Renewable Energy II: Biofuels, Ethanol, and Algae

AOSC/CHEM 433 & AOSC/CHEM 633

Ross Salawitch

Class Web Sites:

http://www2.atmos.umd.edu/~rjs/class/fall2020

https://myelms.umd.edu/courses/1291919

Today:

- **Pros and cons of various aspects of meeting energy needs of society by means of combustion of biomass, biofuels, and biowaste**

http://www.taxpayer.net/library/article/federal-subsidies-for-corn-ethanol-and-other-corn-based-biofuels

Lecture 20

1 December 2020

Announcements: Class

- Problem Set #4 has been posted:

  https://www2.atmos.umd.edu/~rjs/class/fall2020/problem_sets/ACC_2020_problem_set_04.pdf

  and is due a week from today. Please get started early, and email me and Laura McBride mcbridel@terpmail.umd.edu if you have any questions

- As for P Set #3, this problem set will be completed outside of ELMS. Prefer you mail me and Laura McBride either one PDF file (entire P Set) or two PDF files (one per question) when the problem set is complete, with an email subject such as:

  AOSC 433: Problem Set 4 *or* CHEM 633: Problem Set 4 etc

Student Papers

- **Mandatory for 633 students:** paper grade will count towards final grade in an amount equal to each exam
- **Optional for 433 students:** can use paper grade to replace a ***single*** problem set grade: advisable for anyone who failed to turn in a problem set or would otherwise like to replace the grade on a problem set
- **Due Thursday, 10 Dec 2020 (last day of class)**
- **5 to 8 pages** single spaced (not including reference list or figures) on a topic related to class (your choice …we're happy to discuss potential topics)
- Must be ***new work for this class*** but can be related to your dissertation or some other topic in which you've had prior interest
- Paper can build on a topic covered in class or can be on a topic related to Atmospheric Chemistry & Climate not covered in class: should have about 5 to 10 citations to material outside of that provided in class
- Request all students who will complete a paper provide a **2 to 3 sentence description of their topic** **one week** from today: **Tues, 3 Nov 2020**
  https://umd.instructure.com/courses/1291919/quizzes/1351196
  Please use next week to speak to exchange email with me about a topic
- ***Delighted to provide feedback if you turn in a draft by 11:59 pm on 1 Dec***

Announcement: Outside of Class

Students might be interested in watching *Planet of the Humans* by Jeff Gibbs and Michael Moore, released 21 April 2020, at https://planetofthehumans.com

In my opinion this film, an expose mainly focused on energy from the combustion of biomass, solar, wind, and corporate greed, gets many points "right" and certain other important points "wrong".

https://twitter.com/LibSnoflake/status/1252652168991121411

World Energy & Electricity Supply

World Energy

World Electricity

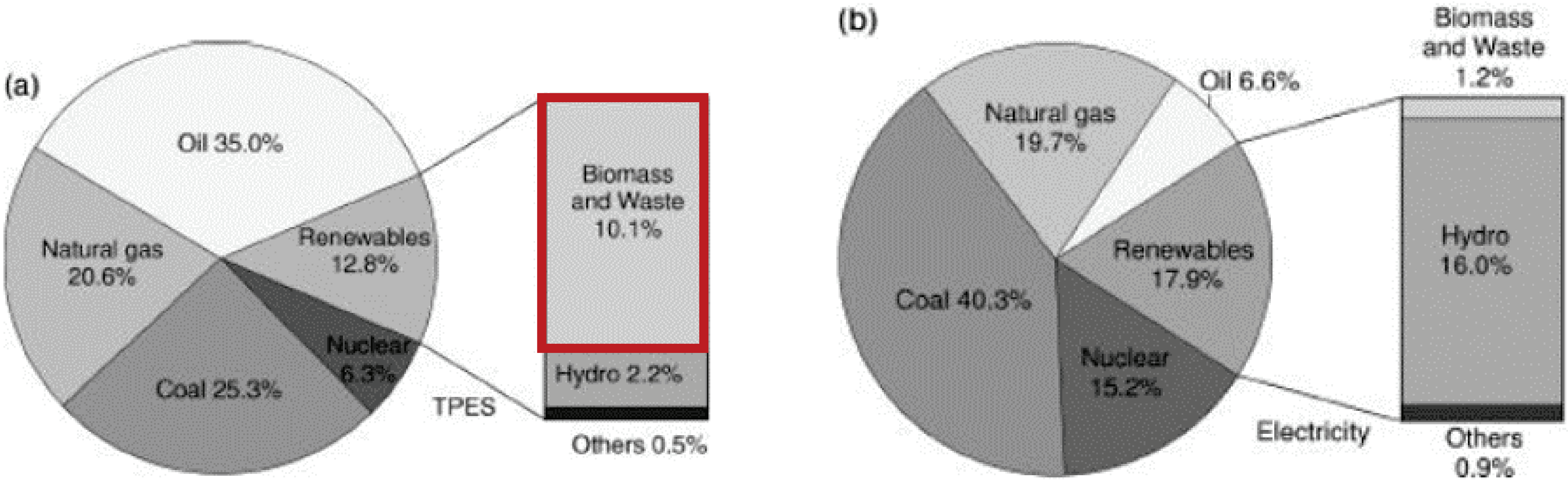
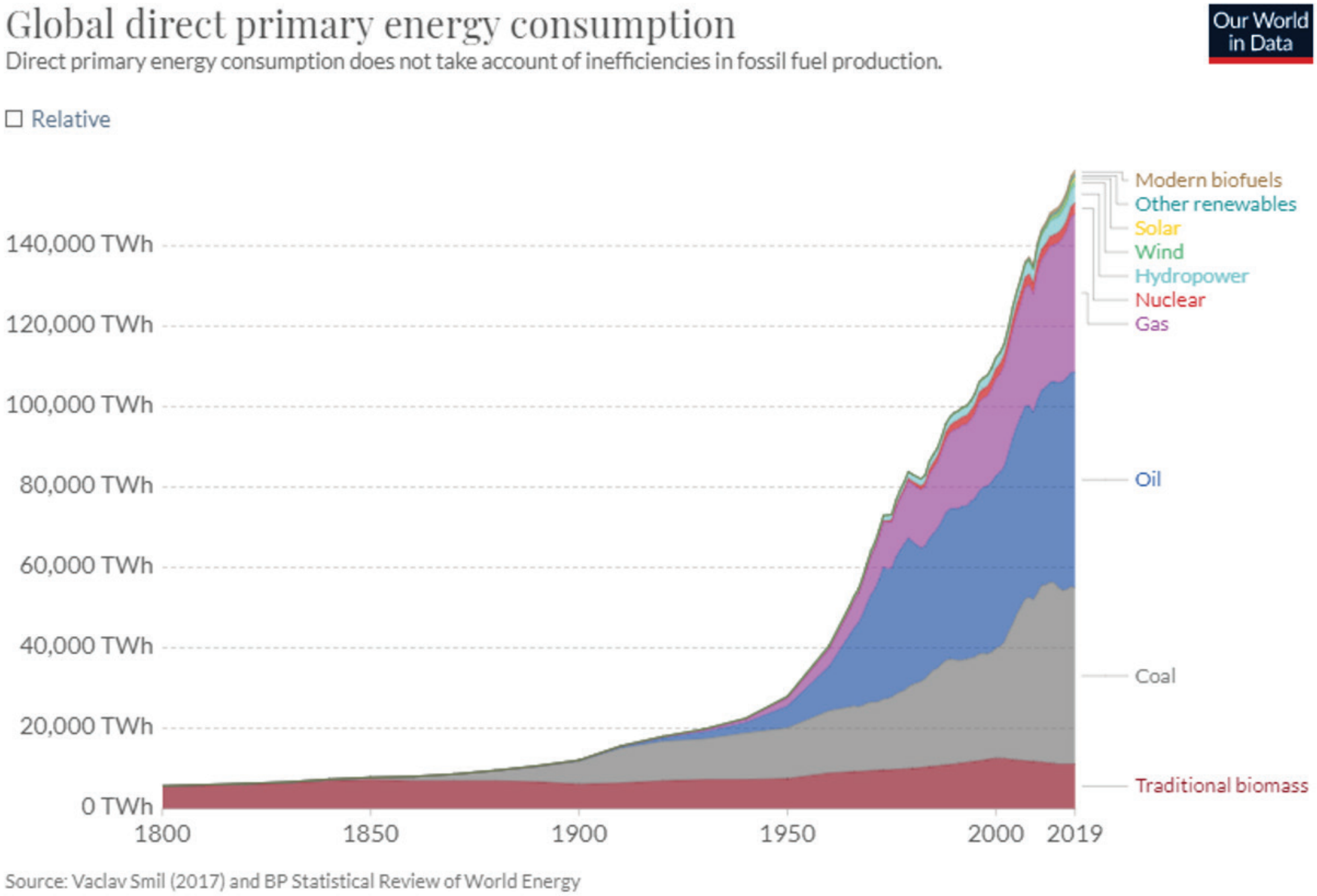


Figure 8.1 (a) Share of renewables in the world total primary energy supply (TPES) in 2005; (b) share of renewables in world electricity production in 2005. (Source: IEA Renewables Information 2007.)

Olah *et al.*, *Beyond Oil and Gas: The Methanol Economy*, 2009

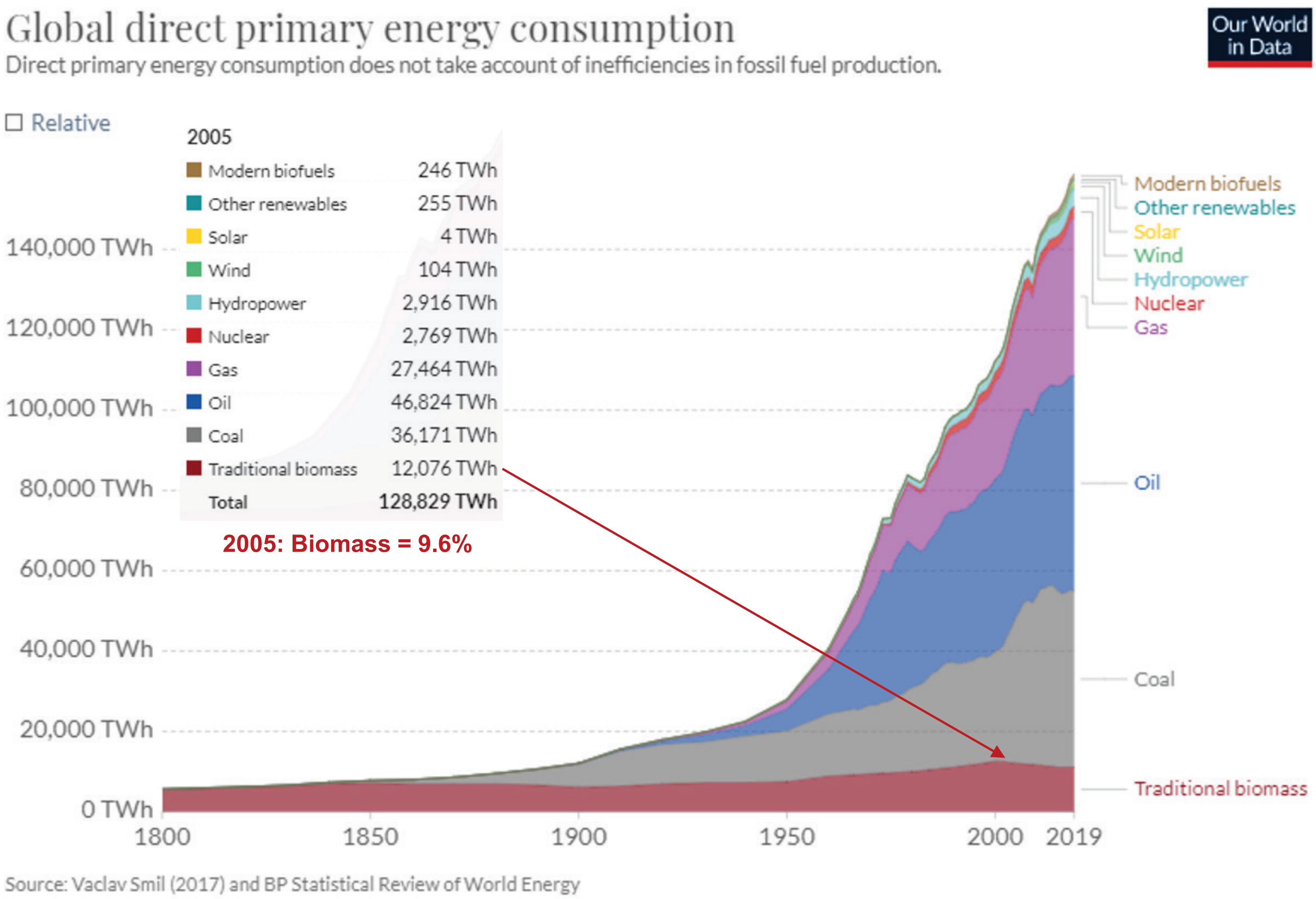
Largest energy source that does not involve combustion of fossil fuels is **Biomass and Waste**

