MEC 3040: Bioenergy

Module 1: Introduction to Bioenergy

1.1: What is bioenergy

1.2: Current & projected energy use

1.3: Forms of bioenergy

1.4: Bioenergy feedstock materials

1.5: Bioenergy co-products

1.6: Drivers of bioenergy use & development

1.7: The bioenergy debate

1.8: Is bioenergy sustainable?

1.9: Bioenergy vs. food debate

1.1: What is bioenergy?

What is bioenergy?

Bioenergy:

- **Renewable* energy** produced from living (or recently living) biological material called biomass [1]
- Useful renewable energy **produced from organic matter** – the conversion of complex carbohydrates in organic matter to energy [2]
- Energy from **biofuels** [3]

*Renewable ***if*** the amount of biomass used is less than the amount of biomass that can be regrown.

1: Dahiya (2015)
2: U.S. DOE's Oak Ridge National Laboratory's (ORNL) Bioenergy Feedstock Network
3: Food & Agriculture Organization of the United Nations (FAO)

Sun power via photosynthesis

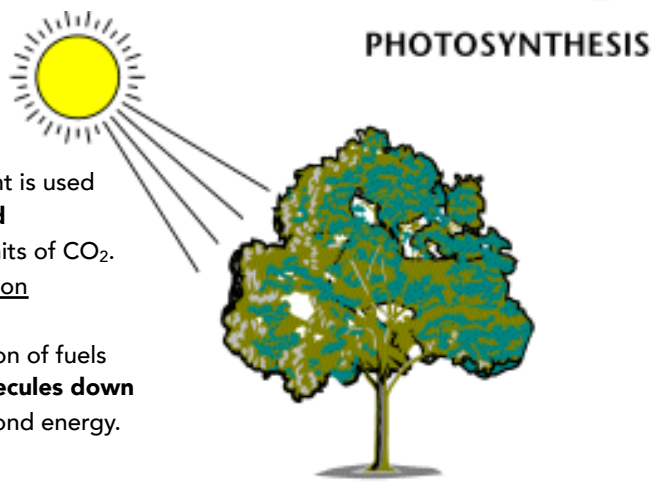
Bioenergy technologies are **sun-powered**.

The energy of sunlight is used to build **carbon-based biomolecules** from units of CO_2.

- Carbon sequestration

Combustion / oxidation of fuels **breaks those biomolecules down into CO_2**, releasing bond energy.

- Carbon cycling



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

The National Energy Education Project (Public Domain)

water + carbon dioxide + sunlight → glucose + oxygen

$6\ H_2O + 6\ CO_2 + \text{radiant energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$

Focus of this course

Biofuels (*actually biogas*):
Biomass converted to (solid), liquid or gaseous fuels like ethanol, methanol, methane and hydrogen

Biodiesel:
Renewable liquid fuel derived from vegetable oils or animal fats by transesterification; fatty acid esters

Biomass:
An energy source derived from organic matter, excluding fossil fuels
- Generally refers to solid bioenergy

Dahiya (2015)

Three paths from biomass to bioenergy

Biofuels:
Biomass converted to (solid), liquid or gaseous fuels like ethanol, methanol, methane and hydrogen

Biomimicry: using (microbial) biology to convert (digest) biomass to biofuel

Biodiesel:
Renewable liquid fuel derived from vegetable oils or animal fats by transesterification; fatty acid esters

Chemistry: using simple organic chemistry to transform biomass into biofuel

Biomass:
An energy source derived from organic matter, excluding fossil fuels
- Generally refers to solid bioenergy

Mechanical means: using simple mechanical processing;
- Sometimes densifying biomass

Dahiya (2015)

