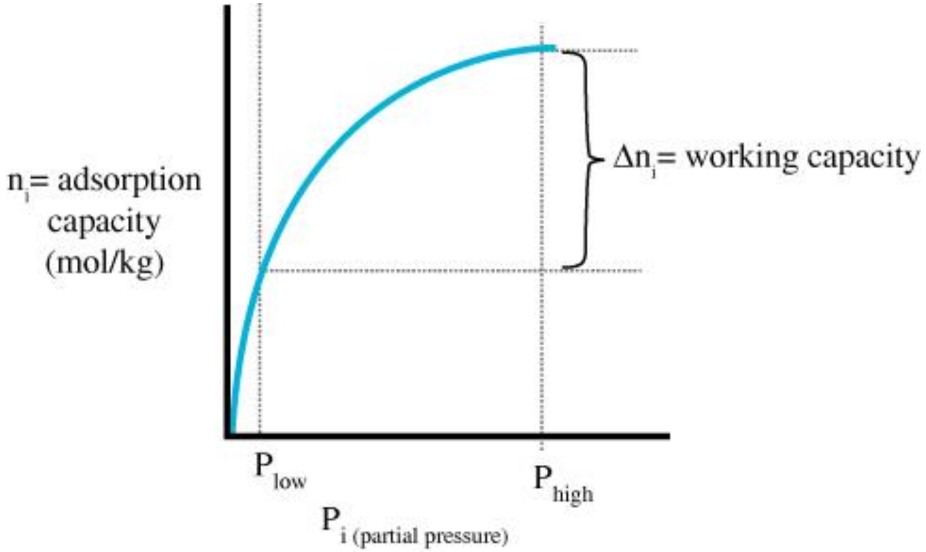
Solid-Supported Amine Contactors

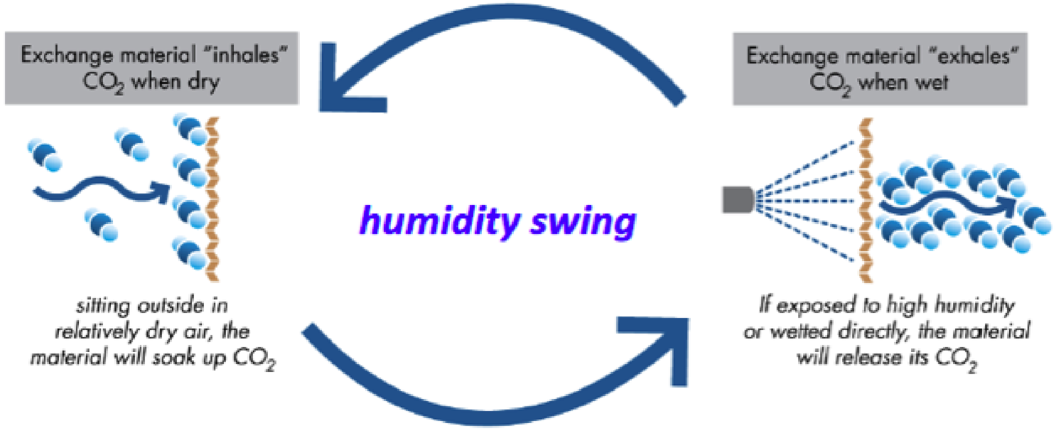


Physical impregnation

Covalent tethering via silane linkage

Direct covalent tethering via in-situ polymerization





Exchange material "inhales" CO_2 when dry

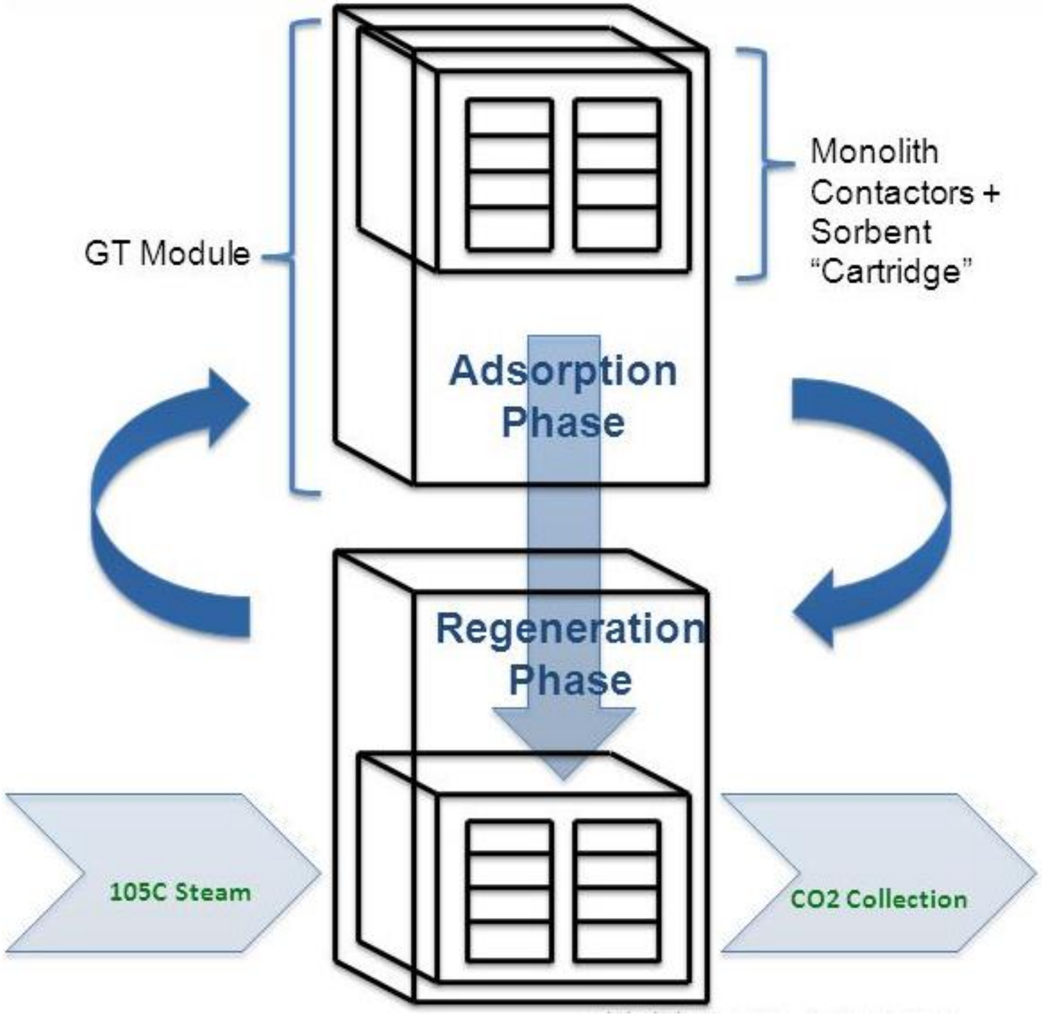
sitting outside in relatively dry air, the material will soak up CO_2