World Total Primary Energy Supply



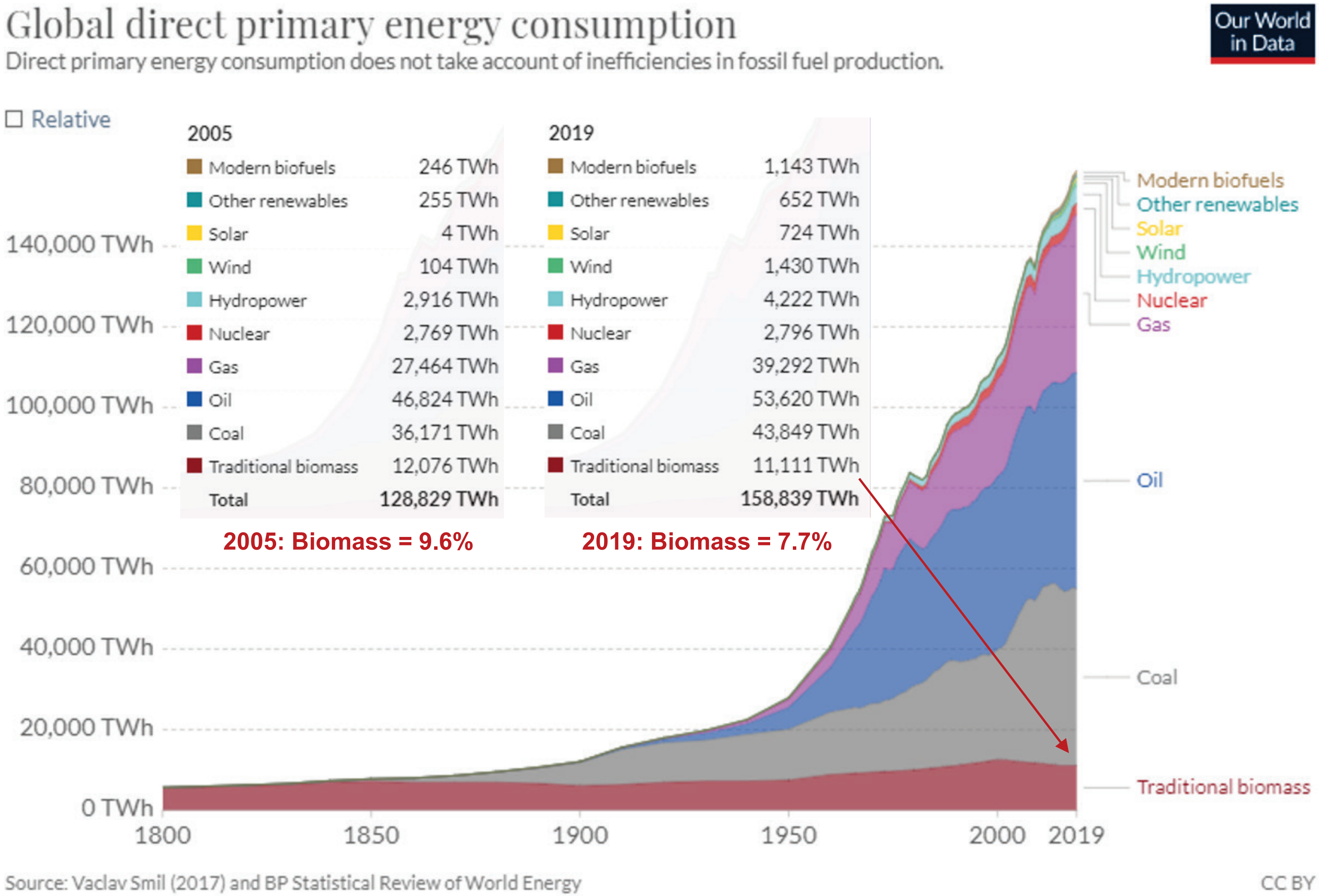
https://ourworldindata.org/energy

World Total Primary Energy Supply



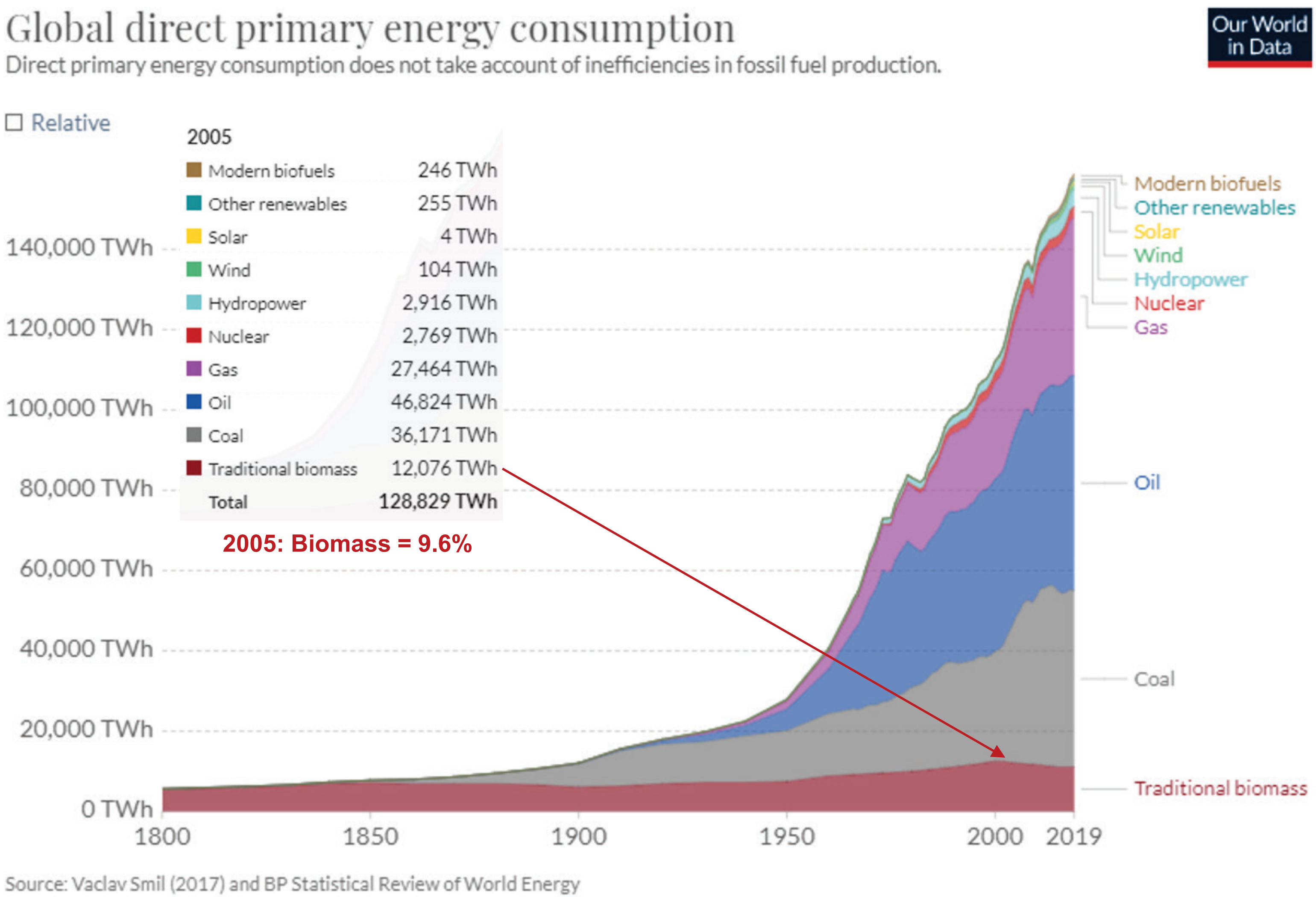
https://ourworldindata.org/energy

World Total Primary Energy Supply



https://ourworldindata.org/energy

World Total Primary Energy Supply



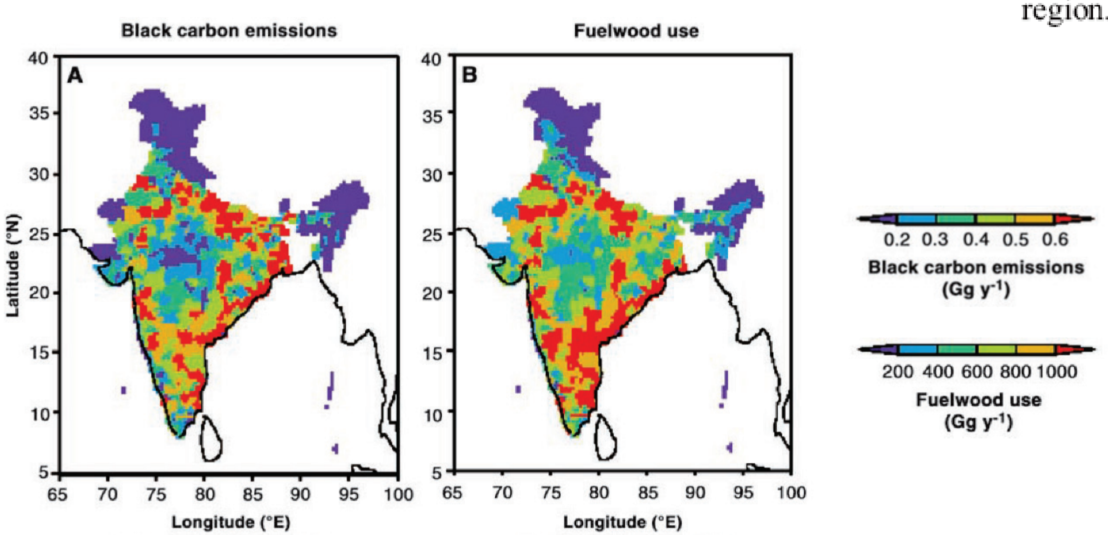
https://ourworldindata.org/energy

Residential Biofuels in South Asia: Carbonaceous Aerosol Emissions and Climate Impacts

C. Venkataraman,[1*] G. Habib,[1] A. Eiguren-Fernandez,[2]
A. H. Miguel,[2] S. K. Friedlander[3]

High concentrations of pollution particles, including "soot" or black carbon, exist over the Indian Ocean, but their sources and geographical origins are not well understood. We measured emissions from the combustion of biofuels, used widely in south Asia for cooking, and found that large amounts of carbonaceous aerosols are emitted per kilogram of fuel burnt. We calculate that biofuel combustion is the largest source of black carbon emissions in India, and we suggest that its control is central to climate change mitigation in the south Asian region.

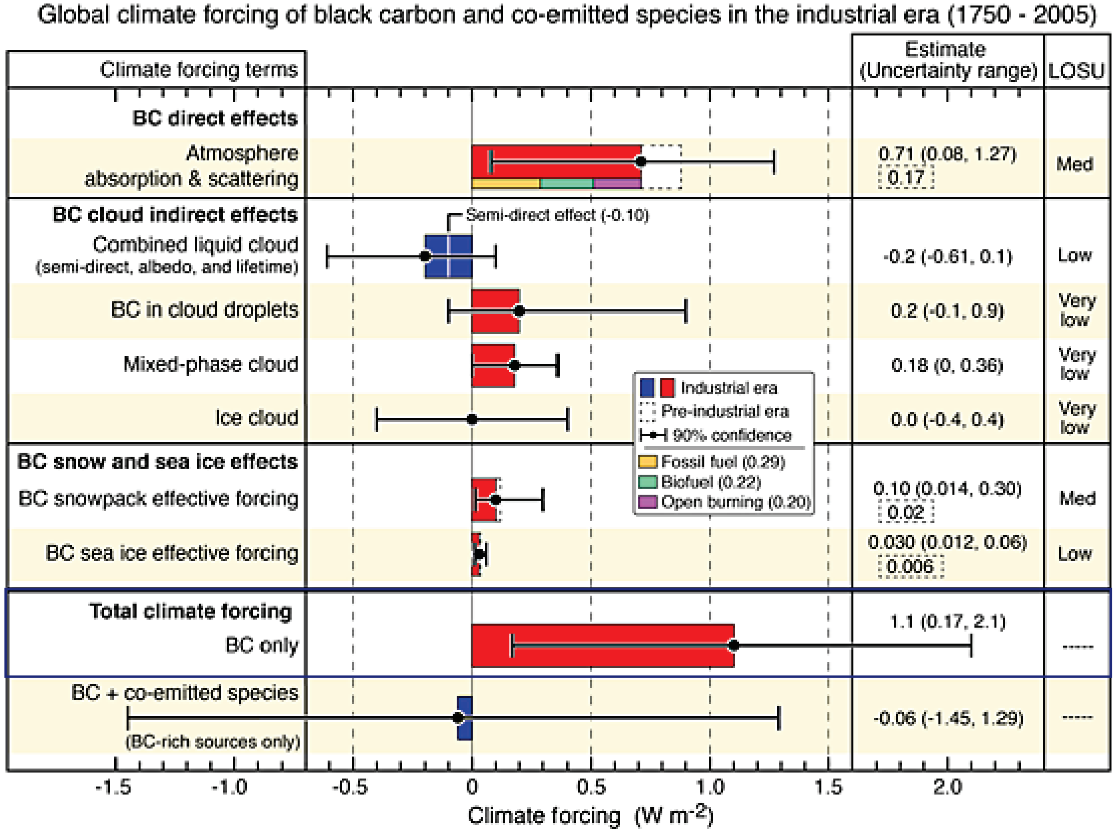
4 MARCH 2005 VOL 307 SCIENCE



An analysis of the climate response of soot emissions from fossil fuel and biofuel combustion has suggested that control of soot, in addition to greenhouse gases, is an important measure to slow global warming, especially on short time scales (*6*, *7*). Our results suggest that biofuel combustion could significantly affect atmospheric BC concentrations in the south Asian region. The climate effects of biofuel combustion aerosols have been combined with the effects of open biomass burning in the scientific consensus reports of the Intergovernmental Panel on Climate Change (*29*). We suggest that biofuel combustion needs to be addressed as a distinct source, and that cleaner cooking technologies not only could yield significant local health and air quality benefits but also could have an important role in climate change mitigation in the south Asian region.

Black Carbon Aerosols

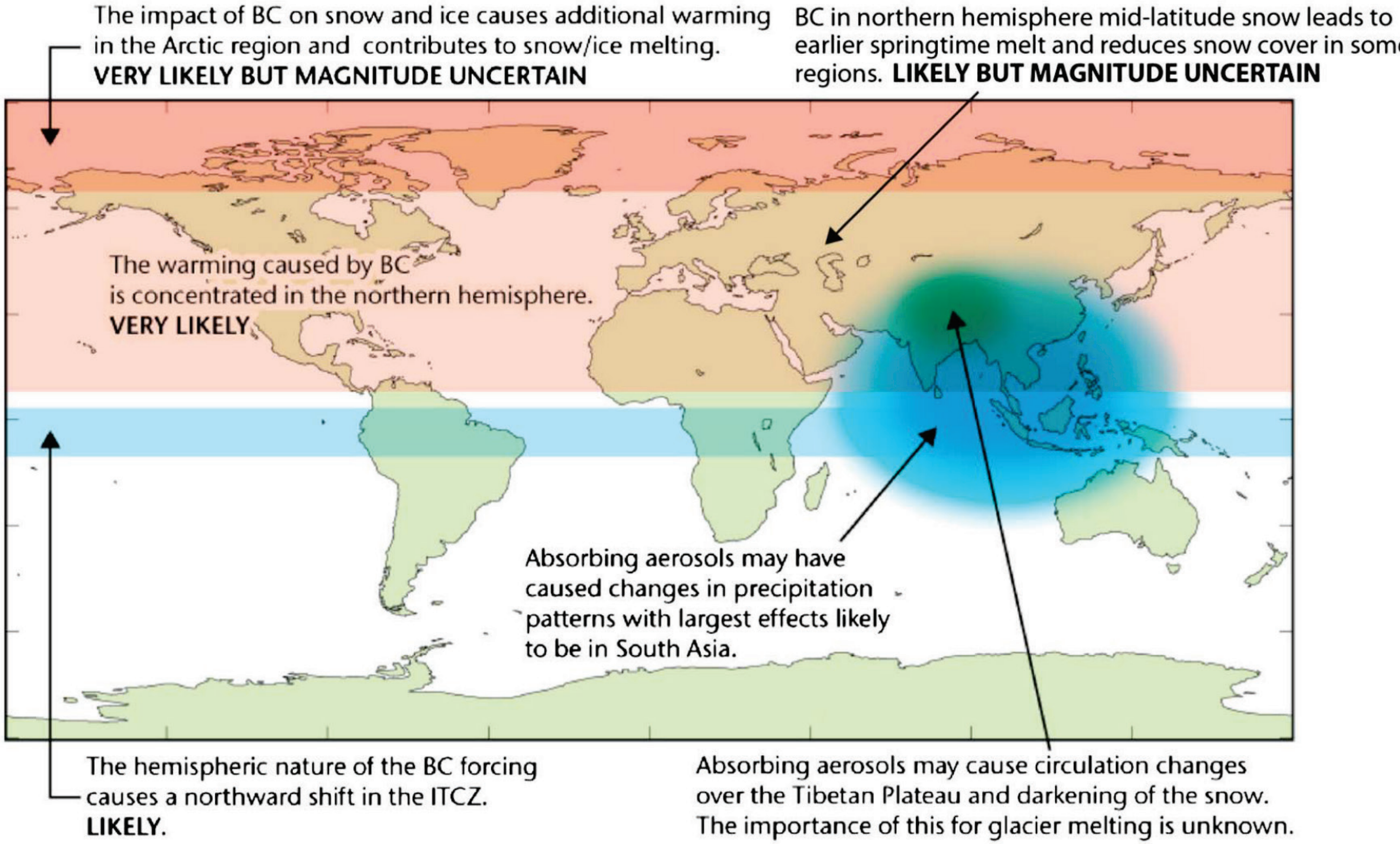
Bond *et al*., Bounding the role of black carbon in the climate system: A scientific assessment, *JGR*, 2013