Brief history of bioenergy

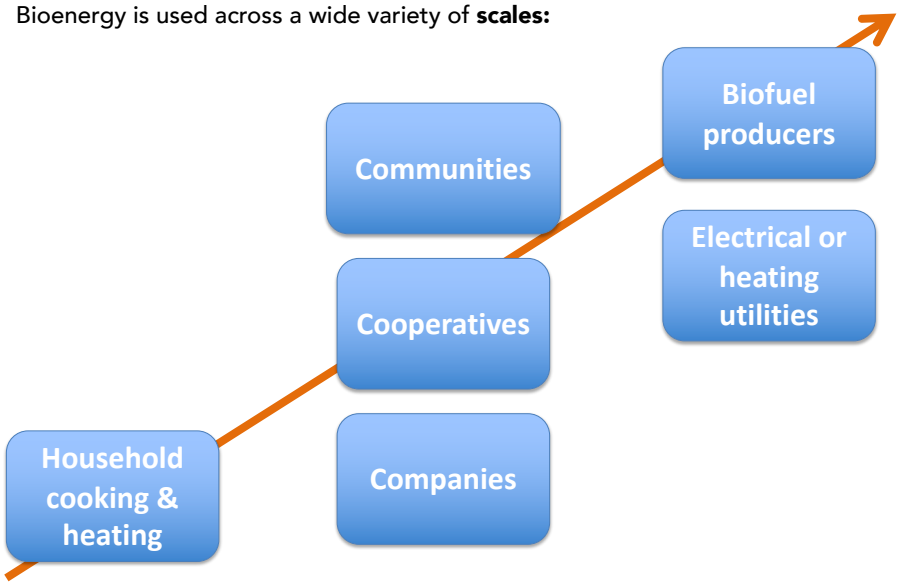
Bioenergy is a **very old technology**.

- Was fire man's first tool?
- For centuries man lived with his animals; the original central heating system.
- Man has burned just about anything as fuel: wood, fiber, dried manure.
- 10th century BC: the Assyrians harnessed biogas for heating water
- 1908: Henry Ford's model T was supposed to be fueled with ethanol
- Ethanol was used throughout the 20th century
- But ethanol use ramped up in 1970s
  - Nov 1975: Brazil created it's National Alcohol Programme (ProAlchohol) using sugarcane as feedstock
  - Late 1970s: US moved towards creating 10/90 ethanol/gasoline blend
  - 1992 Clean Energy Act
  - 2007 Energy Independence & Security Act
  - The EU, China and India are also increasing production & use of biofuels

Rosillo-Calle & Johnson (2010)

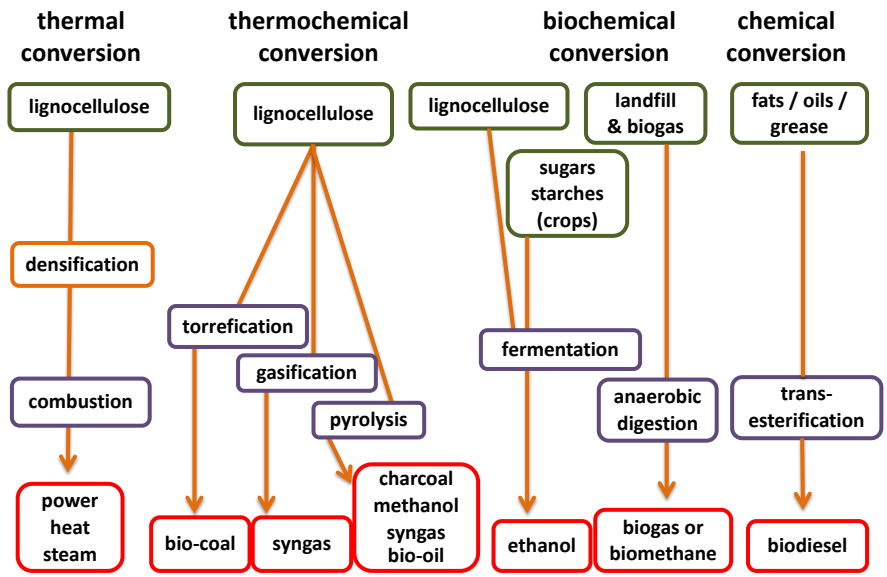
Scale of bioenergy use

Bioenergy is used across a wide variety of **scales:**



Dahiya (2015)