humidity swing

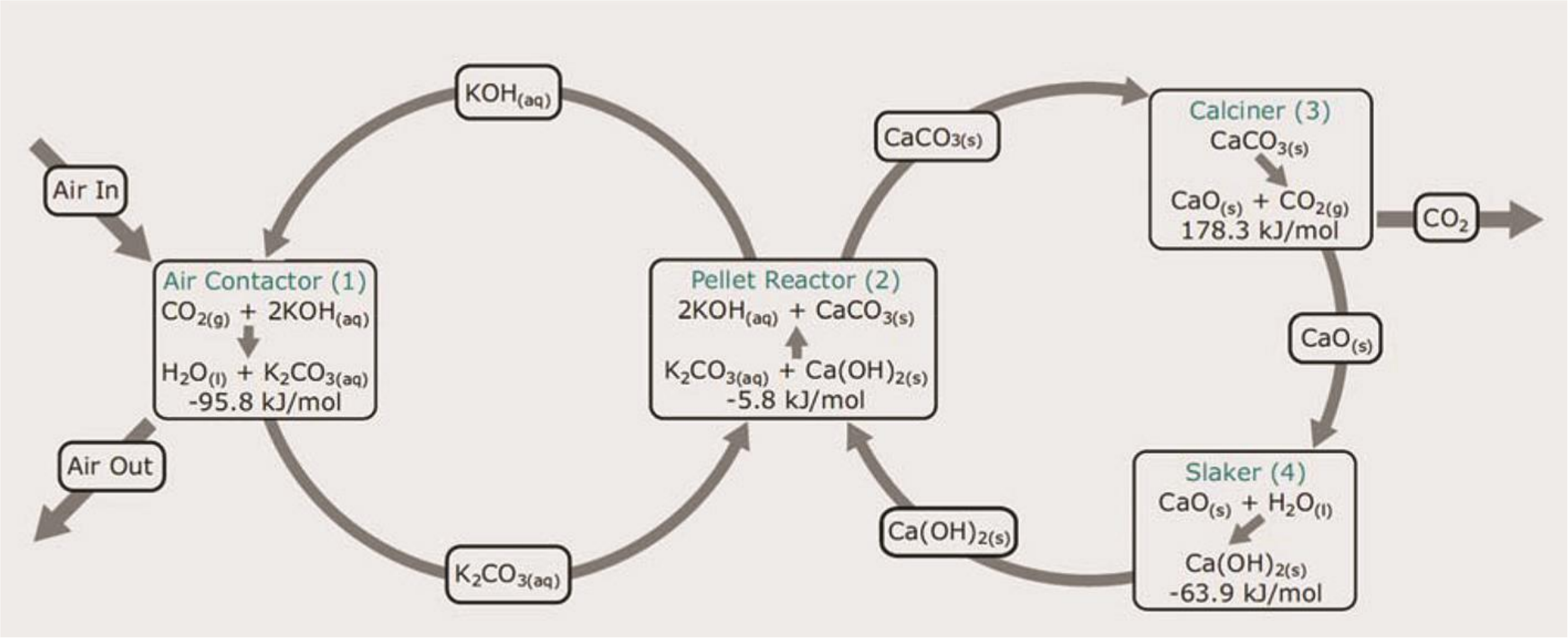
Exchange material "exhales" CO_2 when wet

If exposed to high humidity or wetted directly, the material will release its CO_2

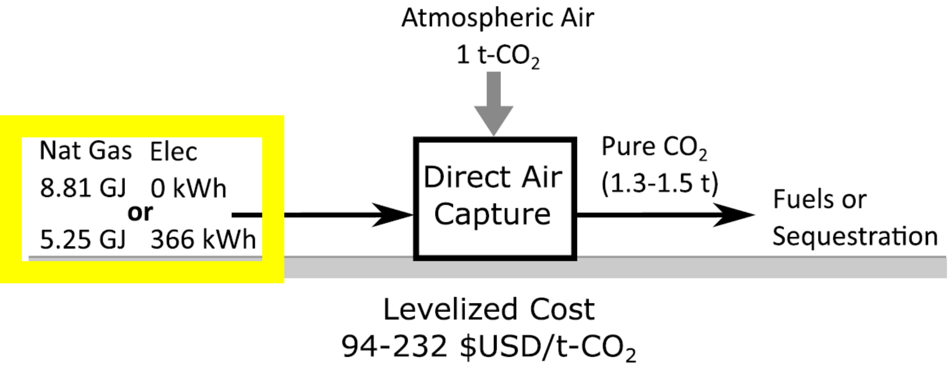
Current: 10.5 GJ·ton^{-1};
long-term: 7.2 GJ·ton^{-1}