	Total Climate Forcing, Black Carbon Aerosols (W m^{-2})			
Report	IPCC (1995)	IPCC (2001)	IPCC (2007)	**IPCC (2013)**
ΔRF, BC	0.1 (0.03 to 0.3)	0.2 (0.1 to 0.4)	0.2 (0.05 to 0.35)	**0.4 (0.05 to 0.80)**

Lecture 7, Slide 61

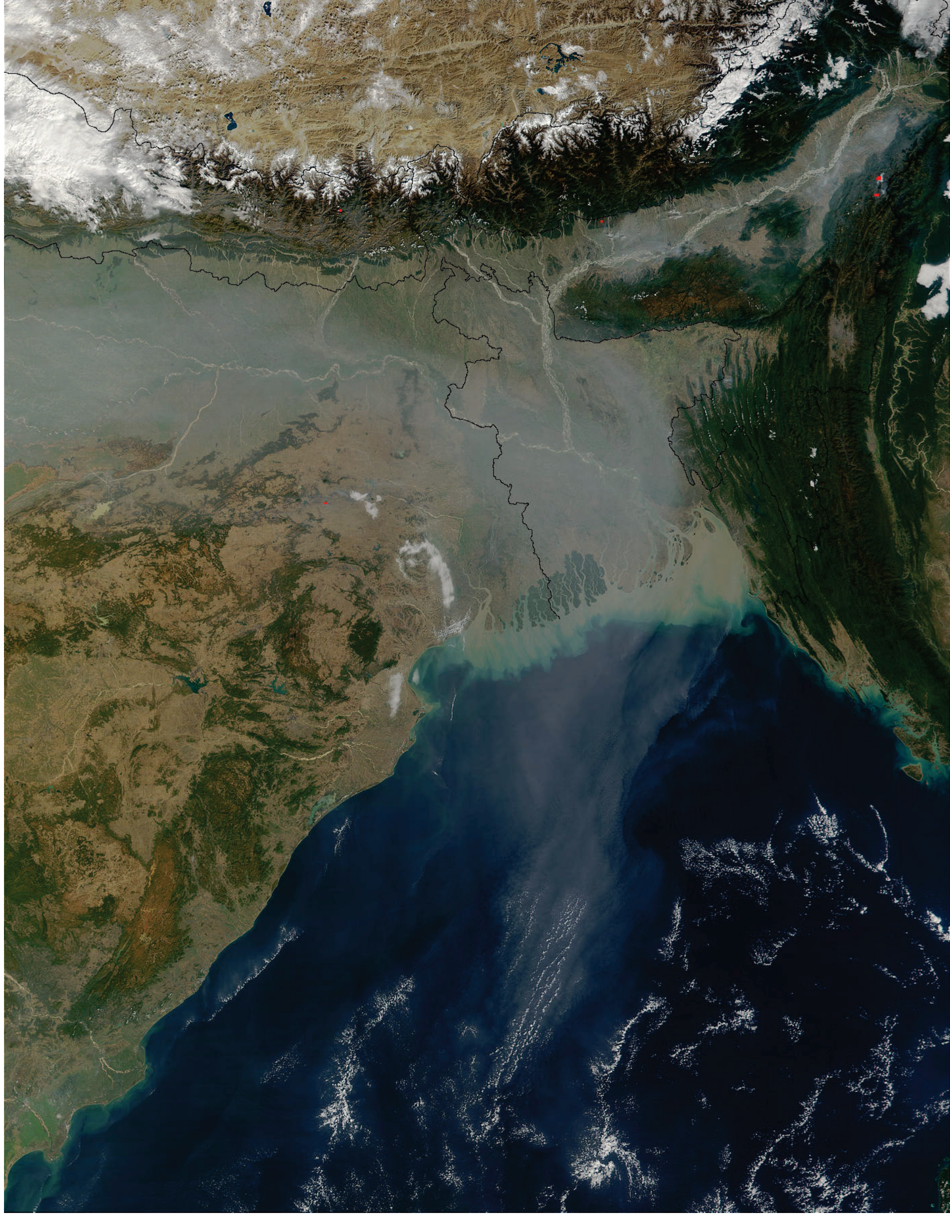
Black Carbon & Climate



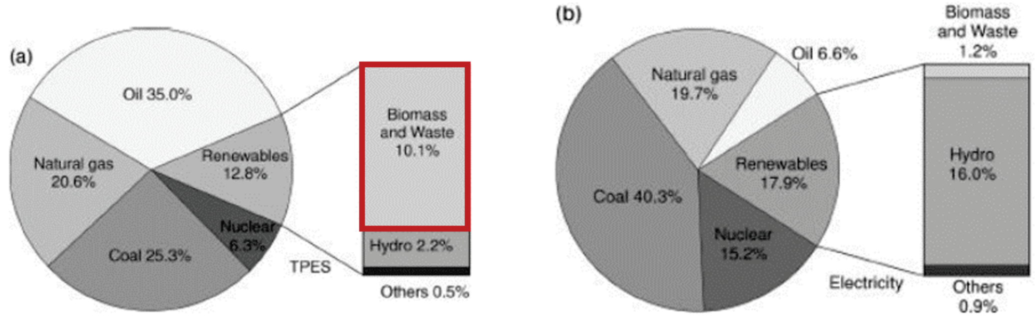
Bond *et al*., JGR, 2013

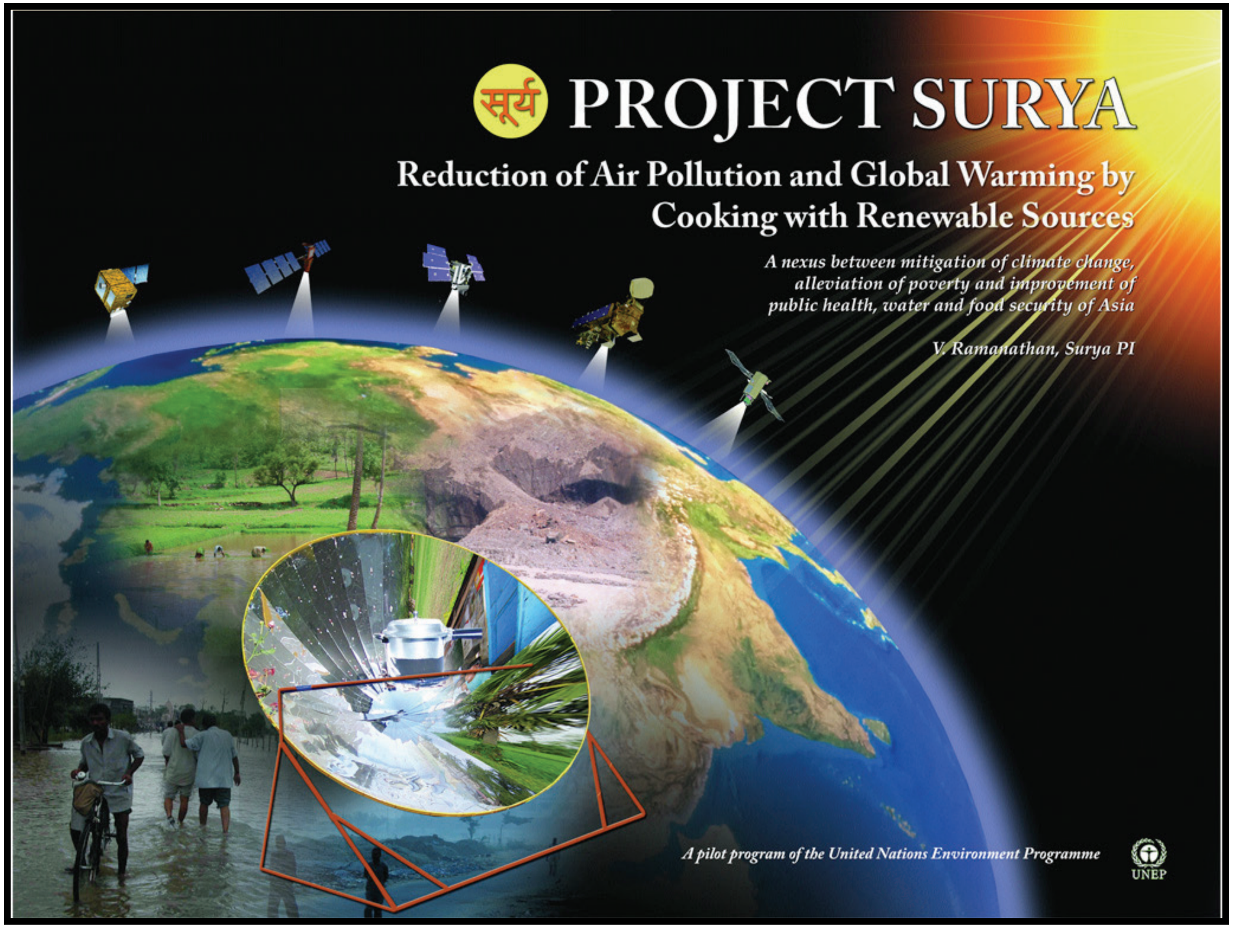
Poor air quality over India (left) and Bangladesh (center),

This NASA MODIS image from 12 Jan 2002 shows a thick blanket of pollution butting up against the Himalayas (arcing across the top of the image) and stretching out into the Bay of Bengal (bottom). Tan-colored sediment fills the Bay through the Mouths of the Ganges River (image center). North of the Himalayas, the skies are clear over the Tibetan Plateau.

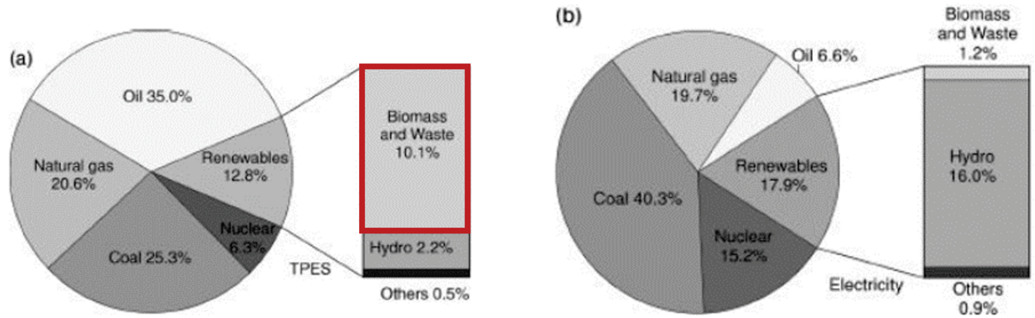


http://visibleearth.nasa.gov/view.php?id=57559





https://www.apc.org/en/resources/project-surya



Surya – Sanskrit for Sun

- 65 villages (6500 homes) covering 1500 km^2, where most residents use wood for cooking, will be provided with either solar and/or biogas burners
- Air quality, soot, and particulates will be monitored for 6 months prior to installation of alternate cookers and for at least 1 year subsequent
- Indoor air quality will be measured in selected homes
- Outdoor air quality will also be monitored using NASA satellite instruments
- PI: V. Ramanathan, Scripps

https://www.apc.org/en/resources/project-surya

The New York Times

Environment

BY DEGREES

Third-World Stove Soot Is Target in Climate Fight

Adam Ferguson for The New York Times

Cooking in Kohlua, India. Soot from tens of thousands of villages in developing countries is responsible for 18 percent of the planet's warming, studies say. More Photos >

By ELISABETH ROSENTHAL
Published: April 15, 2009

KOHLUA, India — "It's hard to believe that this is what's melting the glaciers," said Dr. Veerabhadran Ramanathan, one of the world's leading climate scientists, as he weaved through a warren of mud brick huts, each containing a mud cookstove pouring soot into the atmosphere.

http://www.nytimes.com/2009/04/16/science/earth/16degrees.html?_r=3&ref=earth

Project Surya: Nature Climate Change Paper

nature climate change

LETTERS

PUBLISHED ONLINE: 31 OCTOBER 2016 | DOI: 10.1038/NCLIMATE3141

Wireless sensors linked to climate financing for globally affordable clean cooking

Tara Ramanathan[1], Nithya Ramanathan[1]*, Jeevan Mohanty[2], Ibrahim H. Rehman[2], Eric Graham[1] and Veerabhadran Ramanathan[3]

Three billion of the world's poorest people mostly rely on solid biomass for cooking, with major consequences to health[1] and environment[2]. We demonstrate the untapped potential of wireless sensors connected to the 'internet of things' to make clean energy solutions affordable for those at the bottom of the energy pyramid. This breakthrough approach is demonstrated by a 17-month field study with 4,038 households in India. Major findings include: self-reported data on cooking duration have little correlation with actual usage data from sensors; sensor data revealed that the distribution of high and low users varied over time, and the actual mitigation of climate pollution was only 25% of the projected mitigation; climate credits were shown to significantly incentivize the use of cleaner technologies.

http://projectsurya.squarespace.com/storage/Nclimate3141.pdf

The New York Times

Environment

BY DEGREES

Third-World Stove Soot Is Target in Climate Fight

What other deleterious effects might result from Third-World Stove Soot ?

The New York Times

BY DEGREES

Third-World Stove Soot Is Target in Climate Fight

What other deleterious effects might result from Third-World Stove Soot ?

ENVIRONMENT: Indoor Air Pollution - Silent Killer of Women

print send share

By T V Padma

2007

NEW DELHI, Jan 3 (IPS) - Women and young girls coughing and choking as they cook food over traditional stoves that burn wood, leaves or dung is a common a sight in poor homes across Asia, Africa and Latin America. But no one notices the deleterious effects.

Over 1.5 million females die prematurely every year by inhaling poisonous fumes as they cook or heat their homes with these organic fuels but catch little attention from governments, policy experts, scientists and medical experts.

