Renewable Energy II:
Biofuels, Ethanol, Methanol, and Algae

AOSC / CHEM 433 & CHEM 633

Ross Salawitch & Walt Tribett

Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2019

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

30 April 2019

Course Logistics

- Problem Set #4 has been posted
  - Due Tues, 7 May (one week from today)
  - Of course, last problem set
  - Review will be held on Mon, 13 May
- Energy Plan (assigned only to 433 students) has also been posted
  - Due Thurs, 9 May (9 days hence)
  - Several will be selected for presentation in class on 14 May

Plan for The U.S. To Meet Its Future Energy and Needs (50 points)

Ross & Walt will read each reply carefully and make an assessment based on our view of how well material presented throughout the class, or perhaps gleaned from other sources, is integrated into a coherent, thoughtful reply. We look forward to learning from your replies ☺.

You are the Energy Advisor to Repreesntative Alexandria Ocasio-Cortez (AOC) , the sponsor of the Green New Deal: https://www.npr.org/2019/02/07/691997301/rep-alexandria-ocasio-cortez-releases-green-new-deal-outline

She has asked you to help her articulate a plan for the U.S. to meet its future energy needs, taking into account climate change, air quality, and her vision for a high quality of life for all citizens. Specifically, AOC has asked you to address the Nation's future *electricity supply* and *energy* needs in a manner that is both environmentally friendly and cost effective over the long–term, even if the plan requires significant initial investment.

Her candidate's parting words when describing this request were "when dealing with energy, it is hard for me to simplify this complex problem into a manner the news media can digest". As a consequence, AOC has asked you to prepare a "one page" briefing paper that highlights the energy plan.

World Energy & Electricity Supply

World Energy

World Electricity

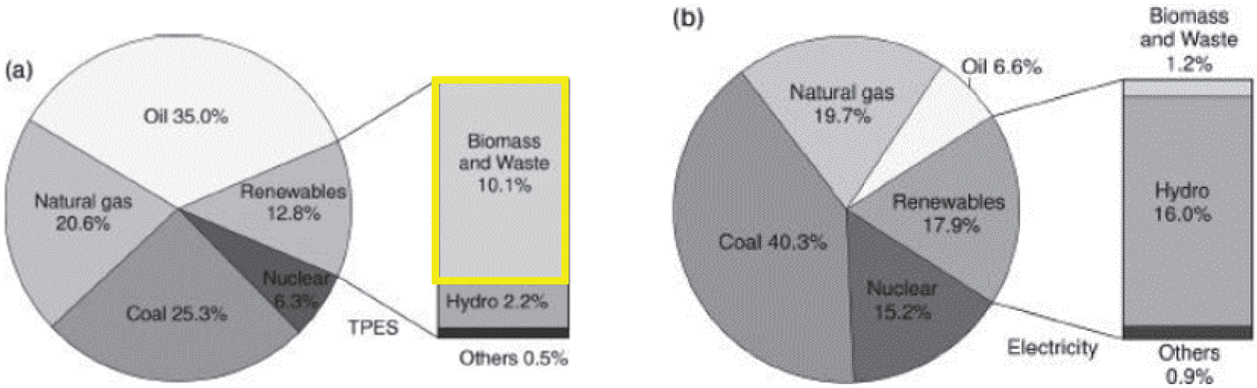


Figure 8.1 (a) Share of renewables in the world total primary energy supply (TPES) in 2005; (b) share of renewables in world electricity production in 2005. (Source: IEA Renewables Information 2007.)

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**

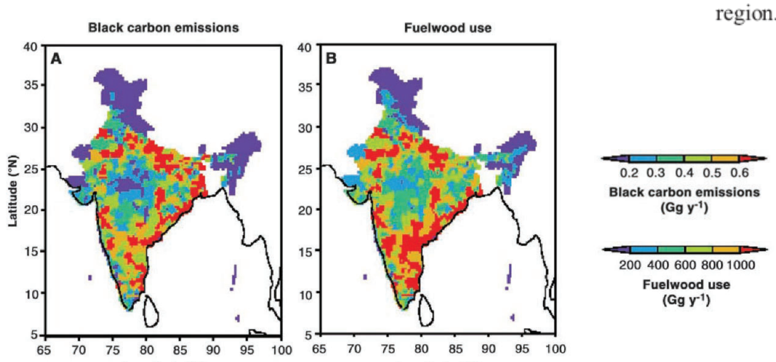
Residential Biofuels in South Asia: Carbonaceous Aerosol Emissions and Climate Impacts