global thermostat
a carbon negative solution

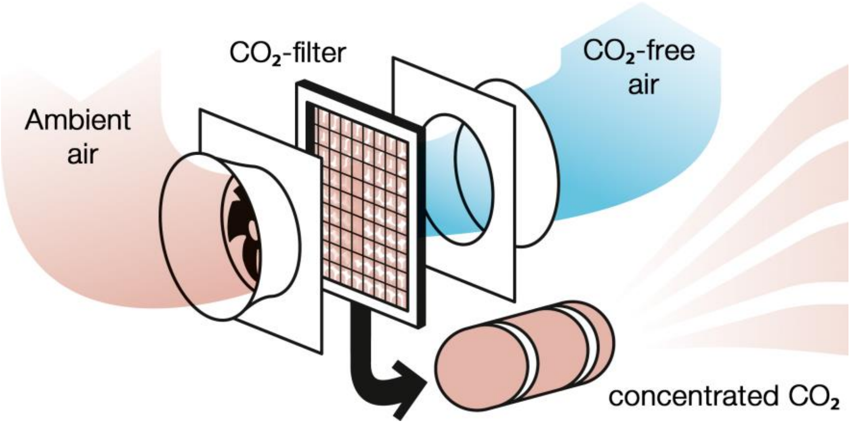


Carbon Engineering



We Have a Target…

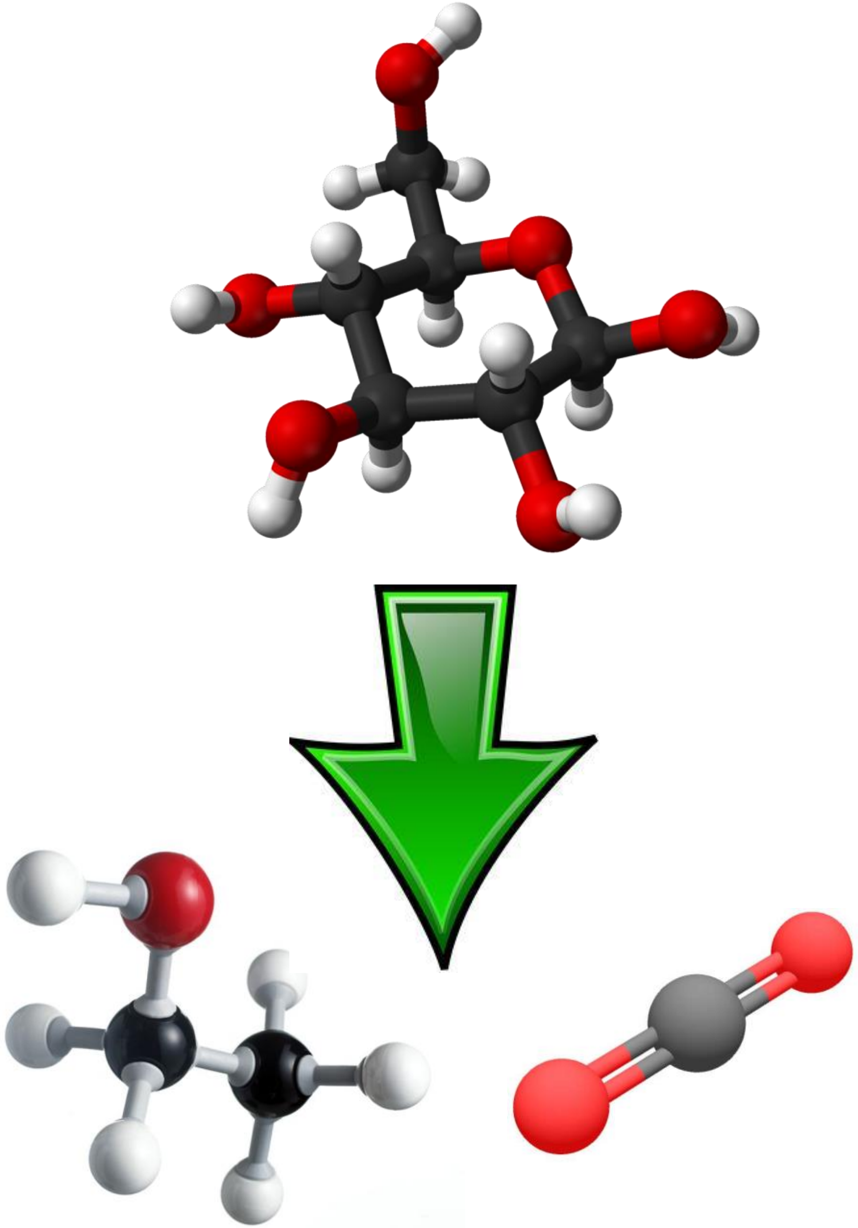
$\$12.50\ \text{bbl}^{-1}$



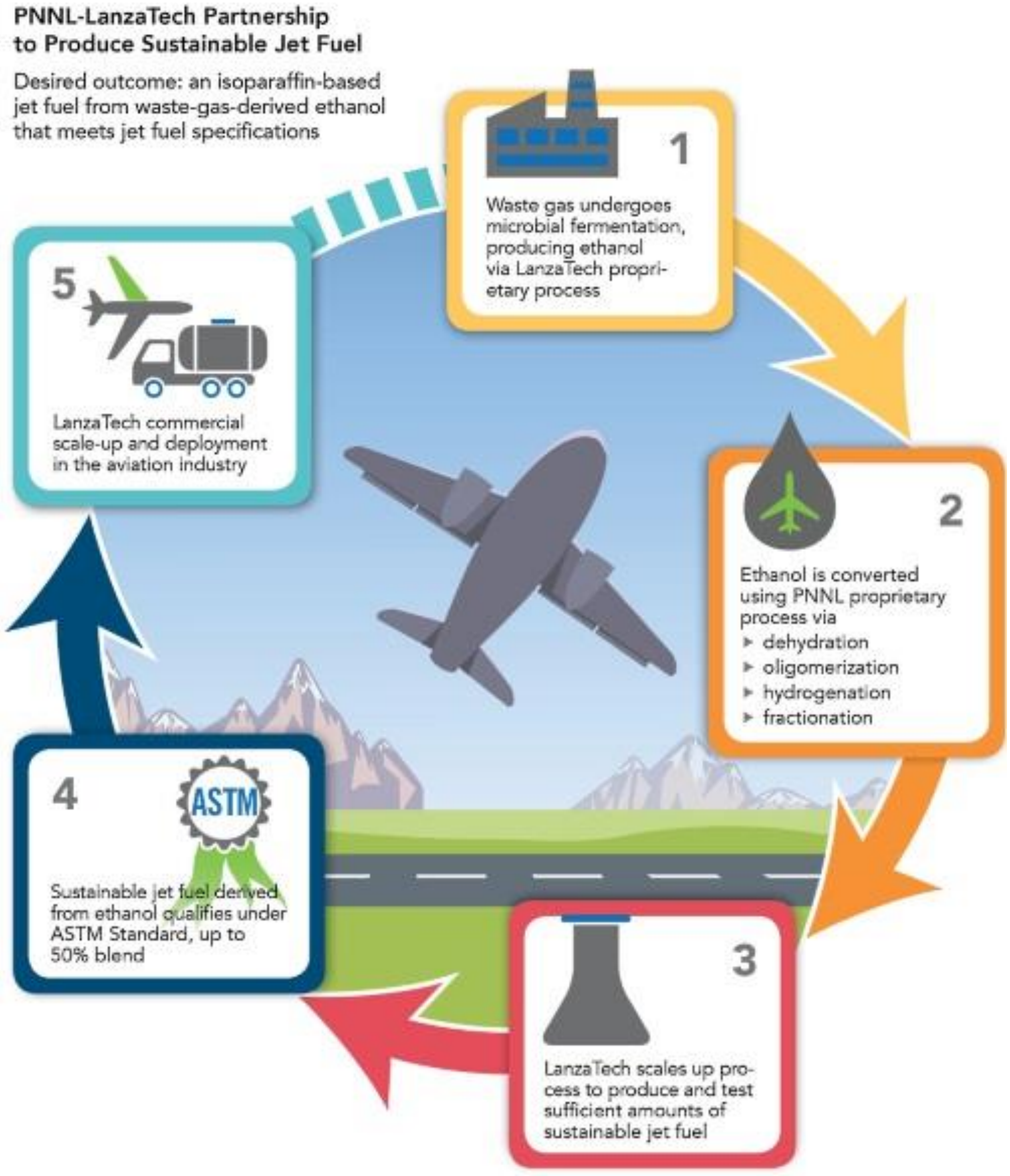
$\$60\ \text{bbl}^{-1}$

$\$2.73$ gal^{-1}

$\$100\ \text{ton}^{-1}$



~97% Theoretical Yield



PNNL-LanzaTech Partnership to Produce Sustainable Jet Fuel

Desired outcome: an isoparaffin-based jet fuel from waste-gas-derived ethanol that meets jet fuel specifications

1 Waste gas undergoes microbial fermentation, producing ethanol via LanzaTech proprietary process