Almost three billion people burn traditional fuels indoors for cooking and heating and their numbers are expected to "rise substantially by 2020," John Mitchell, coordinator of the partnership for clean indoor air at the United States Environmental Protection Agency told IPS at an international meeting on better air quality held in Yogyakarta, in December.

Most people in the region rely on firewood for cooking and heating, but this not only destroys the local forest but also causes serious health problems due to indoor air pollution. TNC initiated an alternative energy programme in 2001 to protect the rich biodiversity in northwest Yunan and use energy strategies.

http://ipsnews.net/news.asp?idnews=36052

UC San Diego News Center

UC San Diego

thisweek@ucsandiego | By Robert Monroe | Nov 03, 2016 | Previous Issues | Subscribe

Creating a New Kind of Climate Warrior

Scripps researchers help rural women in India improve health and slow global warming through clean cookstove use

A woman in rural India using both a mud and clean cookstove at the same time with wall-mounted Nexleaf device monitoring usage. Photos by Tanvi Mishra

For several months out of the year, a band of brown haze almost a mile thick blankets northern India, trapped there by the Himalayas. It produces smog dense enough to be visible *indoors* in Delhi and other urban centers.

And daily, Indian women who are among the world's poorest people add mass to the choking pollution cloud when they feed kindling to homemade stoves. They spend several hours a day preparing meals huddled over the fire, breathing in

Lots of great info at https://ucsdnews.ucsd.edu/feature/creating_a_new_kind_of_climate_warrior

Cooking food over a traditional wood-burning stove is *believed to improve the taste*. It is also widely used to heat homes in many countries. However, it turns out that the risks associated with this cooking and heating method outweigh its benefits.

A new study from Canada found that regular exposure to the black carbon pollutants in wood smoke can increase the risk of cardiovascular diseases in women. Researchers from McGill University recorded levels of different types of air pollutants present in the rural Yunnan province of China. During the study, about 280 women wore air samplers to measure the fine particular matter present in the environment.

"We found that exposure to black carbon pollutants had the largest impact on women's blood pressure, which directly impacts cardiovascular risk…" researcher Jill Baumgartner from McGill's Institute for the Health and Social Policy said. The findings reported in PNAS support previous warnings released by experts. The small particles can remain many months in the lungs and can cause structural damage and chemical changes to the organ and also increase risk of heart attacks and strokes … The pollutants produced while burning wood in fireplaces, woodstoves, include **sulphur oxides**, **carbon monoxide**, **nitrogen oxides**, **polycyclic aromatic hydrocarbons**, **benzene**, **formaldehyde** and **dioxins**.

26 Aug 2014 http://www.ibtimes.co.in/traditional-wood-burning-stoves-bad-health-study-607692

Electricity from Biomass

Table 8.1 Production of electricity from biomass and waste in 2006.

Data source: EDF and IEA key statistics.

Country	Energy Production (TWh)	Percentage of world electricity production from biomass	Percentage of the country's total electricty production
United States	58.7	29.3	1.5
Germany	19.7	9.9	3.4
Brazil	14.6	7.3	3.9
Finland	11.8	5.9	14.0
Japan	11.6	5.8	1.1
United Kingdom	9.3	4.6	2.5
Canada	9	4.5	1.6
Spain	8.2	4.1	3.1
Rest of the world	57.2	28.6	0.6
World	200.1	100	1.2

Olah *et al*., *Beyond Oil and Gas: The Methanol Economy*, 2009.

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World electricity consumption (2006) = 19,000 TWh

Electricity from Biomass = 200.1 TWh

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World electricity consumption (2006) = 19,000 TWh

Electricity from Biomass = 200.1 TWh

or 200.1 / 19,000 = 0.01053 ⇨ 1.1% of total world consumption

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

Total Source	GW (year 2020)
Coal	2154
Natural Gas	1662
Hydro-electric	1262
Solar	700
Wind	646
Nuclear	374
Liquid Fossil Fuel	297
Other Renewable (Biomass)	**121**
Geothermal	13
Total	7229

Source: https://www.eia.gov/outlooks/ieo/tables_ref.php

In 2020, only **1.7%** of global electricity generating capacity occurs via the combustion of biomass

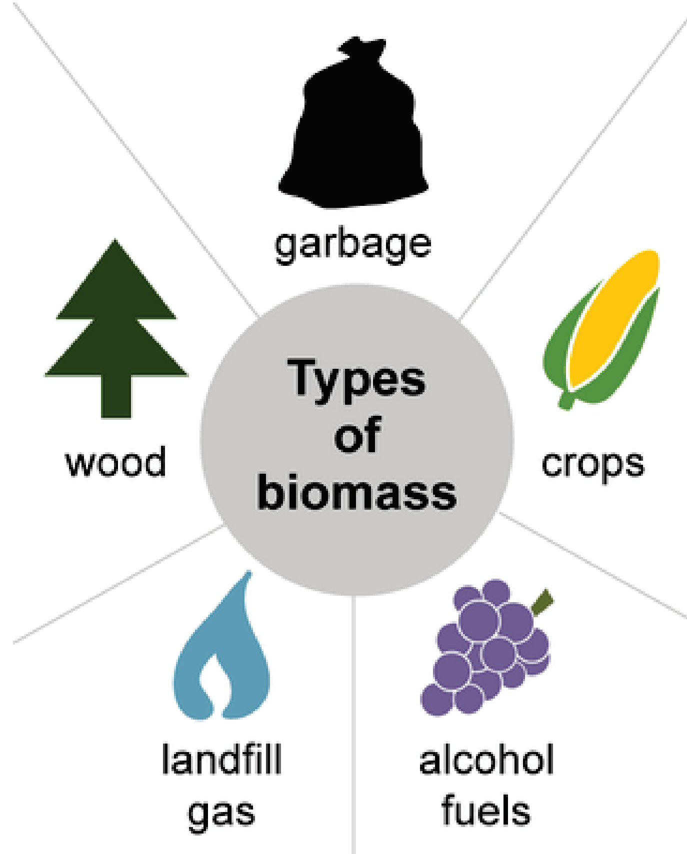
Electricity from Biomass: Overview

Photosynthesis

In the process of photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose—or sugar.

(water)		(carbon dioxide)		(sunlight)		(glucose)		(oxygen)
$6H_2O$	+	$6CO_2$	+	radiant energy	$\rightarrow$	$C_6H_{12}O_6$	+	$6O_2$

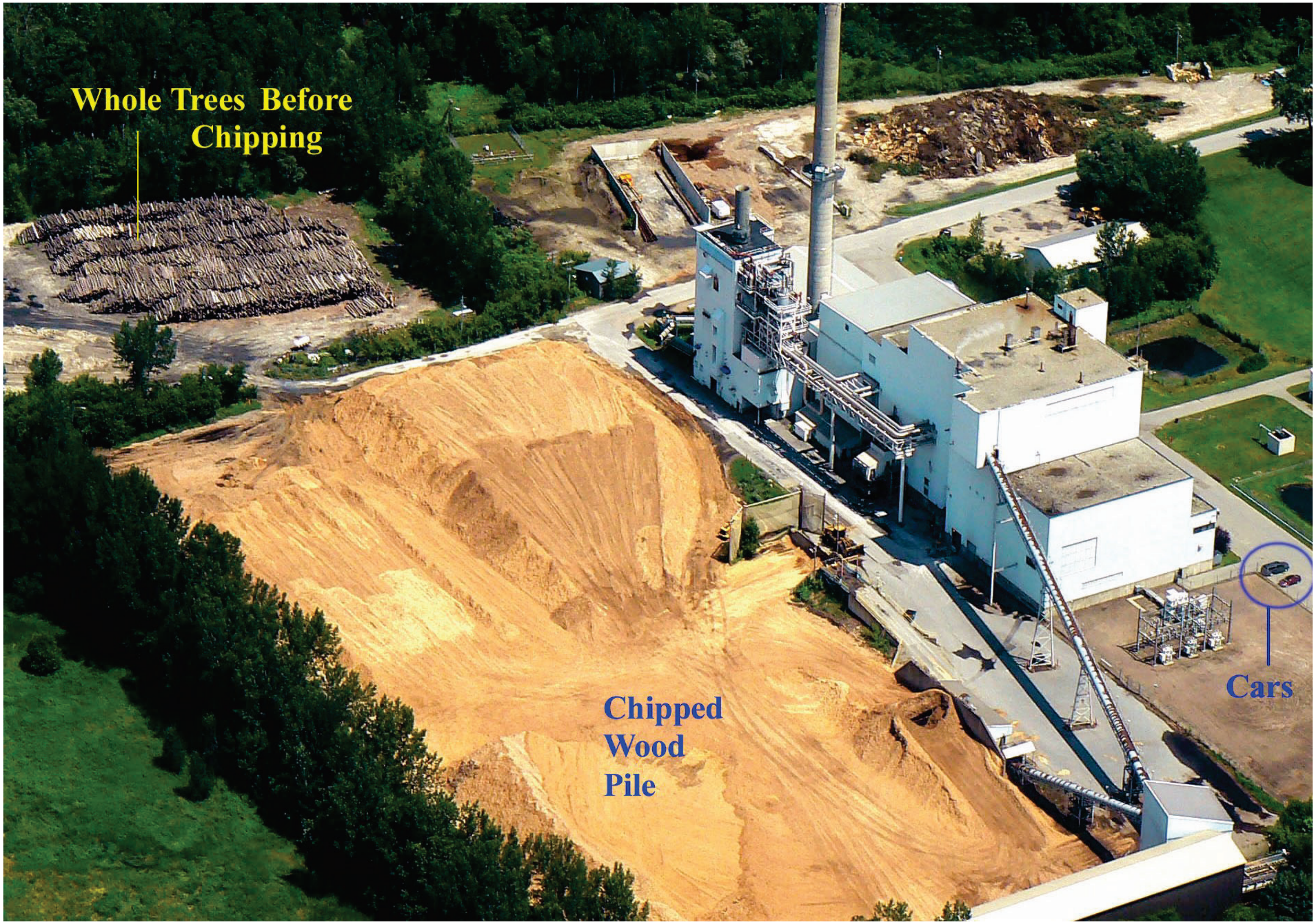
Source: Adapted from The National Energy Education Project (public domain)



Source: Adapted from The National Energy Education Project (public domain)

https://www.eia.gov/energyexplained/biomass/

Electricity from Biomass: Overview



https://sites.google.com/site/ecosytemadvocates/biomass-whole-trees

Electricity from Biomass: Overview

McNeil Biomass Plant - Burlington, VT

Generation Cost Calculations

2.1 Coal

Average Coal Plant: 328 GW / 518 = 0.633 GW or 633 MW

In 2013, there were 518 operational coal plants in the U.S., accounting for about 328 GW of nameplate generation capacity.[6] Of these 518 plants, 392 were operated by electric utilities or IPPs to supply electricity to the grid (i.e., not combined heat and power systems). The locations of these plants are shown in Figure 5.

https://energy.mit.edu/wp-content/uploads/2016/03/MITEI-WP-2016-01.pdf

Electricity from Biomass: Overview

How large is McNeil Biomass Plant ?

McNeil Biomass Plant - Burlington, VT

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https://energy.mit.edu/wp-content/uploads/2016/03/MITEI-WP-2016-01.pdf

Campus Combined Heat and Power, along Route 1

How large is our campus CHP Plant?

UMD's natural gas power plant keeps sustainability out of reach

Sonja Neve · August 29, 2019

The combined heat and power plant on the University of Maryland campus (File photo).

https://dbknews.com/2019/08/29/umd-climate-change-energy-carbon-renewable-fossil-fuel-power-plant/
https://vpaf.umd.edu/sites/default/files/reports/Utilities%20Master%20Plan.pdf

Electricity from Biomass: Overview

Courtesy A. Truman Schwartz

Fig 4.24, *Chemistry in Context*

- Plant size average 20 MW
- Efficiencies range from 15 to 30% (electricity only) to 60% (electricity + heat)
  - co-firing uses biomass to supplement fossil fuel
- Use wood, agricultural residues, and municipal waste
- 85 plants in U.S generate some type of energy from waste
- Addresses energy need and growing “mountain of waste”:
  - waste converted to CO_2 and water; unburned residue about 10% of initial volume
  - iron-containing metals often recovered and recycled

Electricity from Waste

Baltimore RESCO (Refuse Energy Systems Company) Plant
Russell Street & U.S Interstate 95 (shadow of Ravens Stadium)
http://www.eia.doe.gov/kids/energy.cfm?page=RESCOE_Plant

- Opened in 1984
- Site of old pyrolysis plant
- Burns 2,250 tons of trash per day
- Metals recovered; volume of trash reduced by factor of 10
- Can generate 60,000 kW of electricity ⇨ 60 MW (900 × size of Univ Park Elem School 66 kW solar array, but only 6% typical nuclear plant)
- Heat used for direct steam heating / cooling downtown Baltimore
- One of 16 such plants in the U.S.

ENVIRONMENT BY FERN SHEN 11:42 AM APR 22, 2020

Baltimore will appeal Clean Air Act ruling, city solicitor says

The decision comes after lobbying by community and environmental activists, who held an Earth Day protest at the BRESCO incinerator today

Above: The tall smokestack of the Wheelabrator plant emits three times more pollutants than any other facility in Baltimore. (Brew file photo)

https://www.baltimorebrew.com/2020/04/22/baltimore-will-appeal-clean-air-act-ruling-solicitor-says

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The decision comes after lobbying by community and environmental activists, who held an Earth Day protest at the BRESCO incinerator today

Under pressure from community and environmental activists, the Young administration today said the city will appeal last month's federal court decision striking down the Baltimore Clean Air Act.

"I have recommended to Mayor Young that the city appeal Judge Russell's decision in the Wheelabrator case regarding the city's Clean Air Act," acting City Solicitor Dana P. Moore told *The Brew* this morning.

"He has concurred and authorized me to proceed," she said.

Moore said she entered her appearance in the case this morning and directed outside counsel to file a notice of appeal.

"Die-In" Protest

The decision came just as activists were **mounting** an Earth Day "die-in" protest on Russell Street near the Wheelabrator BRESCO incinerator, Baltimore's biggest source of industrial air pollution.

News of the mayor's decision broke after they concluded.

Protest organizers applauded the city's announcement, saying much is at stake in the battle to get the city to defend the Clean Air Act.

https://www.baltimorebrew.com/2020/04/22/baltimore-will-appeal-clean-air-act-ruling-solicitor-says

The Clean Air Act was enacted by the City Council to improve health outcomes for residents. It imposes stricter limits on nitrogen oxides, sulfur dioxide, mercury and other air emissions by large incinerators.

Wheelabrator and Curtis Bay Energy, a medical waste incinerator, challenged the new law and won a favorable ruling from U.S. District Judge George L. Russell III.

Russell said the law undermined the authority of state and federal governments to regulate air pollution. Wheelabrator has said it would be impossible to operate BRESCO profitably under the law's emissions strictures.

Reacting to today's news, United Workers' Greg Sawtell said he was "proud of the work everybody from the grassroots groups to our City Council did to get us here."