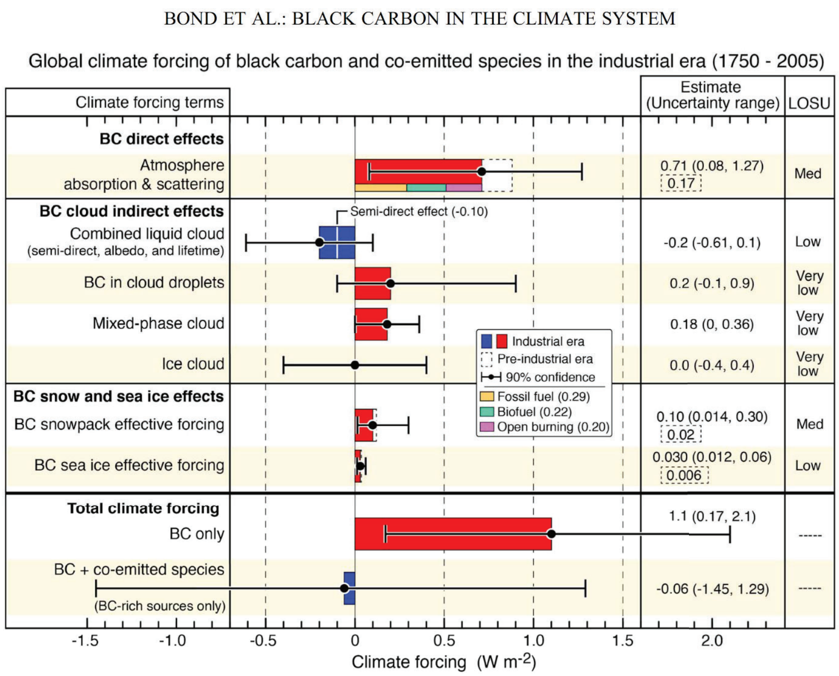
C. Venkataraman,[1*] G. Habib,[1] A. Eiguren-Fernandez,[2] A. H. Miguel,[2] S. K. Friedlander[3]

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.

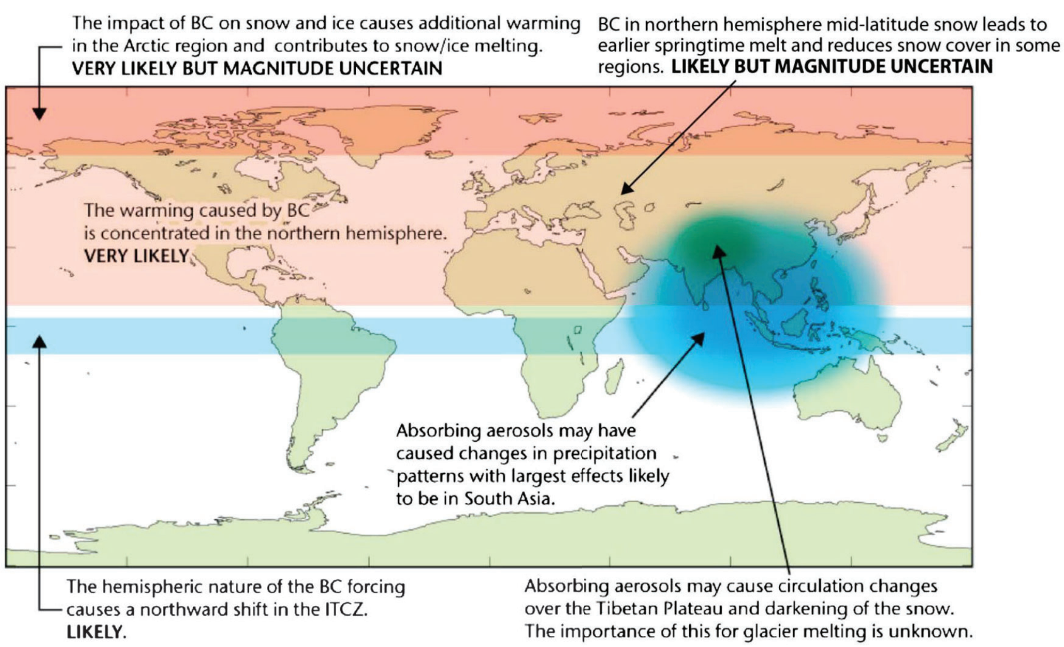




Bond *et al.*, JGR, 2013

New Estimate: Black carbon causes 0.7 W m^{-2} warming
IPCC (2007): Black carbon 0.2 W m^{-2} warming