2 Ethanol is converted using PNNL proprietary process via
- dehydration
- oligomerization
- hydrogenation
- fractionation

3 LanzaTech scales up process to produce and test sufficient amounts of sustainable jet fuel

4 Sustainable jet fuel derived from ethanol qualifies under ASTM Standard, up to 50% blend

5 LanzaTech commercial scale-up and deployment in the aviation industry

>95% Theoretical Yield

Where Do We Need to Be?

$1

$0.08

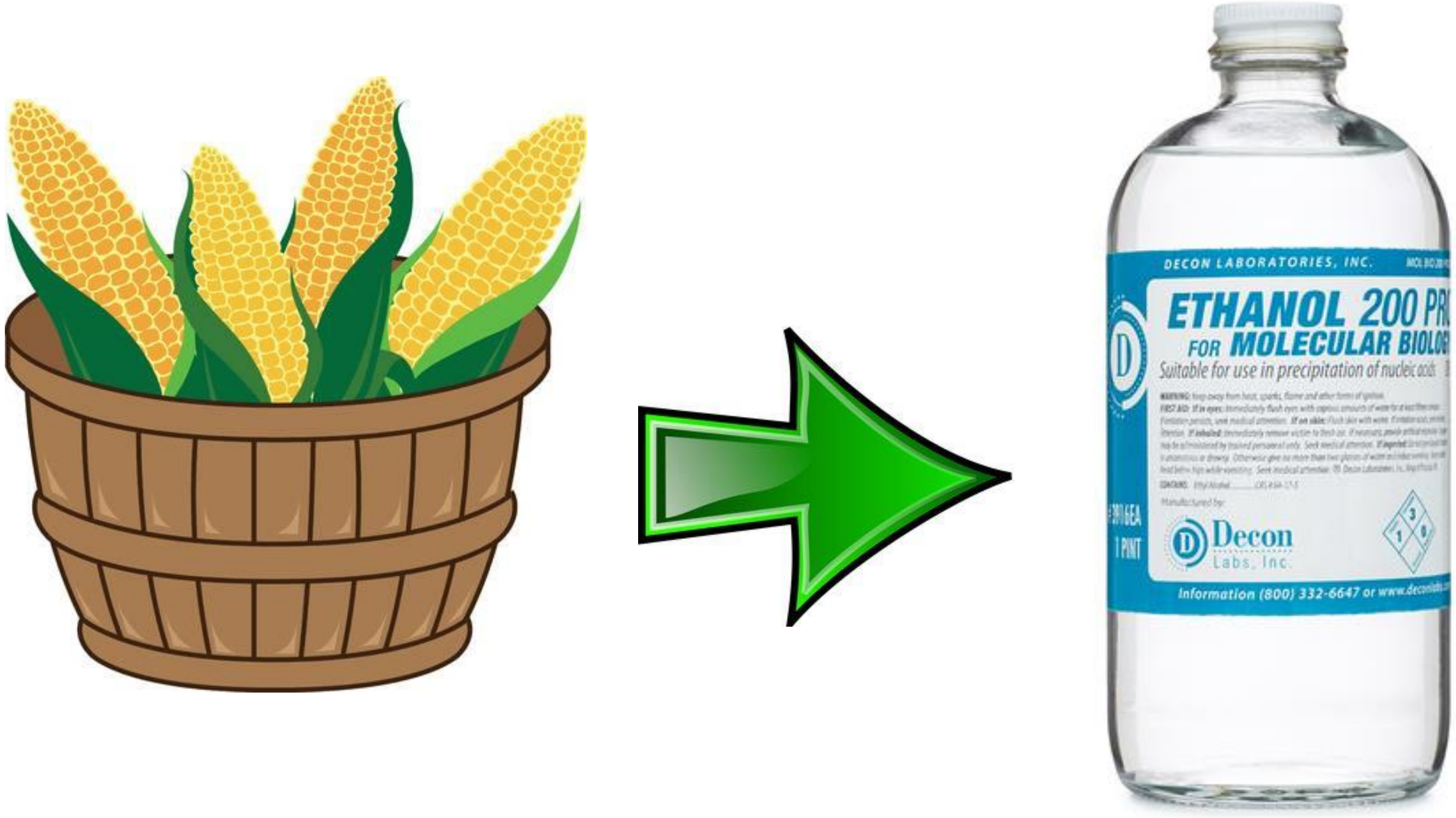
$1.10

$2.73 gal^{-1}

Where Are We Now?