But he was already looking forward to the group's next goal, to persuade the city to end its relationship with Wheelabrator when the contract to burn Baltimore's trash at its BRESCO facility expires on December 2021.

To Dr. Gwen DuBois, of the Chesapeake Physicians for Social Responsibility, shutting down the incinerator is an equity issue.

"We wonder why people of color and low income people suffer more in Baltimore from from pandemics and environmental injustice, and a big part of this is we need to close BRESCO, so that people who are downwind don't inhale this, so that children don't get asthma," DuBois said, speaking at a news conference before the die-in.

"It's not fair, not right, and we don't need incineration," she said. "There are alternatives."

– *Louis Krauss contributed to this story.*

https://www.baltimorebrew.com/2020/04/22/baltimore-will-appeal-clean-air-act-ruling-solicitor-says

BRIEF

Baltimore grants Wheelabrator 10-year contract extension, with emissions requirements, to settle suit

AUTHOR

E.A. Crunden
@eacrunden

UPDATED

Nov. 5 2020, 8:23 a.m. EST

PUBLISHED

Nov. 4, 2020

- Baltimore has granted Wheelabrator an extension to continue operating an incinerator owned by the Northeast Maryland Waste Disposal Authority until Dec. 31, 2031. The company would invest $39.9 million in emissions control upgrades, in a nod to community concerns around air pollution. Wheelabrator's contract is set to expire at the end of 2021.
- The city's Board of Estimates approved the extension on a 3-2 vote this morning. Multiple attendees slammed the day-after-election timing, with several community members calling it "appalling" and "inappropriate." A legal action challenging the approval has been filed by the Energy Justice Network (EJN), Trilogy Financial Group, and City Councilmembers Mary Pat Clarke and Ed Reisinger.
- At the heart of the back-and-forth is the city's 2019 Clean Air Act, which spurred Wheelabrator to sue. Court documents show that litigation is ongoing, although the new agreement would settle the case now. Acting City Solicitor Dana Moore said Baltimore was not in a strong position to win that suit, which played a role in the city's decision.

https://www.wastedive.com/news/baltimore-wheelabrator-lives-on-controversy-zero-waste/588279/

Ethanol

Question 1

2 pts

Ethanol is frequently added to gasoline. According to *Chemistry in Context*, does this lead to better or worse gas mileage compared to use of pure octane, and, briefly, why is this the case?

- ◯ The addition of ethanol (C_2H_5OH) to pure gasoline (C_8H_{18}) results in a higher octane rating, as well as ***increased*** fuel mileage because the blended fuel has ***higher*** energy content. As shown in Figure 4.16, hydrocarbons that are oxygenated tend to release ***more*** energy than hydrocarbons that lack oxygen.
- ◯ The addition of ethanol (C_2H_5OH) to pure gasoline (C_8H_{18}) results in a higher octane rating, as well as ***reduced*** fuel mileage because the blended fuel has ***lower*** energy content. As shown in Figure 4.16, hydrocarbons that are oxygenated tend to release ***more*** energy than hydrocarbons that lack oxygen.
- ◯ The addition of ethanol (C_2H_5OH) to pure gasoline (C_8H_{18}) results in a higher octane rating, as well as ***increased*** fuel mileage because the blended fuel has ***higher*** energy content. As shown in Figure 4.16, hydrocarbons that are oxygenated tend to release ***less*** energy than hydrocarbons that lack oxygen.
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Ethanol

Question 1

2 pts

Ethanol is frequently added to gasoline. According to *Chemistry in Context*, does this lead to better or worse gas mileage compared to use of pure octane, and, briefly, why is this the case?

- ○ The addition of ethanol (C_2H_5OH) to pure gasoline (C_8H_{18}) results in a higher octane rating, as well as ***increased*** fuel mileage because the blended fuel has ***higher*** energy content. As shown in Figure 4.16, hydrocarbons that are oxygenated tend to release ***more*** energy than hydrocarbons that lack oxygen.
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Ethanol

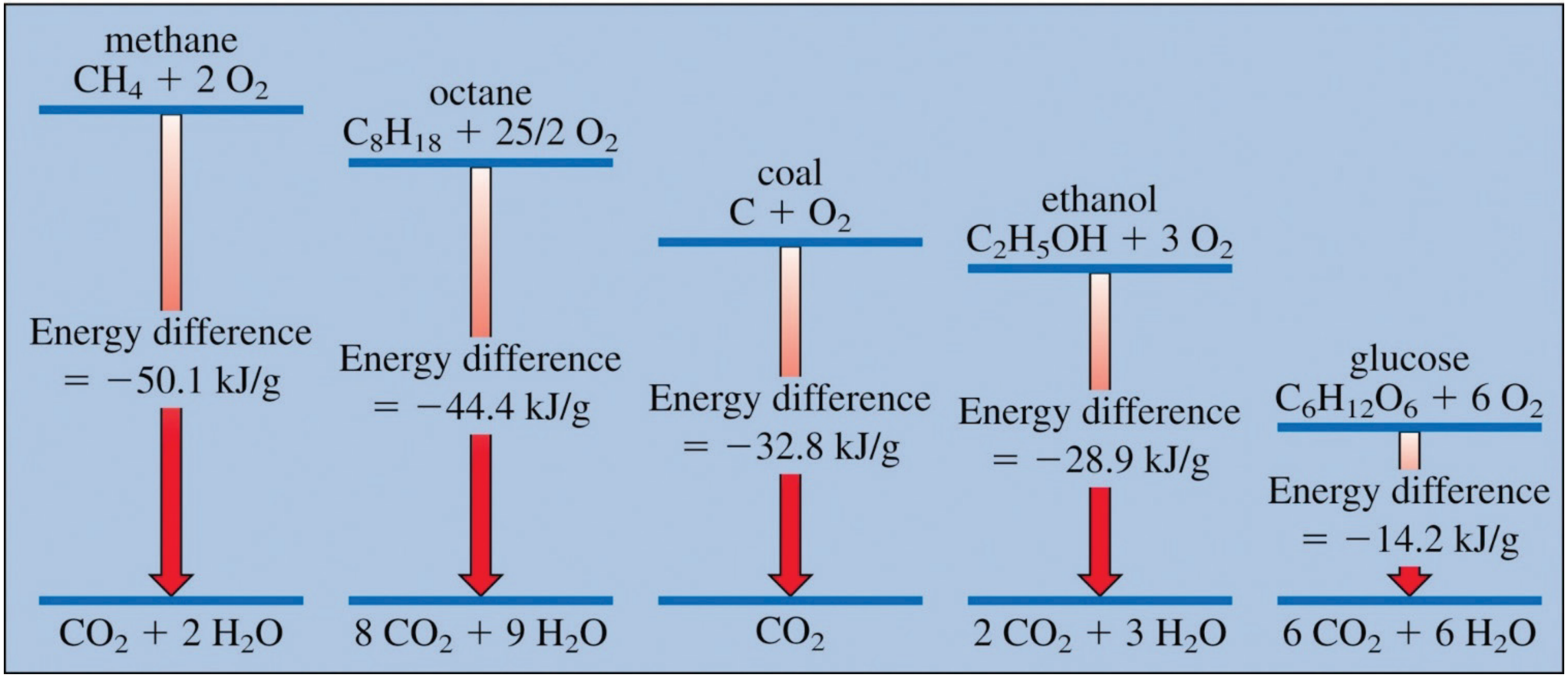
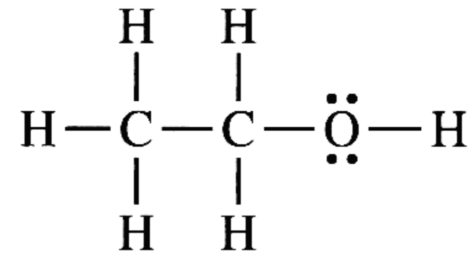


Fig 4.16. Energy differences (in kJ/g) for the combustion of methane (CH_4), n-octane (C_8H_{18}), coal (assumed to be pure carbon), ethanol (C_2H_5OH), and wood (assumed to be glucose).

Chemistry in Context

Ethanol

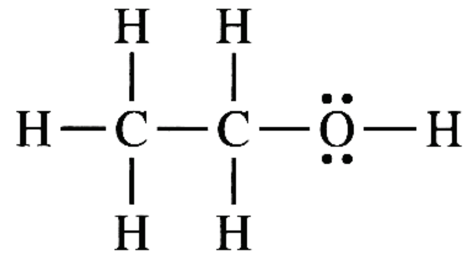


- Ethanol : C_2H_5OH
- Alcohol
- $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$ (ΔH_f = 228 kJ/mol or 5 kJ/g)
- Reaction catalyzed by enzymes; theoretically, can be close to carbon neutral
- Ethanol combustion:

  $C_2H_5OH + 3\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$ + 29.7 kJ/g

  Heat release less than combustion of C_8H_{18} (47.8 kJ/g) because C_2H_5OH is already partially oxidized
- However … ethanol has a higher octane than gasoline

Ethanol



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  Heat release less than combustion of C_8H_{18} (47.8 kJ/g) because C_2H_5OH is already partially oxidized
- However … ethanol has a higher octane than gasoline

What is octane rating?

Octane rating is the measure of a fuel's ability to resist "knocking" or "pinging" during combustion, caused by the air/fuel mixture detonating prematurely in the engine.

In the U.S., unleaded gasoline typically has octane ratings of 87 (regular), 88–90 (midgrade), and 91–94 (premium). Gasoline with an octane rating of 85 is available in some high-elevation areas of the U.S. (more about that below).

https://www.fueleconomy.gov/feg/octane.shtml

Ethanol Production

Question 2 **2 pts**

According to *Olah et al.:*

a) what crop is used by Brazil to derive almost all of its biogenic automotive fuel?

b) how is a waste product from this crop used to derive an additional benefit?

- ◯ a) sugar cane
  b) sugar cane husk is ground and composted into fertile soil
- ◯ a) corn
  b) corn husk is burned to generate heat that is used to add energy to the grid
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Ethanol Production

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- U.S.: Ethanol produced from corn
- Brazil: Ethanol produced from sugar cane, which thrives in tropical climate

Ethanol Production

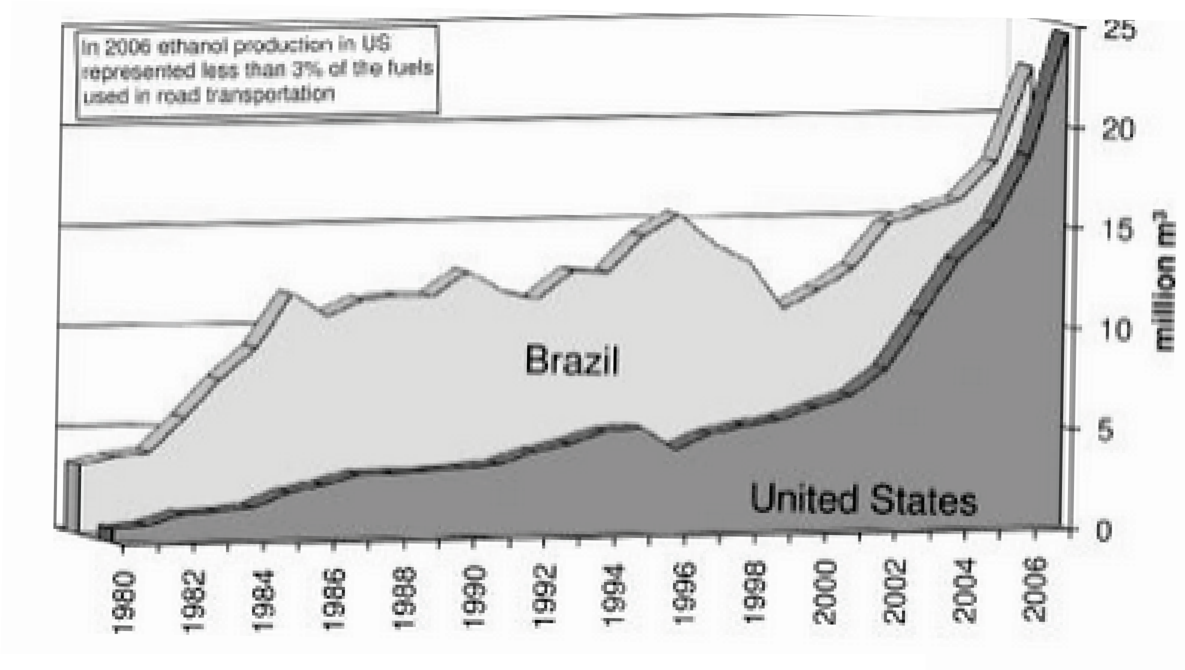

Figure 8.13 Historic production of ethanol in the United States and Brazil. (Based on data from Renewable Fuel Association and Sao Paulo Agroindustry Union (UNICA).)

Olah *et al.*, *Beyond Oil and Gas: The Methanol Economy*, 2009.