Bioenergy process overview



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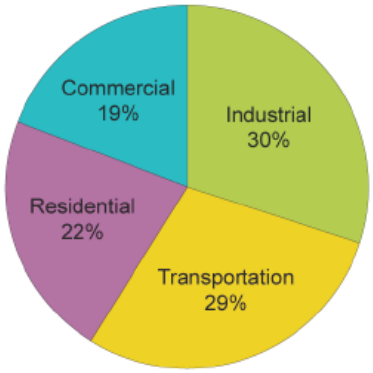
1.2: Current & projected energy use

Current US energy use

US energy uses can generally be divided into rough thirds:

- 1/3 for industry & manufacturing;
- 1/3 for transportation; and
- 1/3 for commercial & residential use.

Share of Energy Consumed by Major Sectors of the Economy, 2009



Source: U.S. Energy Information Administration, *Annual Energy Review 2009*.

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US primary energy sources (2016)

Recent changes (2011 – 2016) in US primary energy sources:

- Coal down 6%
- NG up 4%
- RE up 1%

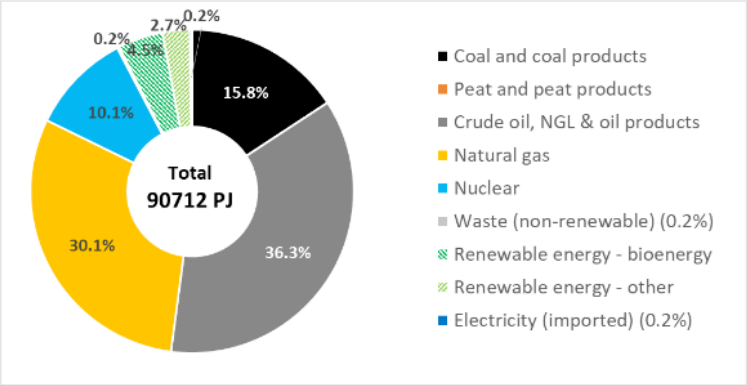


***Figure 1**: Total primary energy supply[7] in the US in 2016 (Source: World Energy Balances © OECD/IEA 2018)*

https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UnitedStates_final.pdf

Most primary RE is bioenergy (2016)

Bioenergy overall only increased from 3.0 to 4.5% from 2005 to 2013 with little change since then.

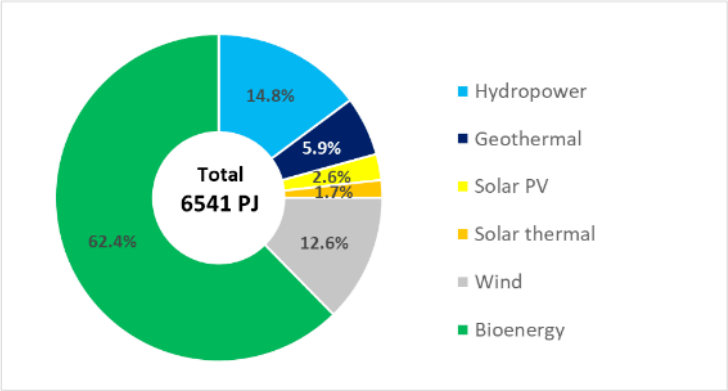


Figure 2: Total primary energy supply of Renewable Energy Sources in the US in 2016 (Source: World Energy Balances © OECD/IEA 2018)

https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UnitedStates_final.pdf

Primary bioenergy is ½ biomass (2016)