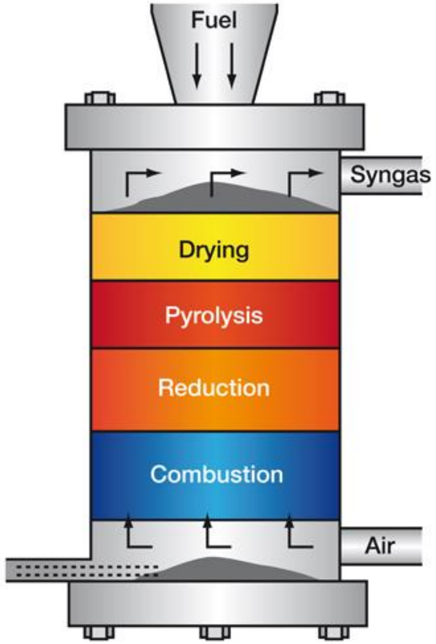
$\$3.72\ \text{Bu}^{-1}$

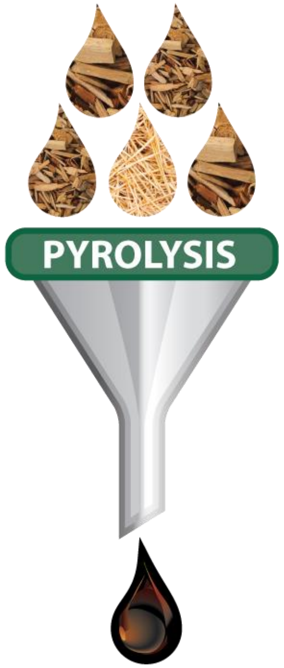
$\$0.12\ \text{lb}^{-1}$

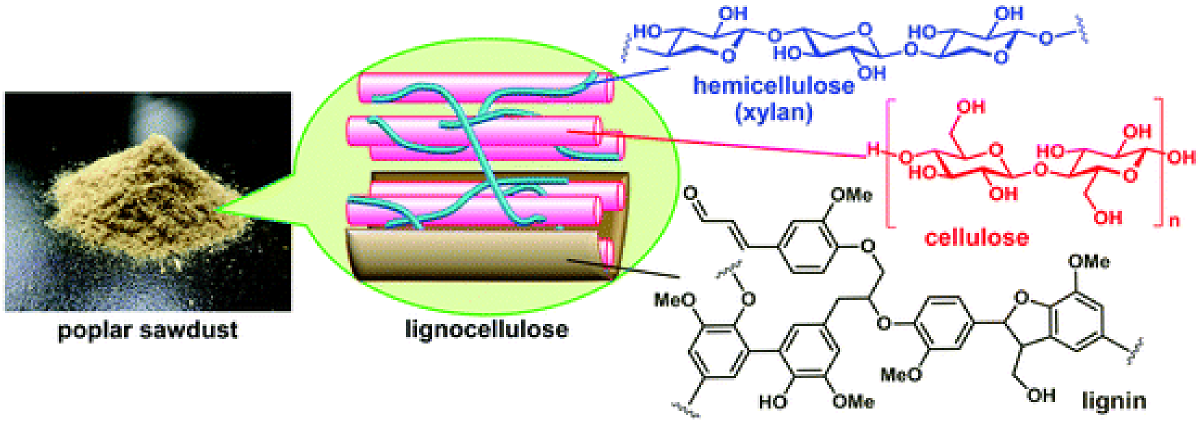


$\$1.60\ \text{Gal}^{-1}$

Cellulosics?

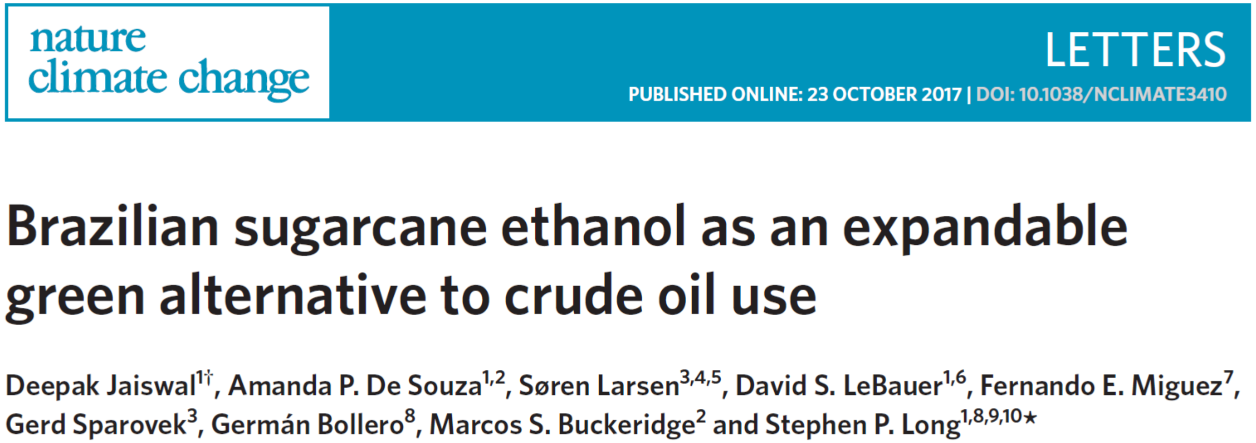






\$1 Gal^{-1} EtOH requires biomass at <\$50 ton^{-1}

Does a Viable Low-Cost Feedstock Exist?