- U.S.: Ethanol produced from corn
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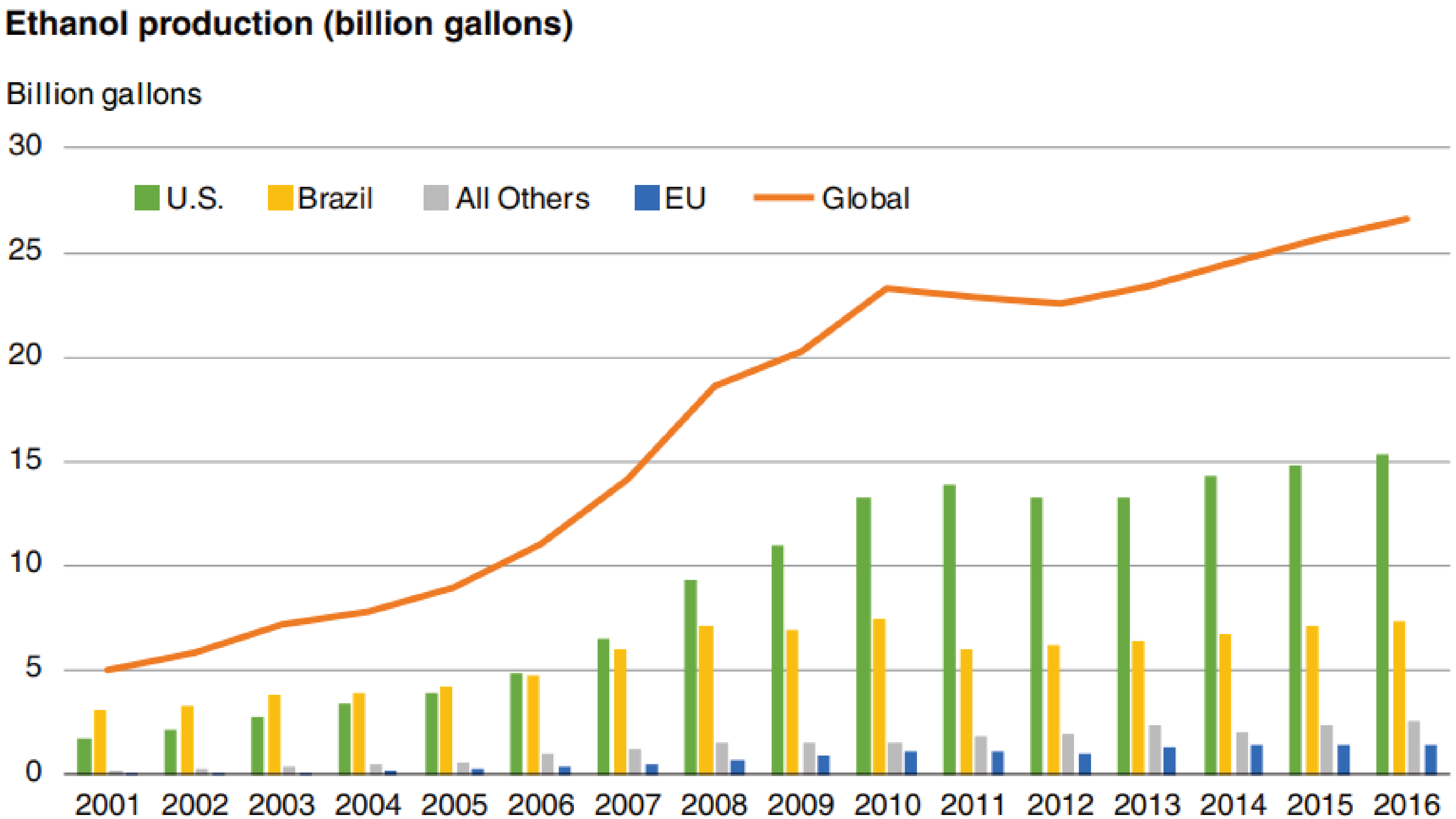
Ethanol Production

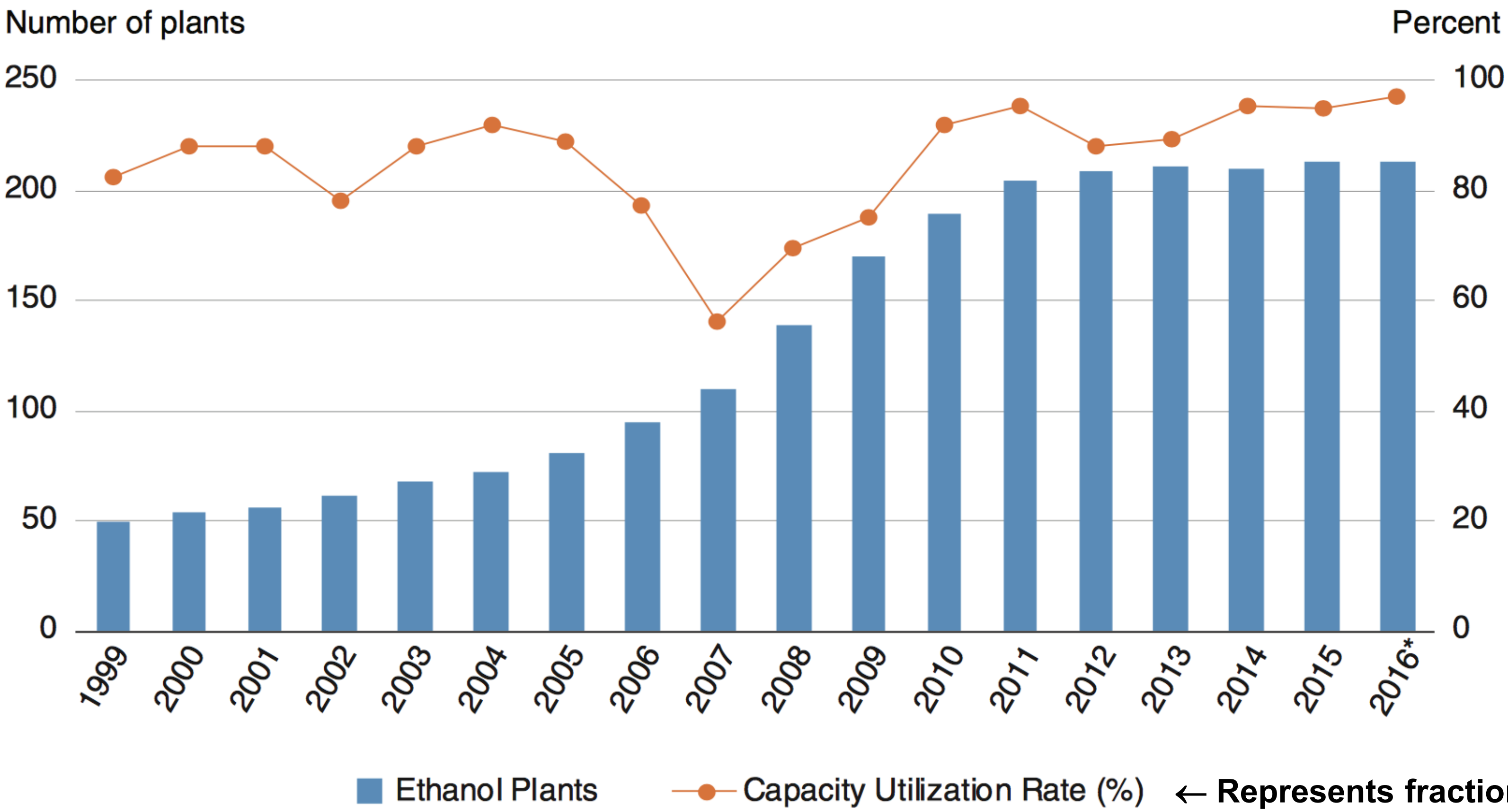


Source: U.S. Department of Energy, Energy Information Administration (EIA, 2016a), 2000-12 data; Renewable Fuels Association (RFA, 2017), 2013-16 data.

https://farmpolicynews.illinois.edu/2017/10/usda-ers-u-s-exports-ethanol/

U.S. Ethanol Plants and Domestic Utilization

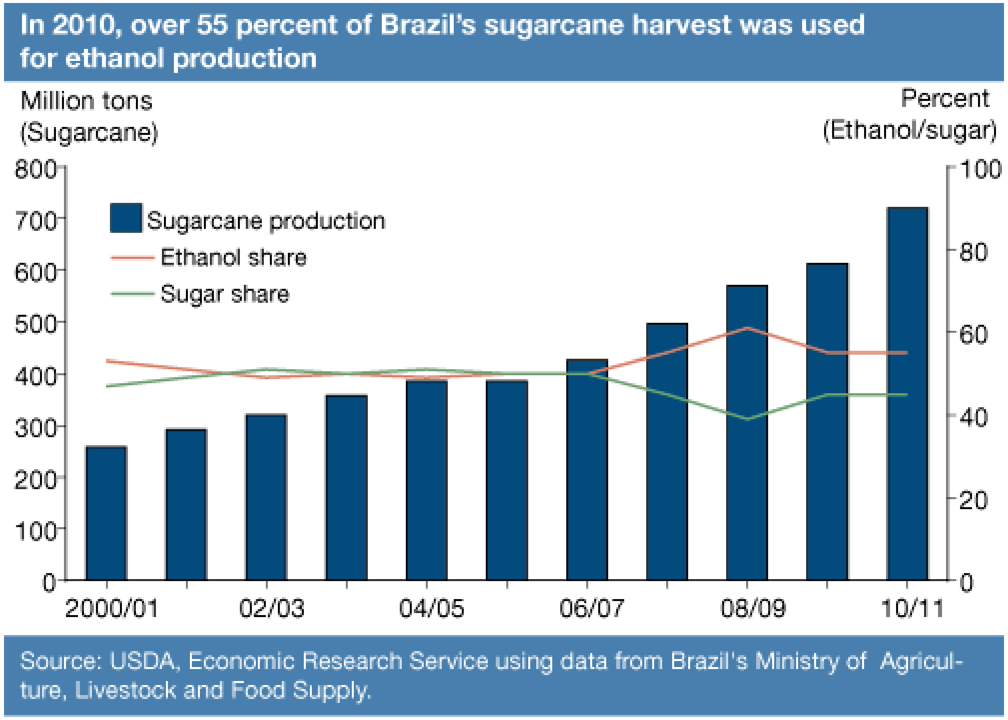
Figure 2
U.S. ethanol plants and utilization rate, 1999-2016*



← Represents fraction of U.S. ethanol consumed domestically

https://farmpolicynews.illinois.edu/2017/10/usda-ers-u-s-exports-ethanol/

Ethanol Production: Good News



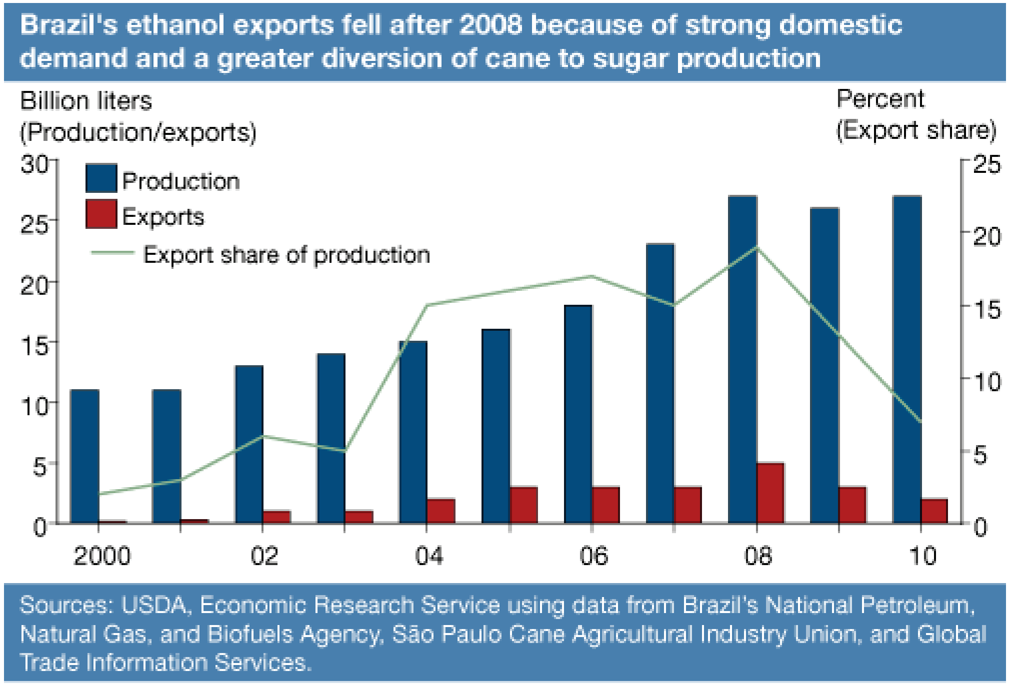
https://www.ers.usda.gov/amber-waves/2011/december/can-brazil-meet-the-world-s-growing-need-for-ethanol/

- Brazil: Ethanol produced from sugar cane, which thrives in tropical climate
  - energy to convert sugar to ethanol supplied by burning bagasse (sugar cane husk)
- About half cars in Brazil are “flex fuel vehicles (FFV)”
  - can run on 100 percent ethanol or any ethanol-gasoline mixture.
- Ethanol accounts for ~40% of non-diesel fuel use in Brazil
- 2010: Brazil produces 26% of world ethanol (US produces most)

Ethanol in Brazil

https://www.youtube.com/watch?v=1Jn2AIAWmjg

Ethanol Production: Bad News



https://www.ers.usda.gov/amber-waves/2011/december/can-brazil-meet-the-world-s-growing-need-for-ethanol/

- **Annual Brazil ethanol production < 1 day world petroleum consumption**
- **Brazil consumes nearly all the ethanol it produces due to high domestic demand**

Ethanol Production Nuance

Question 3 **3 pts**

According to *Olah et al.:*

a) what is meant by the term "carbon debt"?

b) how often does it take to repay the "carbon debt" for current biofuels such as ethanol from corn and biodiesel from palm and soybean oil?

- ◯ a) carbon debt refers to the inequity in the release of GHGs between the developed and developing world

  b) it can take 35 to 450 years to repay this carbon debt

- ◯ a) carbon debt refers to the inequity in the release of GHGs between the developed and developing world

  b) it can take 10 to 20 years to repay this carbon debt

- ◯ a) carbon debt refers to the rise in CO_2 resulting from the conversion of land (i.e., deforestation) need to prepare fields for the growth of biofuels.

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Ethanol Production Nuance

Question 4 **3 pts**

Based on the *McElroy* article:

a) what crop is used by the United States to derive almost all of its biogenic automotive fuel?

b) why is production of biofuel from this crop not a clear environmental win?

- ○ a) corn

  b) the energy balance for the production of ethanol from corn is only marginally positive, and the production of ethanol from corn places pressure on the food supply:

- ○ a) corn

  b) the production of corn is incredibly water intensive, and the demand for water to produce corn is causing a major shortage of ground water

- ○ a) sugar cane

  b) the energy balance for the production of ethanol from sugar cane is only marginally positive, and the production of ethanol from sugar cane places pressure on the food supply

- ○ a) sugar cane

  b) the production of sugar cane is incredibly water intensive, and the demand for water to produce corn is causing a major shortage of ground water

Ethanol Production Nuance

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b) the energy balance for the production of ethanol from sugar cane is only marginally positive, and the production of ethanol from sugar cane places pressure on the food supply

○ a) sugar cane

b) the production of sugar cane is incredibly water intensive, and the demand for water to produce corn is causing a major shortage of ground water

Ethanol Production: Carbon Debt

Land Clearing and the Biofuel Carbon Debt

SCIENCE VOL 319 29 FEBRUARY 2008

Joseph Fargione,[1] Jason Hill,[2,3] David Tilman,[2]* Stephen Polasky,[2,3] Peter Hawthorne[2]

Increasing energy use, climate change, and carbon dioxide (CO_2) emissions from fossil fuels make switching to low-carbon fuels a high priority. Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. Converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels in Brazil, Southeast Asia, and the United States creates a "biofuel carbon debt" by releasing 17 to 420 times more CO_2 than the annual greenhouse gas (GHG) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.

[1]The Nature Conservancy, 1101 West River Parkway, Suite 200, Minneapolis, MN 55415, USA. [2]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN 55108, USA. [3]Department of Applied Economics, University of Minnesota, St. Paul, MN 55108, USA.

Nice summary of the debate over the climate benefit of sugar and corn based biofuels at:

http://cen.acs.org/articles/85/i51/Costs-Biofuels.html

Ethanol Production: Carbon Debt

SCIENCE VOL 319 29 FEBRUARY 2008

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,[1*] Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

Most prior studies have found that substituting biofuels for gasoline will reduce greenhouse gases because biofuels sequester carbon through the growth of the feedstock. These analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years.