Black Carbon & Climate



Bond *et al.*, JGR, 2013

Aerosol Direct RF of Climate, IPCC

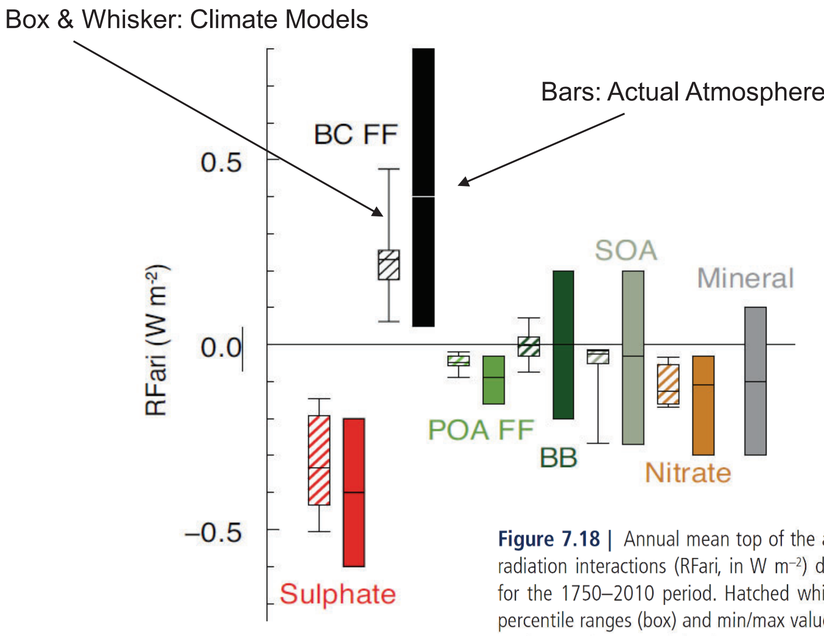
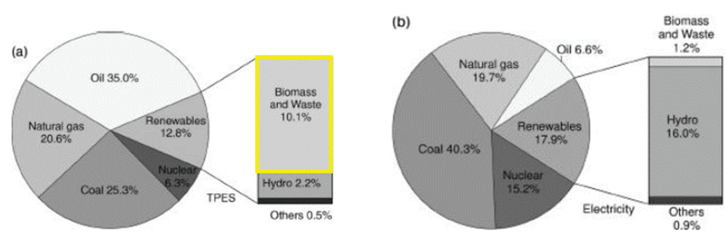


Figure 7.18 | Annual mean top of the atmosphere radiative forcing due to aerosol–radiation interactions (RFari, in W m^{-2}) due to different anthropogenic aerosol types, for the 1750–2010 period. Hatched whisker boxes show median (line), 5th to 95th percentile ranges (box) and min/max values (whiskers) from AeroCom II models (Myhre et al., 2013) corrected for the 1750–2010 period. Solid coloured boxes show the AR5 best estimates and 90% uncertainty ranges. BC FF is for black carbon from fossil fuel and biofuel, POA FF is for primary organic aerosol from fossil fuel and biofuel, BB is for biomass burning aerosols and SOA is for secondary organic aerosols.

IPCC (2013)



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

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

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

Project Surya: Nature Climate Change Paper

nature climate change
LETTERS
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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]

Affordability of cleaner stoves is one of the major barriers addressed in this study through a breakthrough approach, hereafter referred to as SCF for sensor-enabled climate financing, described below and further detailed in the Methods and Supplementary Methods A–H. SCF differs from traditional approaches to rural cookstove interventions in the following ways: data collected from wireless sensors are used to measure and verify daily cooking duration in each household in near real time; sensor data are converted into climate credits to pay each woman directly for her role in climate change mitigation.

The results demonstrate the potential of widespread monitoring via wireless sensors to produce unprecedented insights into energy access, science-based measurements for carbon mitigation and financing for distributed and decentralized energy access in rural areas. Results-based financing models such as SCF are relevant today, as they can provide a solid basis for understanding how best to apply the approximately US$100 billion per year of pledged climate financing from UN signatory nations that backed the 2015 Paris Agreement[22], declaring the protection of vulnerable populations in developing countries a primary goal.

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

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.

World electricity consumption (2006) = 19,000 TWh

Electricity from Biomass = 200.1 TWh

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

Power (Energy/Time)

Total Source	GW (year 2018)
Coal	2,167
Natural Gas	1,769
Hydro-electric	1140
Wind	524
Liquid Fossil Fuel	381
Nuclear	374
Solar	352
Other Renewable (Biomass)	**290**
Geothermal	19
Total	7016

Source: https://www.eia.gov/outlooks/archive/ieo17/ieo_tables.php

In 2018, **4.1%** of global electricity generating capacity occurs via the combustion of biomass (nearly the same as solar; about half the capacity of wind)

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 (2700 × size of UP 22.7 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.

THE BALTIMORE SUN

LATEST ENEWSPAPER PROMS MAYOR PUGH ASK US POPULAR SPORTS OBITS ADVERTISING

By **Scott Dance** · **Contact Reporter**
The Baltimore Sun

AUGUST 20, 2018, 3:30 PM

Maryland environmental regulators are demanding that a Baltimore trash incinerator cut its emissions of one harmful air pollutant by about one-fifth and study whether it can clean its exhaust even more aggressively.

The Wheelabrator Baltimore incinerator, the city's single largest source of industrial air pollution, would be required to reduce its output of nitrogen oxides by about 200 tons a year under a regulation proposed Friday. The compounds contribute to smog and irritate the respiratory system, increasing the likelihood of lung diseases and stroke.