nature climate change

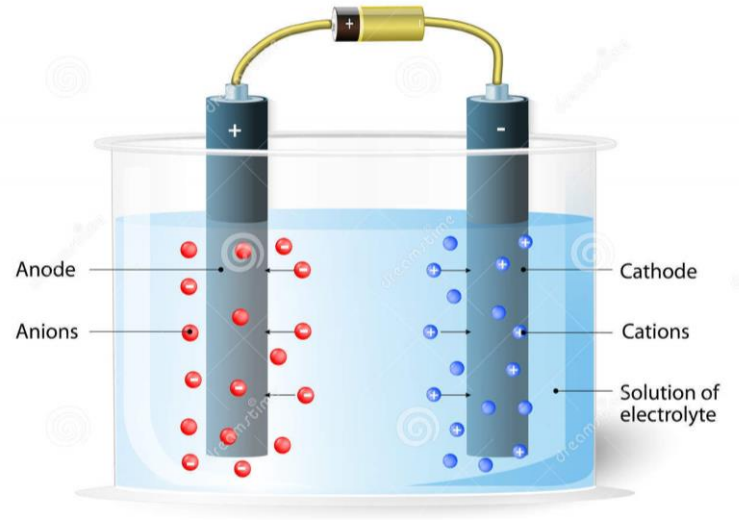
LETTERS

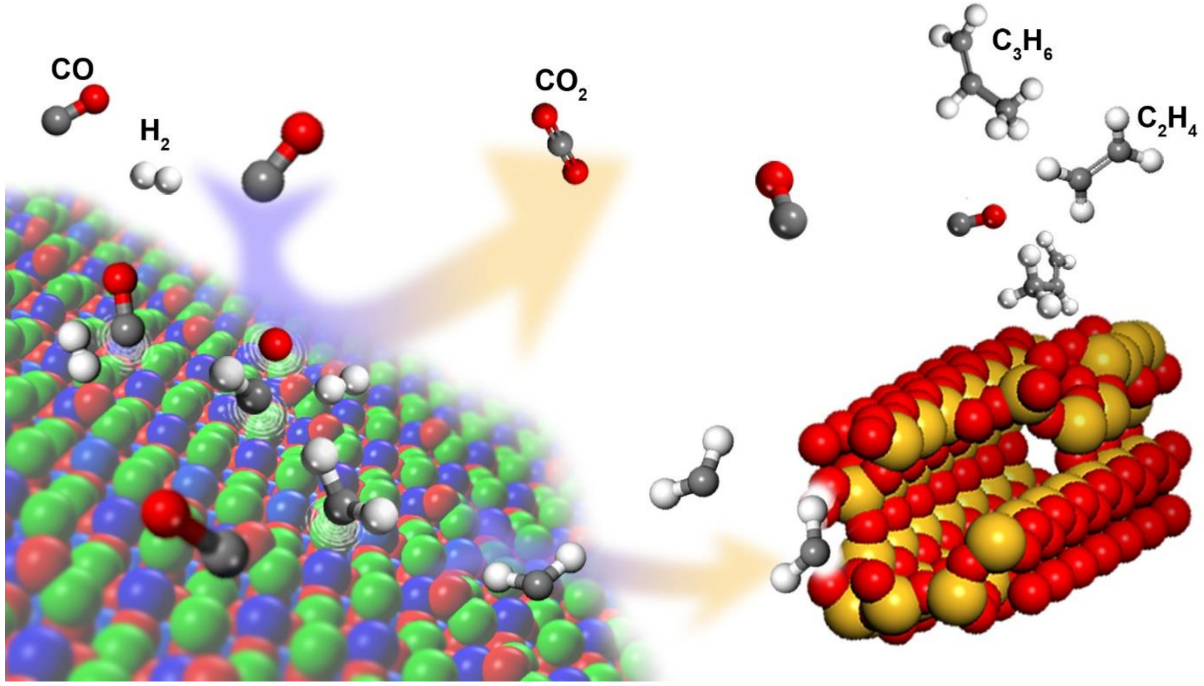
PUBLISHED ONLINE: 23 OCTOBER 2017 | DOI: 10.1038/NCLIMATE3410

Brazilian sugarcane ethanol as an expandable green alternative to crude oil use

Deepak Jaiswal[1†], Amanda P. De Souza[1,2], Søren Larsen[3,4,5], David S. LeBauer[1,6], Fernando E. Miguez[7], Gerd Sparovek[3], Germán Bollero[8], Marcos S. Buckeridge[2] and Stephen P. Long[1,8,9,10★]

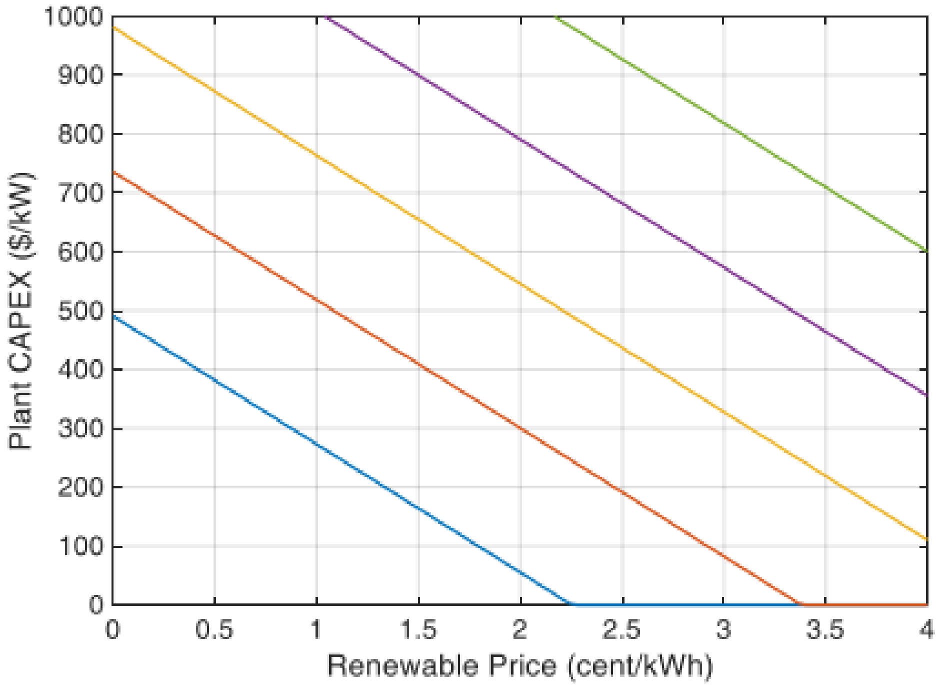
Low Cost Renewables?





How Low Cost?

Assumed CAPEX + OPEX	Implied Max H_2 Price
\$0.75 Gal^{-1}	\$1.34 kg^{-1}
\$1.25 Gal^{-1}	\$0.84 kg^{-1}