[1]Woodrow Wilson School, Princeton University, Princeton, NJ, USA. German Marshall Fund of the U.S., Georgetown Environmental Law and Policy Institute. [2]Agricultural Conservation Economics, Laurel, MD, USA. [3]Woods Hole Research Center, Falmouth, MA, USA. [4]Center for Agricultural and Rural Development, Iowa State University, Ames, IA, USA.

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Ethanol Production: Fertilizer and Food Production

The New York Times

Biofuels Threaten Fertilizer

By KEITH BRADSHER and ANDREW MARTIN
Published: April 30, 2008

The squeeze on the supply of fertilizer has been building for roughly five years. Rising demand for food and biofuels prompted farmers everywhere to plant more crops. As demand grew, the fertilizer mines and factories of the world proved unable to keep up.

Some dealers in the Midwest ran out of fertilizer last fall, and they continue to restrict sales this spring because of a limited supply.

“If you want 10,000 tons, they’ll sell you 5,000 today, maybe 3,000,” said W. Scott Tinsman Jr., a fertilizer dealer in Davenport, Iowa. “The rubber band is stretched really far.

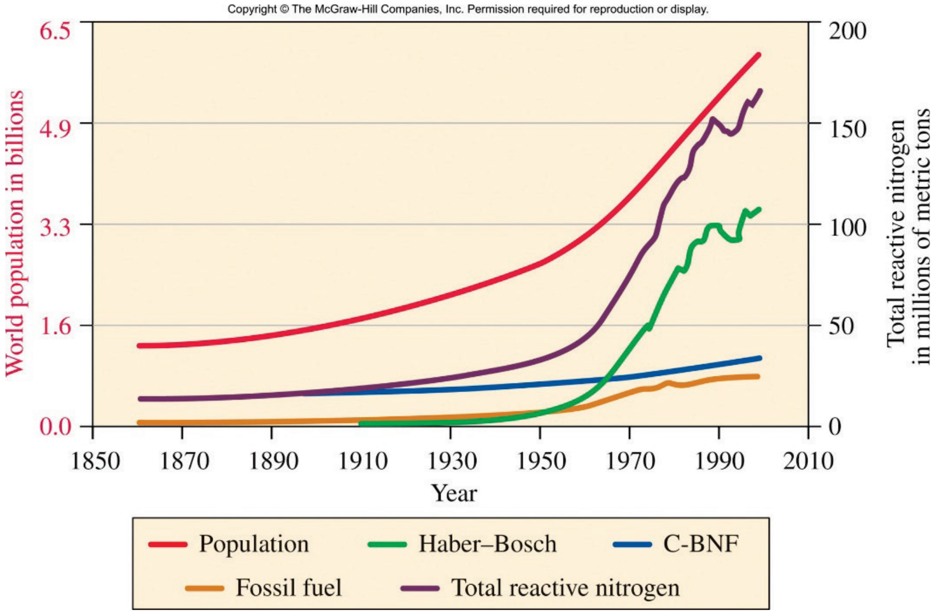


Fig 6.19, *Chemistry in Context*

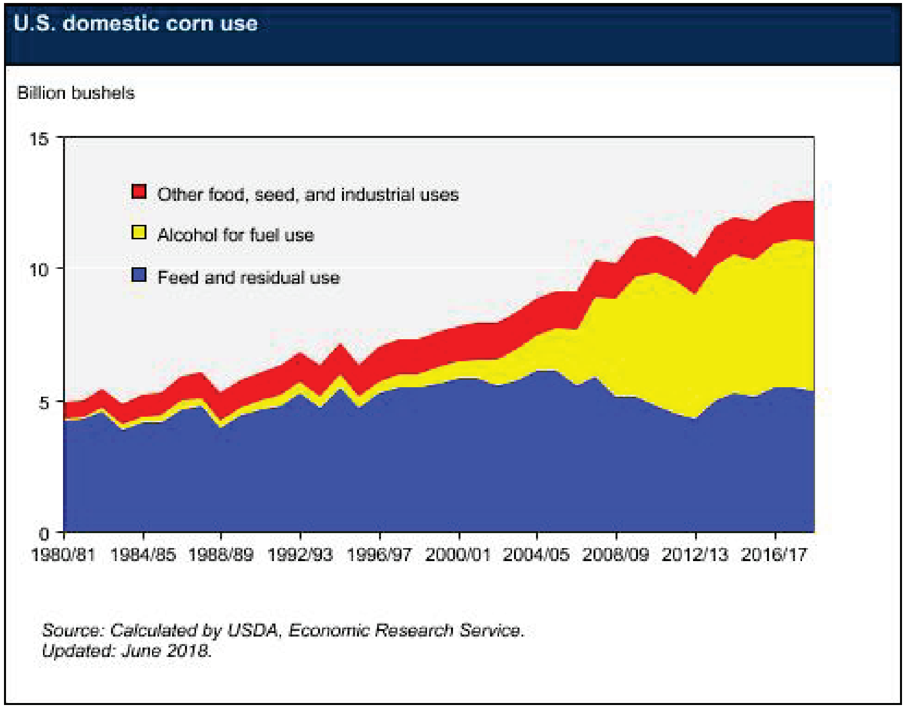
- Ammonium leached as nitrite or nitrate, contaminating water supply
- Ammonia converted to NO, increasing acidity of atmosphere and soils
- N_2O produced by NO and fertilizer production

Nice summary of the debate over the climate benefit of sugar and corn based biofuels at:

http://cen.acs.org/articles/85/i51/Costs-Biofuels.html

U.S. Ethanol Production: The Show Must Go On

- Despite these debates the "show goes on"
  - US produced 15.3 × 10^9 gallons of ethanol in 2016
  - 90 million acres (**20% of cultivated land area**) harvested for corn
  - ~50% of US corn produced goes to ethanol production
  - "The maze of historic subsidies for corn ethanol has allowed the federal government to pick winners and losers, distort energy and agriculture markets, and contributed to expansion and overproduction of corn and ethanol"
    https://www.taxpayer.net/energy-natural-resources/federal-subsidies-corn-ethanol-corn-based-biofuels

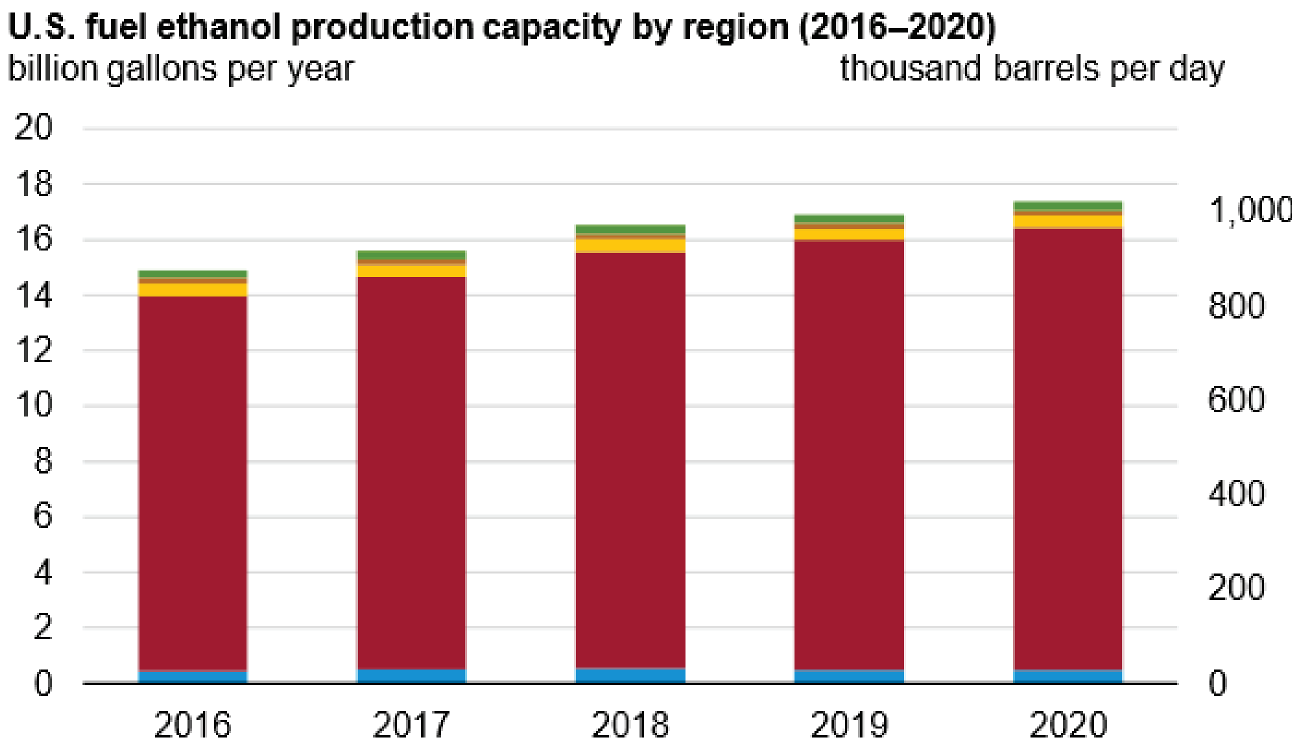


https://www.ers.usda.gov/webdocs/charts/83915/cornuse.jpg?v=8618.3

Chemistry in Context

McElroy, Ethanol Illusion, *Harvard Magazine,* Nov-Dec 2006.

U.S. Ethanol Update

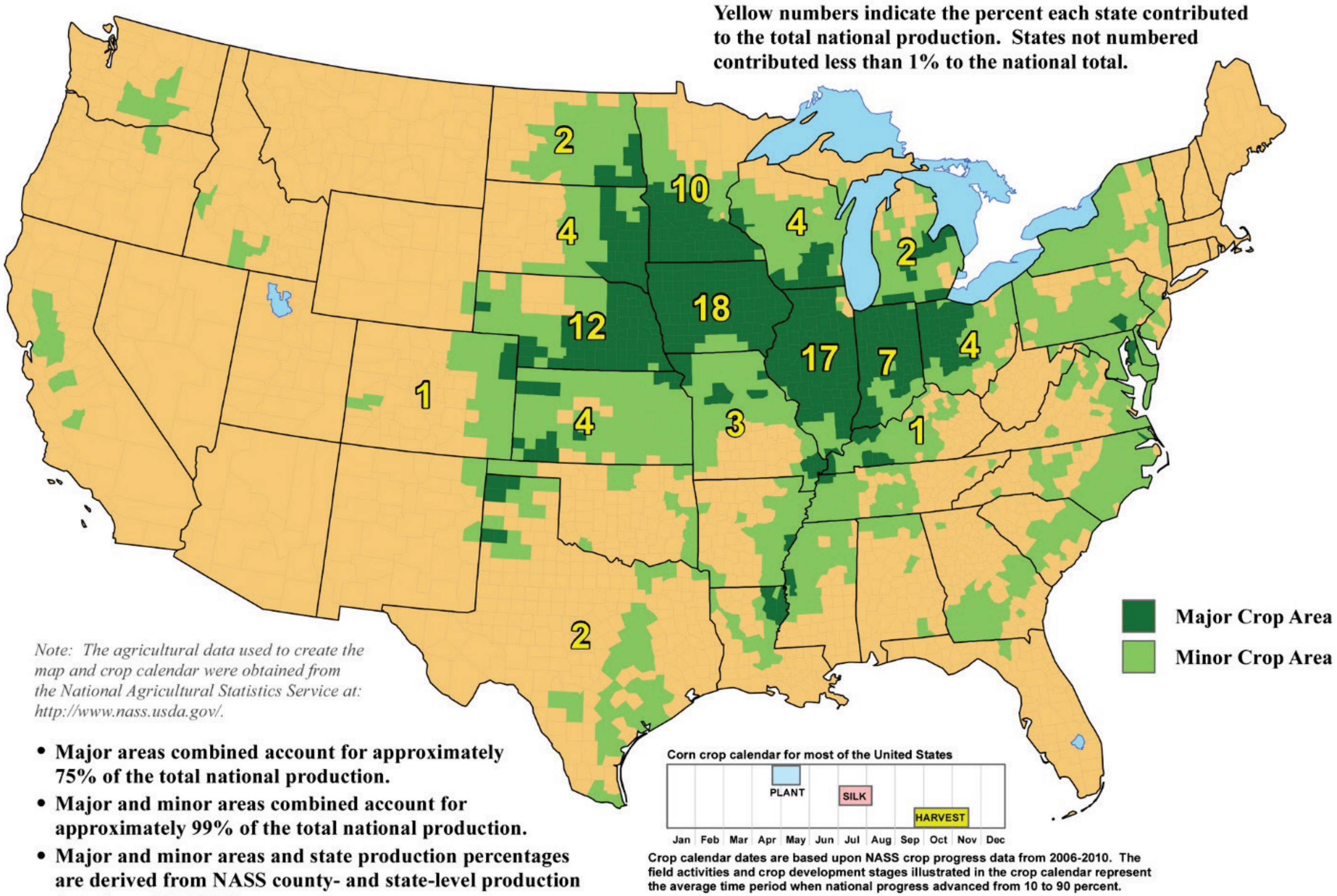


Source: U.S. Energy Information Administration, *U.S. Fuel Ethanol Plant Production Capacity Repo*

Note: PADD=Petroleum Administration for Defense District.

https://www.eia.gov/todayinenergy/detail.php?id=45316

United States: Corn



- **Major areas combined account for approximately 75% of the total national production.**
- **Major and minor areas combined account for approximately 99% of the total national production.**
- **Major and minor areas and state production percentages are derived from NASS county- and state-level production data from 2006-2010.**

USDA **Agricultural Weather Assessments**
World Agricultural Outlook Board

http://ctgpublishing.com/peach-and-blossom-illustration-circa-1878/united-states-top-corn-producing-areas-map/

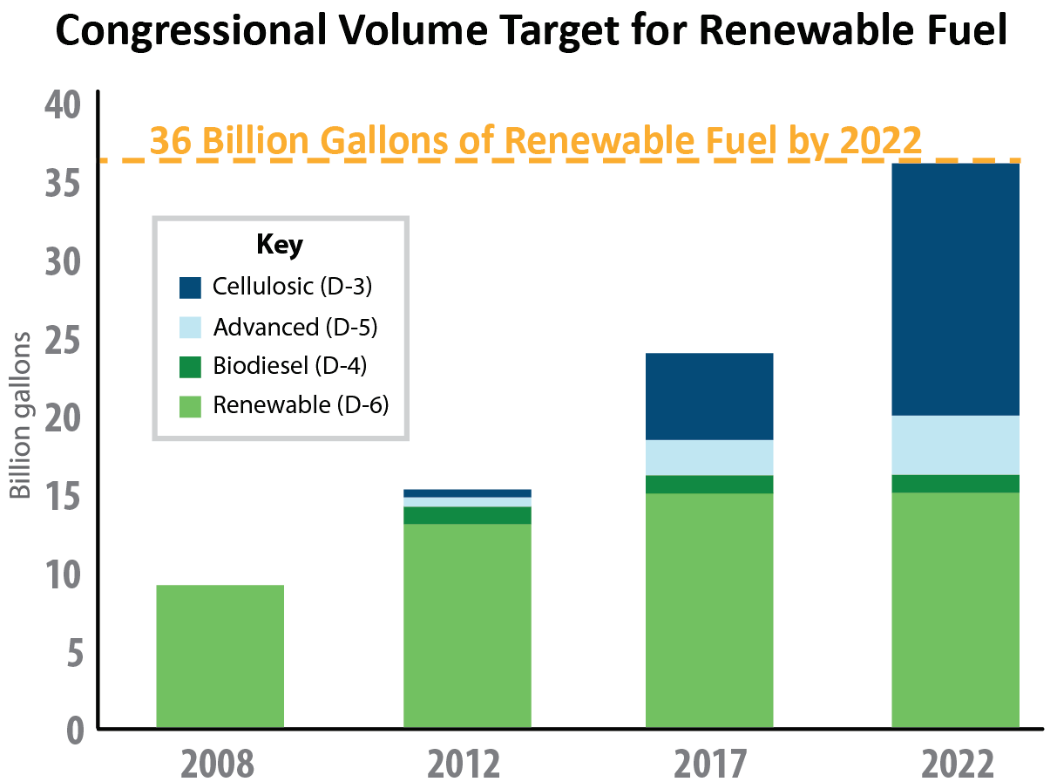
U.S. Ethanol: High Stakes Politics

[redacted] advocates eliminating the multibillion-dollar annual government subsidies that domestic ethanol has long enjoyed. As a free trade advocate, [redacted] also opposes the 54-cent-a-gallon tariff that the United States slaps on imports of ethanol made from sugar cane, which packs more of an energy punch than corn-based ethanol and is cheaper to produce.