But the incinerator, which burns most of the region's trash, is not being held to as stringent a standard as a similar facility in Montgomery County because it's older and less sophisticated. The state is not requiring Wheelabrator to install more modern pollution controls, instead allowing it to tinker with its existing technology at an expected cost of about $250,000 a year to its owner, New Hampshire-based Wheelabrator Technologies.

https://www.baltimoresun.com/news/maryland/environment/bs-md-trash-incinerator-pollution-20180820-story.html

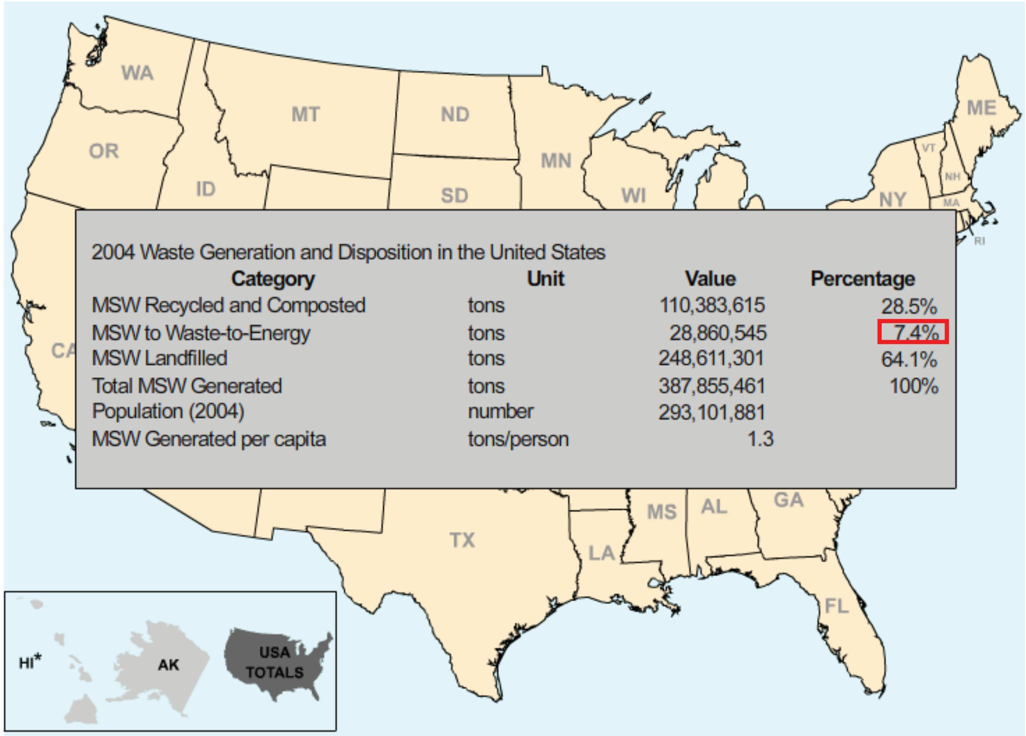
The Baltimore incinerator, known to many as BRESCO, burns more than 700,000 tons of garbage a year from Baltimore City and Baltimore, Anne Arundel and Howard counties, along with other jurisdictions across the mid-Atlantic. It is considered a renewable energy facility under a state incentive program, allowing it to collect millions of dollars each year in subsidies from Maryland electricity ratepayers.

Under the proposed rules, beginning May 1, 2019, the Baltimore incinerator's nitrogen oxide output would not be allowed to exceed a concentration of 150 parts per million, averaged out over a 24-hour period. The standard would be 10 parts per million lower for the Montgomery County Resource Recovery Facility, a trash incinerator owned by Covanta Energy that opened in 1995 near the Potomac River in Dickerson.

Both incinerators will also be held to new nitrogen oxide limits averaged out over a 30-day period starting May 1, 2020: 145 parts per million for the Baltimore facility, and 105 parts per million for the one in Dickerson.

https://www.baltimoresun.com/news/maryland/environment/bs-md-trash-incinerator-pollution-20180820-story.html