Royal Dutch Shell

sasol

enVIA

HYGEAR

GasTechno®
Energy Efficient Recycle®

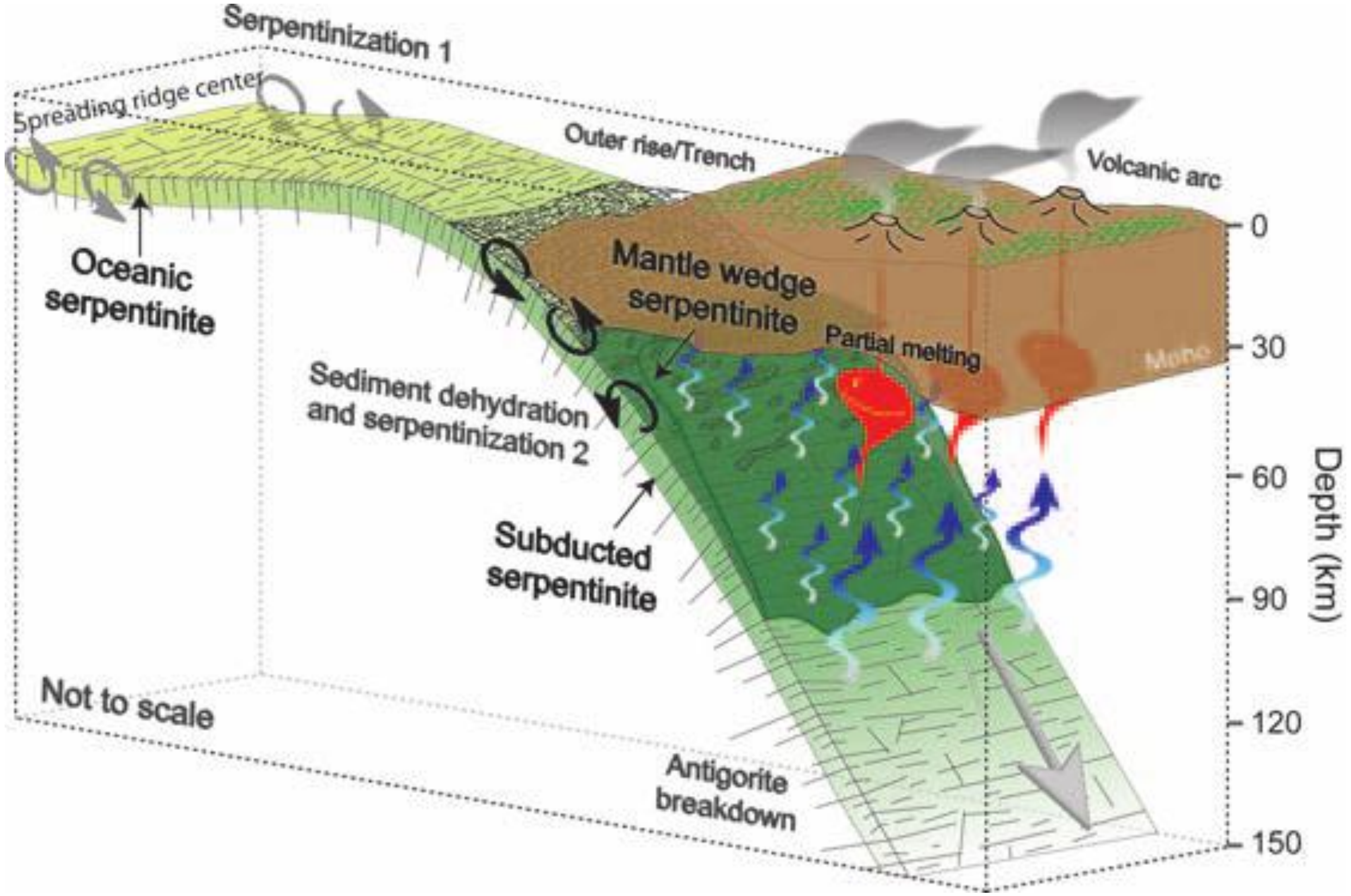
sunfire

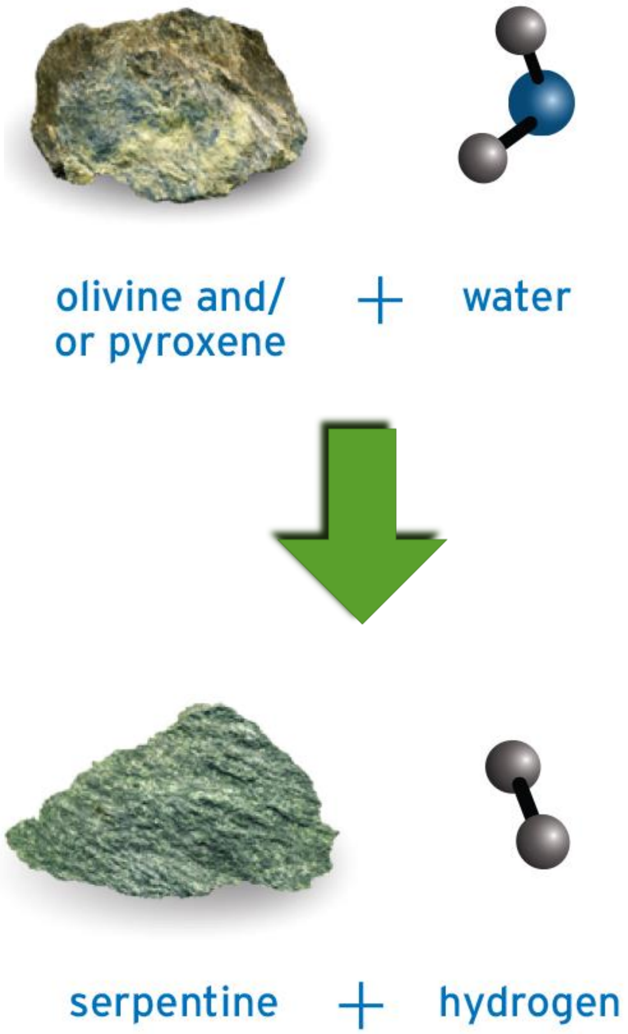
VELOCYS

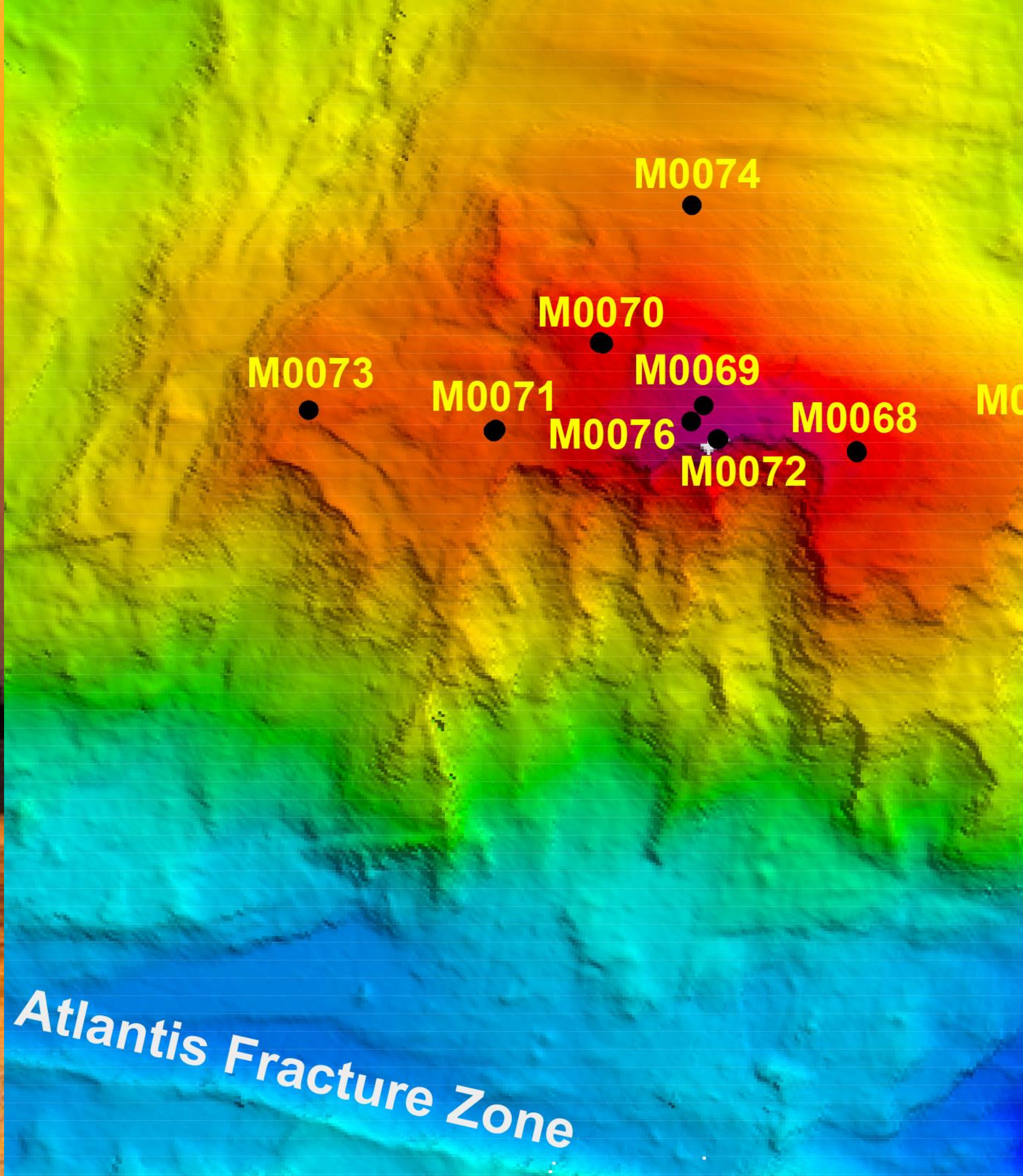
CompactGTL
The modular gas solution

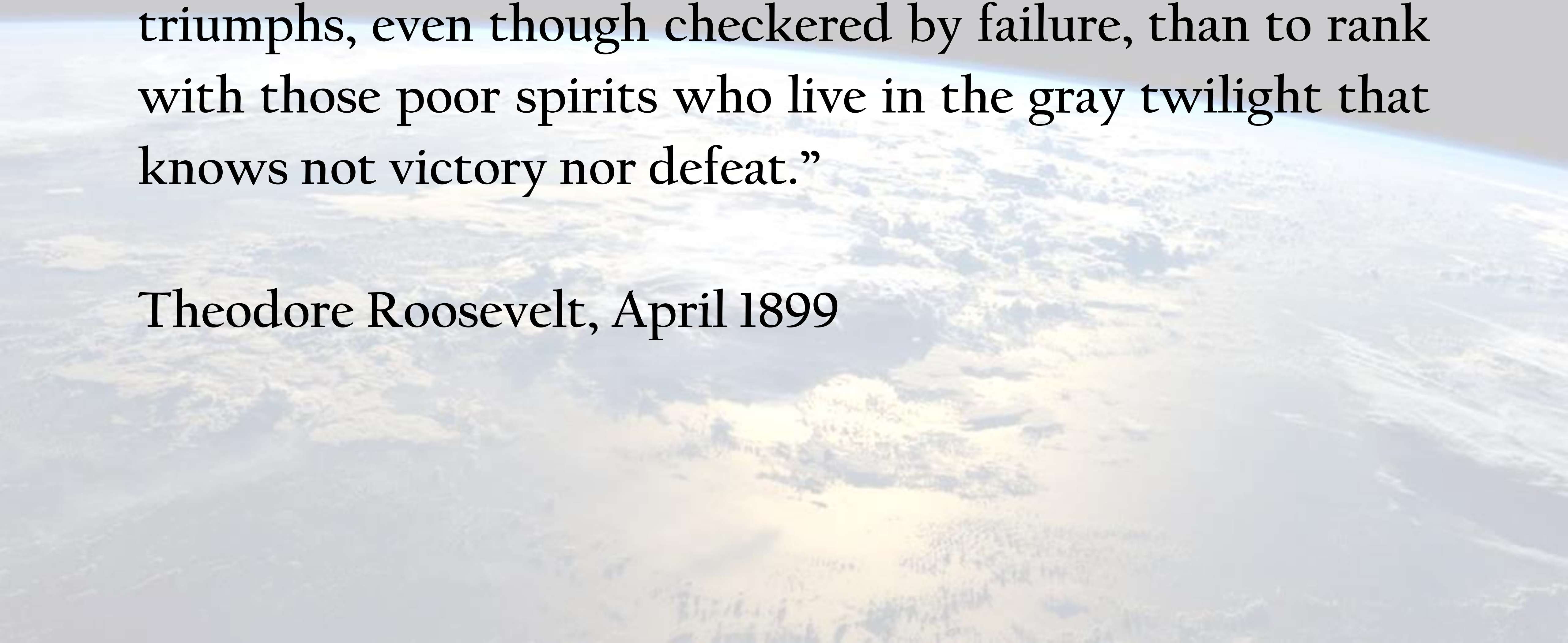
GREYROCK

Geologic Hydrogen?






M0074
M0070
M0073
M0069
M0071
M0068
M0076
M0072
M0
Atlantis Fracture Zone



“Far better it is to dare mighty things, to win glorious triumphs, even though checkered by failure, than to rank with those poor spirits who live in the gray twilight that knows not victory nor defeat.”

Theodore Roosevelt, April 1899