"We made a series of mistakes by not adopting a sustainable energy policy, one of which is the subsidies for corn ethanol, which I warned in Iowa were going to destroy the market" and contribute to inflation, [redacted] said this month in an interview with a Brazilian newspaper, O Estado de São Paulo. "Besides, it is wrong," [redacted] added, to tax Brazilian-made sugar cane ethanol, "which is much more efficient than corn ethanol."

[redacted] in contrast, favors the subsidies, some of which end up in the hands of the same oil companies [redacted] says should be subjected to a windfall profits tax. In the name of helping the United States build "energy independence," [redacted] also supports the tariff, which some economists say may well be illegal under the World Trade Organization's rules but which [redacted] advisers say is not.

U.S. Renewable Fuel Standard



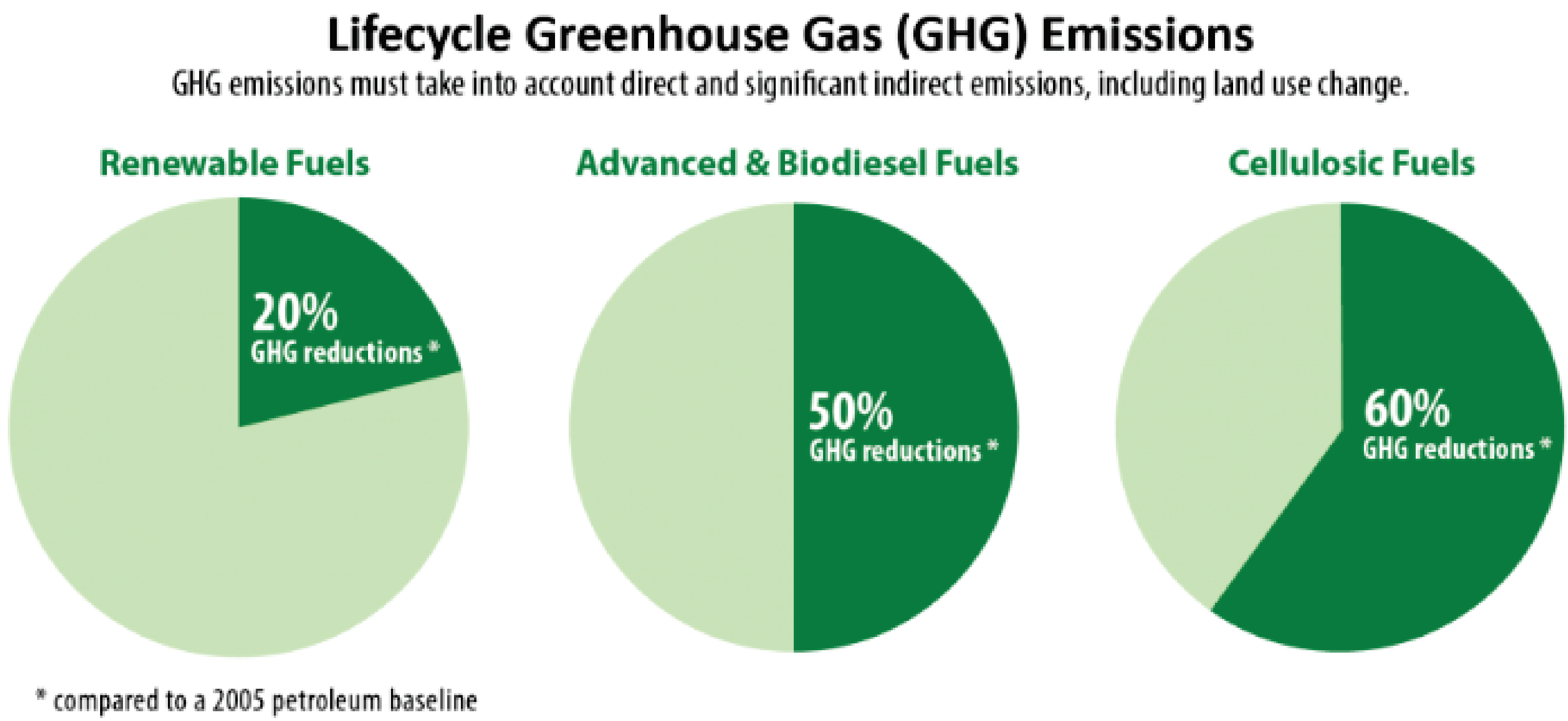
On November 30, 2018, the U.S. Environmental Protection Agency (EPA) issued a final rule for the 2019 Renewable Fuel Standard (RFS) program, with the total U.S. renewable fuel volume requirement set 3% higher than the 2018 mandate, but nearly 30% lower than the statutory volume standards set forth by the Energy Independence and Security Act of 2007 (EISA 2007). Similar to previous years, EPA exercised its cellulosic waiver authority to decrease volume standards for cellulosic biofuels because growth has been slower than Congress had envisioned in EISA, passed more than a decade ago.

EISA: Energy Independence and Security Act of 2007

https://www.eia.gov/todayinenergy/detail.php?id=37712
https://www.epa.gov/sites/production/files/2015-09/congressional_volume_target-02_0.png
https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

U.S. EPA Mantra

EPA continues to review and approve new pathways, including for fuels made with advanced technologies or with new feedstocks. Certain biofuels are similar enough to gasoline or diesel that they do not have to be blended, but can be simply "dropped in" to existing petroleum-based fuels. These drop-in biofuels directly replace petroleum-based fuels and hold particular promise for the future.



https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

One Last Comparison:

In prior lectures, we have looked at market forces such as:

- Cost of Fossil Fuel ↑
- Cost of Electricity from Renewables ↓

as well as complete life cycle effects of various options:

- Carbon release (early) and methane release (late) from areas flooded for hydro
- N_2O associated with fertilizer production for biofuels

There is one more comparison that could be vital for society to consider, for <u>large-scale transition</u> to energy production from some means other than combustion of fossil fuel

Land Requirements

Table 8.2 Comparison of land requirements for typical power generation options.

Technology	Land use m^2/MW
110 MW geothermal flash plant (excluding wells)	1,260
20 MW geothermal binary plant (excluding wells)	1,415
49 MW geothermal FC-RC plant [1] (excluding wells)	2,290
56 MW geothermal flash plant (including wells, [2] pipes, etc.)	7,460
2,258 MW coal plant (including strip mining)	40,000
670 MW nuclear plant (plant site only)	10,000
47 MW (avg) solar thermal plant (Mojave Desert, CA)	28,000
10 MW (avg) solar PV plant[3] (Southwestern US)	66,000

(1) Typical Flash-Crystallizer/Reactor-Clarifier plant at Salton Sea, Calif.

(2) Wells are directionally drilled from a few well pads.

(3) New land would not be needed if, for example, rooftop panels were deployed in an urban setting.

http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

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http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Wind turbines: 125,000 to 200,000 m^2 / MW

http://www.nrel.gov/docs/fy09osti/45834.pdf

Hydroelectric: enormous impact upstream of reservoir

Ethanol Production: Really Bad News

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Hydroelectric: enormous impact upstream of reservoir

- Annual ethanol production in Brazil < 1 day world petroleum consumption
- Sugar Cane: 650 gal/acre http://www.earth-policy.org/Books/PB2/PB2ch10_ss7.htm

650 gal/acre × 3785.1 cm^3/gal × 0.789 g/cm^3 × 29.7 kJ/g = 5.8×10^7 kJ/acre

5.8×10^7 kJ/acre/year = 1.83 kW/acre = 2,211,390 m^2/MW   Yikes!

Ethanol Production: Really Bad News

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(1) Typical Flash-Crystallizer/Reactor-Clarifier plant at Salton Sea, Calif.
(2) Wells are directionally drilled from a few well pads.
(3) New land would not be needed if, for example, rooftop panels were deployed in an urban setting.

http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Wind turbines: 125,000 to 200,000 m^2 / MW

http://www.nrel.gov/docs/fy09osti/45834.pdf

Hydroelectric: enormous impact upstream of reservoir

- Annual ethanol production in Brazil < 1 day world petroleum consumption
- Corn 350 gal/acre http://www.earth-policy.org/Books/PB2/PB2ch10_ss7.htm

350 gal/acre × 3785.1 cm^3/gal × 0.789 g/cm^3 × 29.7 kJ/g = 3.1×10^7 kJ/acre

3.1×10^7 kJ/acre/year = 0.98 kW/acre = 4,106,870 m^2/MW Yikes; Yikes!

Algae as a Biofuel

Pros:

- High oil content
- Absorbs atmospheric CO_2
- Can use waste as fertilizer
- Not a food staple

Cons:

- Need sunny, warm conditions; certain areas preferred
- Growth limited by “self shading” effect; challenge to exploit entire volume of pond
- Water intensive (rules out many warm, sunny environs for large scale production)
- Efficient processing method still being researched
- Fertilizer intensive
- Water intensive

The promise of algae as an economically viable clean source of fuel is leading many groups to research the large scale viability of this potential resource.

http://www3.signonsandiego.com/stories/2009/apr/29/1n29biofuels005337-new-center-focus-algae-biofuels

http://cosmiclog.msnbc.msn.com/_news/2011/04/14/6471719-is-algae-biofuel-too-thirsty

http://stateimpact.npr.org/texas/2012/12/17/the-downside-of-using-algae-as-a-biofuel

Algae as a Biofuel

Wigmosta *et al*., *Water Resources Res*, 13 April 2011 conclude:

Using current technology, 48% of petroleum needed for US transportation can be produced using:

- 5.5% of U.S. land area (lower 48)
- 3 times the total amount of water used for irrigation

Optimal placement of algae production facility in the humid Gulf Coast, southeastern seaboard, and Great Lakes regions would considerably reduce the water needed

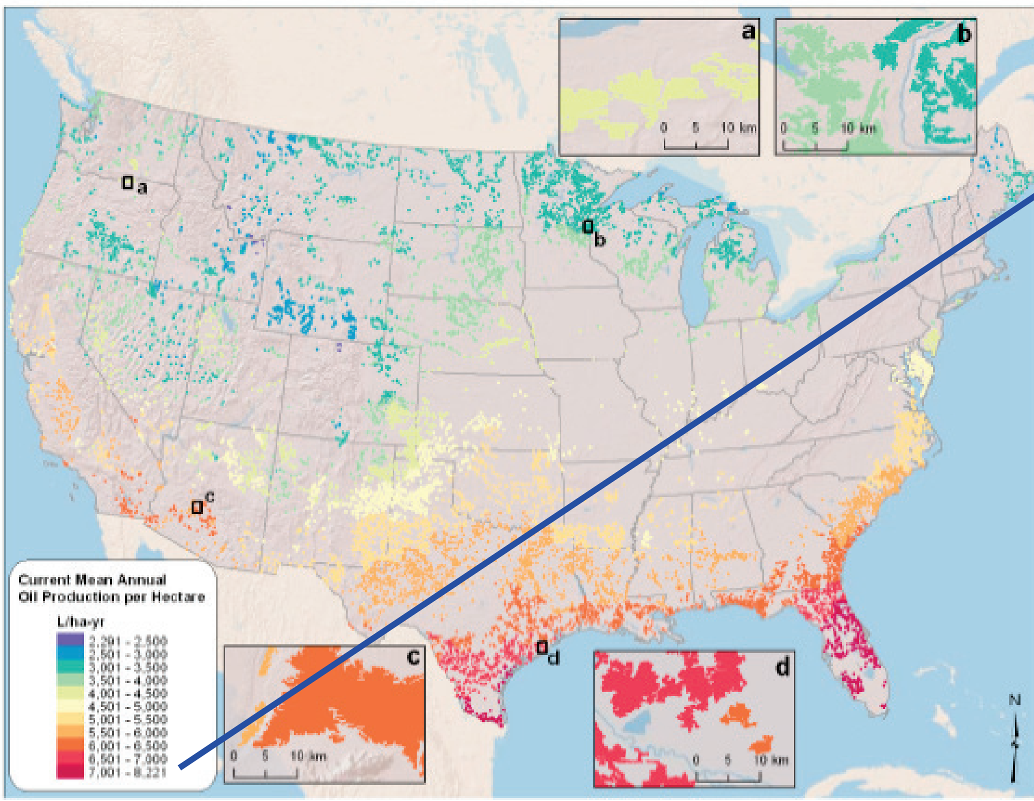

Figure 3. Mean annual biofuel production ($L\ ha^{-1}\ yr^{-1}$) under current technology plotted at the centroid of each pond facility.

High yield: 8000 L/ha/year:

U.S. uses 5.4×10^{11} L/year

Hence, need 6.8×10^{7} ha
or 2.6×10^{5} mi^2

500 x 500 miles
(7% land area, lower 48)
☹

http://www.eia.gov/tools/faqs/faq.cfm?id=23&t=10

Algae To Reduce Smokestack Emissions

https://www.youtube.com/watch?v=Y471u3SMwzc
http://www.hytekbio.com

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

Total Source	GW (year 2020)
Coal	2154
Natural Gas	1662
Hydro-electric	1262
Solar	700
Wind	646
Nuclear	374
Liquid Fossil Fuel	297
Other Renewable (Biomass)	**121**
Geothermal	13
Total	7229

Source: https://www.eia.gov/outlooks/ieo/tables_ref.php

In 2020, **43%** of global electricity generating capacity does not release prodigious GHGs to the atmosphere