Energy from Waste



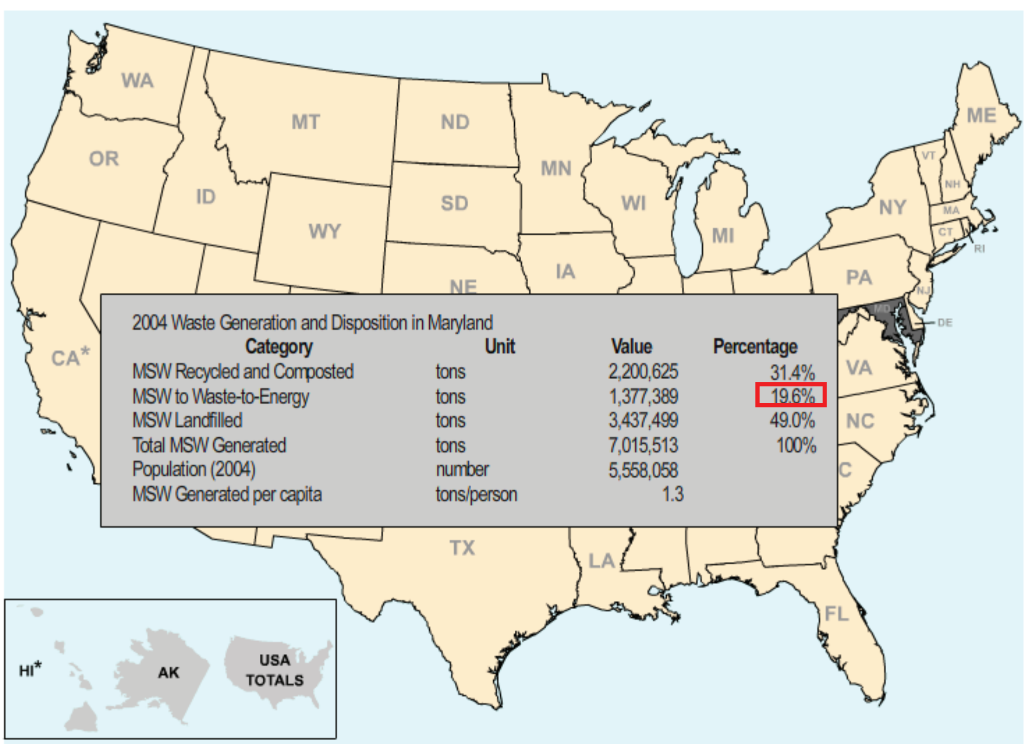
2004 Waste Generation and Disposition in the United States

Category	Unit	Value	Percentage
MSW Recycled and Composted	tons	110,383,615	28.5%
MSW to Waste-to-Energy	tons	28,860,545	7.4%
MSW Landfilled	tons	248,611,301	64.1%
Total MSW Generated	tons	387,855,461	100%
Population (2004)	number	293,101,881	
MSW Generated per capita	tons/person	1.3	

MSW: Municipal Solid Waste

http://www.seas.columbia.edu/earth/recycle/

Energy from Waste



2004 Waste Generation and Disposition in Maryland

Category	Unit	Value	Percentage
MSW Recycled and Composted	tons	2,200,625	31.4%
MSW to Waste-to-Energy	tons	1,377,389	19.6%
MSW Landfilled	tons	3,437,499	49.0%
Total MSW Generated	tons	7,015,513	100%
Population (2004)	number	5,558,058	
MSW Generated per capita	tons/person	1.3	

MSW: Municipal Solid Waste

http://www.seas.columbia.edu/earth/recycle/

CONNECTICUT

Hartford Courant

Hartford trash plant back in operation, but state garbage crisis continues

By GREGORY B. HLADKY | HARTFORD COURANT | MAR 10, 2019 | 6:00 AM

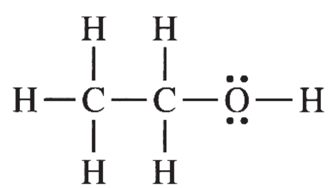
The regional garbage-to-energy plant in Hartford is now back to full operation, more than three months after it was shut down because of "catastrophic failures" of key equipment. But Connecticut's trash crisis is far from over.

About 50 municipalities across the state are now facing higher tipping fees to help cover nearly $15 million in added costs related to the Hartford plant's breakdown. The authority now running the regional trash system will increase garbage disposal charges for member cities and towns in April, and again in July, by a total of 15.3 percent.

The regional trash-to-energy plant in south Hartford is once again burning refuse from about 50 cities and towns across Connecticut. The facility is now fully operational more than three months after catastrophic equipment failures shut it down in early November 2018. (Patrick Raycraft / Hartford Courant)

https://www.courant.com/news/connecticut/hc-news-trash-plant-update-20190310-gooefp3fqzf6tdc2ftlw4rcrzq-story.html

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 Production

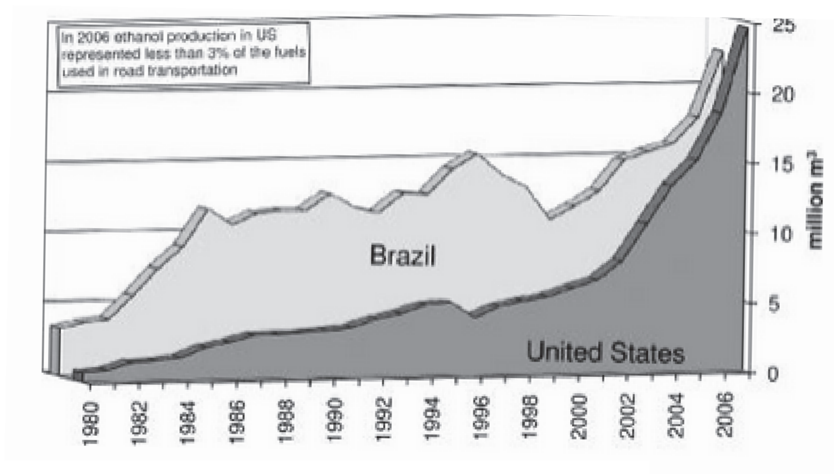


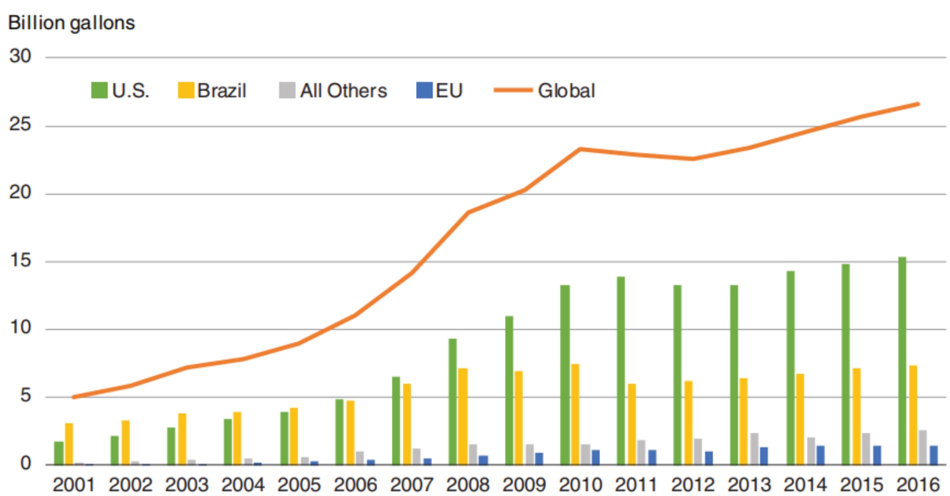
Figure 8.13 Historic production of ethanol in the United States and Brazil. (Based on data from Renewable Fuel Association and Sao Paulo Agroindustry Union (UNICA).)

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

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

Ethanol Production

Ethanol production (billion gallons)



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

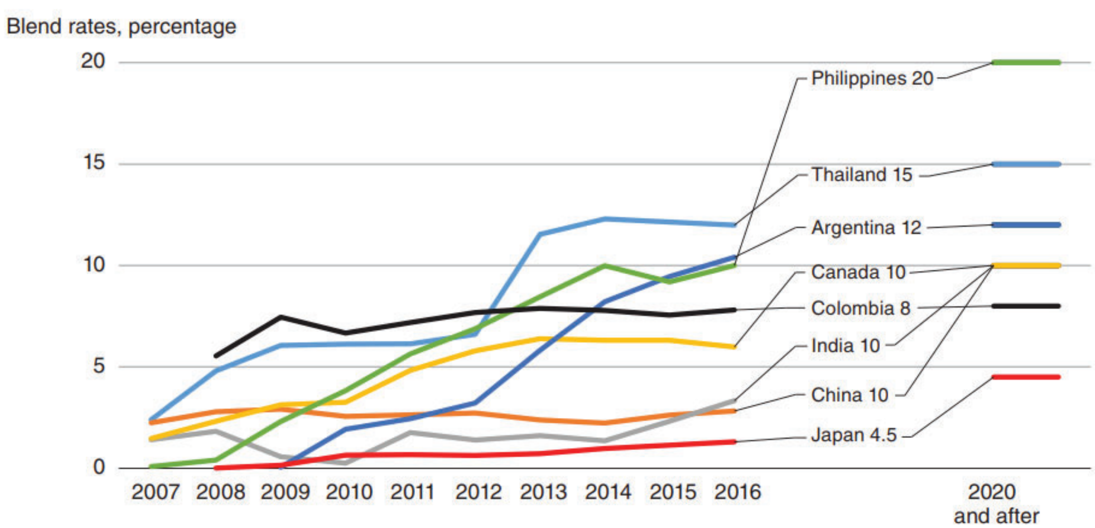
https://www.ers.usda.gov/webdocs/publications/85450/bio-05.pdf

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

Ethanol in Brazil

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

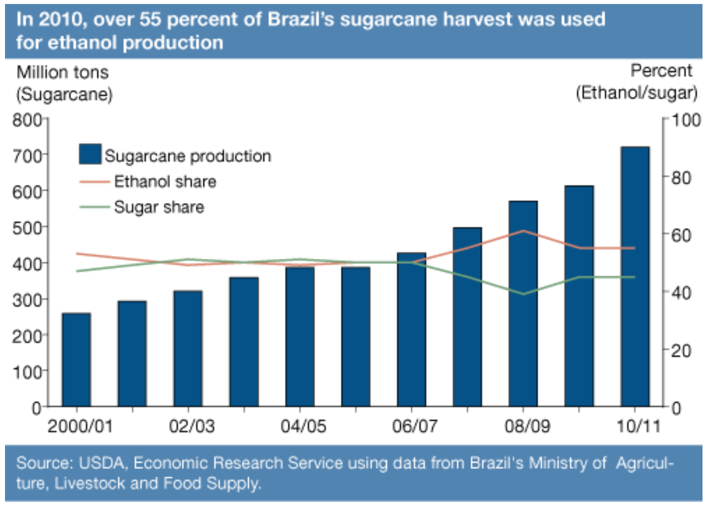
Ethanol Demand



https://www.ers.usda.gov/webdocs/publications/85450/bio-05.pdf

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

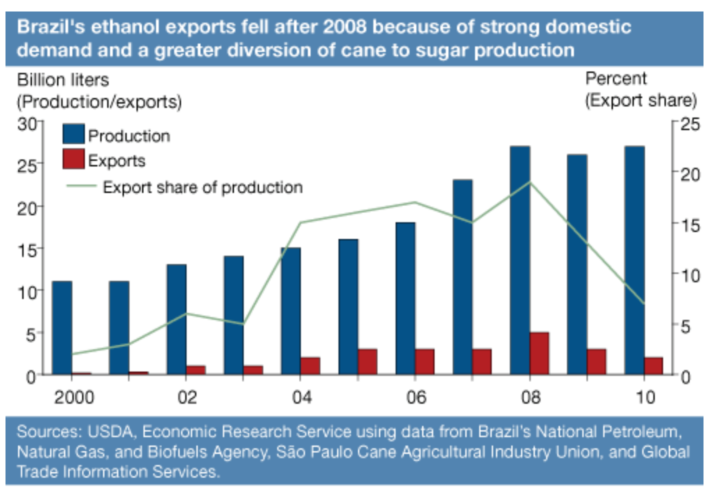
Ethanol Production: Good News



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 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

- McElroy article suggests considering refinement cost, transportation cost, and energy content of ethanol, “the energy captured in the ethanol exceeds the fossil energy consumed in its production by no more than ~25 %”
- McElroy did not consider ______________

Ethanol Production

- Raging debate over “green” aspects of both sugar and corn based biofuels:

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

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.

Ethanol Production

- Raging debate over "green" aspects of both sugar and corn based biofuels:
  Excellent point/counterpoint: http://cen.acs.org/articles/85/i51/Costs-Biofuels.html

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.

Ethanol Production

- Raging debate over "green" aspects of both sugar and corn based biofuels:
  Excellent point/counterpoint: http://cen.acs.org/articles/85/i51/Costs-Biofuels.html

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.

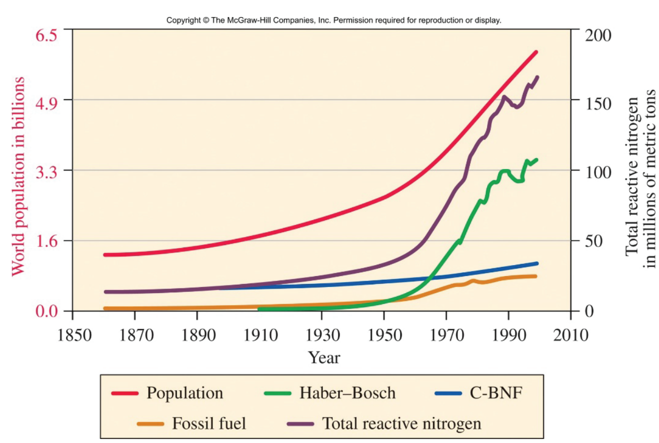
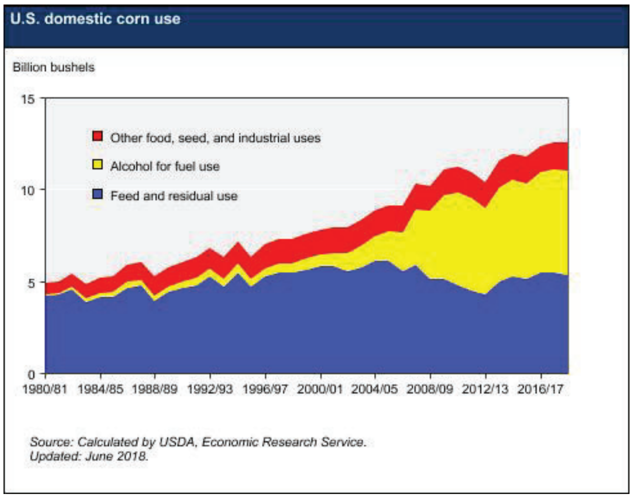


Fig 6.19, *Chemistry in Context*

- 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

Ethanol Production: US

- 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

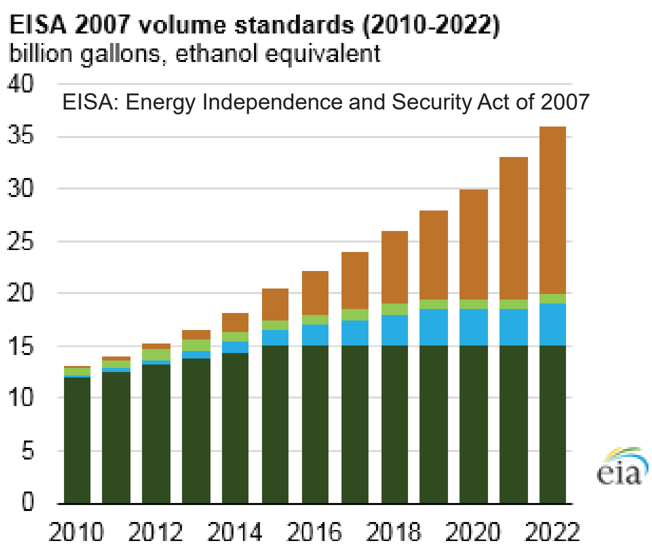


https://www.ers.usda.gov/webdocs/charts/83915/cornuse.jpg?v=8618.3

Chemistry in Context

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

U.S. 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.

https://www.eia.gov/todayinenergy/detail.php?id=37712

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 large-scale transition 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

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!

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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!

The Methanol Economy ®

- Methanol: CH_3OH
- Alcohol
- Methanol combustion:

  $2\ CH_3OH + 3\ O_2 \rightarrow 2\ CO_2 + 4\ H_2O + 41.4$ kJ/g

  Heat release considerable more than ethanol (29.7 kJ/g) and close to that of C_8H_{18} (47.8 kJ/g)
- Octane of 107
- Very clean burning: little or no CO, NO_x, or particulates
- Can be used in “clean diesels”
- Presently used in Indy 500 race cars !

The Methanol Economy ®

- Methanol production from atmospheric CO_2:
  - $CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$
  - Exothermic by 49.3 kJ/mol ; nonetheless, need a catalyst
  - Need to capture CO_2 out of atmosphere (tall order!)
  - Need supply of H_2 that is “carbon neutral” (i.e., not from CH_4 !)

Today, 95% of the hydrogen produced in the U.S., roughly 9 million tons per year, uses a thermal process with natural gas as the feedstock. This process, called steam methane reformation (SMR), consists of two steps: 1) reformation of the feedstock with high temperature steam supplied by burning natural gas to obtain a synthesis gas, and 2) using a water-gas shift reaction to form hydrogen and carbon dioxide from the carbon monoxide produced in the first step.

STEAM METHANE REFORMATION

Step 1: $CH_4 + H_2O \Rightarrow CO + 3\ H_2$

Step 2: $CO + H_2O \Rightarrow CO_2 + H_2$

http://www.hydrogenassociation.org/general/factSheet_production.pdf

The Methanol Economy ®

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  - Need supply of H_2 that is "carbon neutral" (i.e., not from CH_4 !)
  - If electrolysis of seawater to yield H_2 could be powered by solar energy, and an energy efficient way to capture and concentrate atmospheric CO_2 could be devised (i.e., using KOH or MEA-monoethanolamine ($CH_2CH_2OH)NH_2$), then CO_2+3 $H_2 \rightarrow CH_3OH$+H_2O would simulate photosynthesis and could provide a fuel that could be used in cars without major changes to present infrastructure

NOTE: methanol is corrosive to aluminum, zinc, and magnesium, and reactive with some plastics and rubber, so some systems specific to methanol would be needed

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

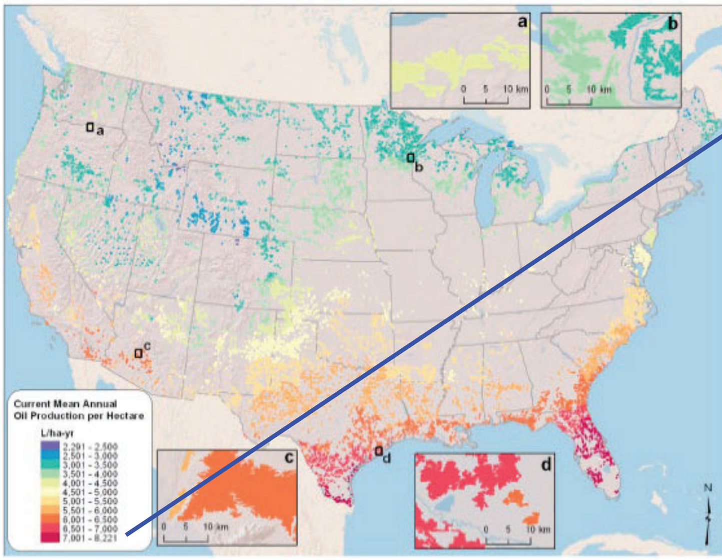

Figure 3. Mean annual biofuel production (L ha^{-1} yr^{-1}) under current technology plotted at the centroid of each pond facility.

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