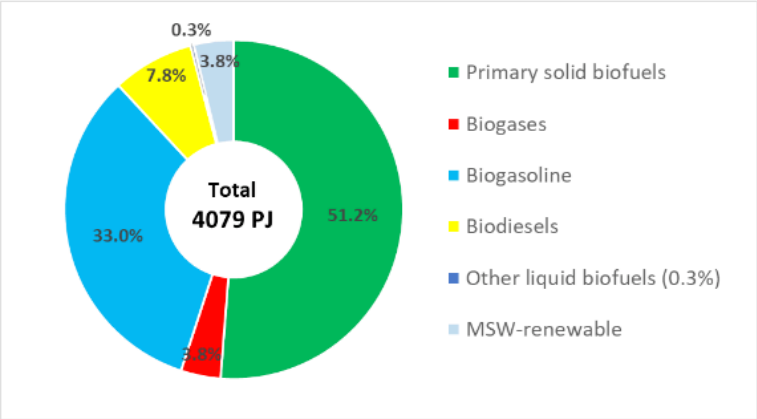


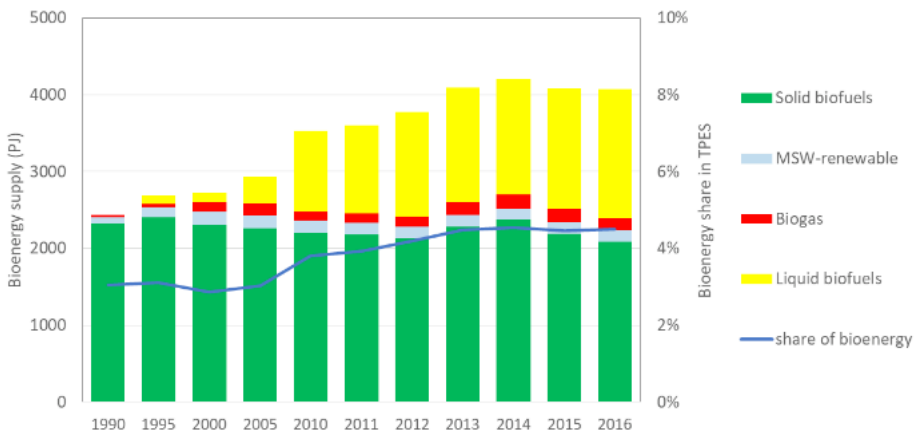
Figure 3: Total primary energy supply from bioenergy in the US in 2016 (Source: World Energy Balances © OECD/IEA 2018)

https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UnitedStates_final.pdf

Gains due to liquid biofuel (2016)

Changes in forms of bioenergy with time: 1990 – 2016

- Note that **liquid biofuels** account for all of the increase.
- And that means **bioethanol.**



https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UnitedStates_final.pdf

Bioenergy: heat ~ power > transport

RE power: 80% is hydro and wind; only 10% is biomass

Transportation energy: 5.6% is biofuel

Heating: about 10% from biomass

Table 3: *Role of bioenergy and renewable energy in electricity production, transport energy consumption and fuel/heat consumption in 2016*

Sector	Share of bioenergy	Share of renewable energy	Overall production/ consumption
Electricity production	1.6%	14.8% (6.3% hydro) (5.3% wind)	4,300 TWh (15,479 PJ)
Transport energy (final consumption)	5.6%	5.6%	25,851 PJ
Overall fuel and heat consumption[8]	Direct biomass: 9.6% Biobased heat: 0.1%	10.3%	18,016 PJ

Source: World Energy Balances © OECD/IEA 2018

https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UnitedStates_final.pdf

Current global energy use

In 2007 & 2008, global energy use favored **fossil fuels over biofuels, 10:1**

Fossil fuel	500 EJ*
Biomass	50 – 54 EJ
• Traditional use	35 – 43 EJ
• Power generation	6.4 EJ
• Transportation	2.6 EJ

What is bioenergy's potential?

The World Bioenergy Association estimates that biofuels could produce:

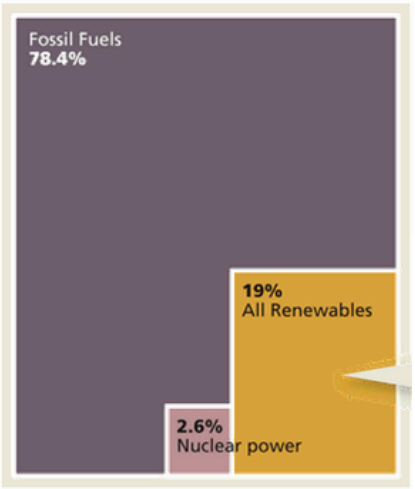
- 1,135 – 1,548 EJ by 2050.

** What's an EJ? Exajoule = one qunitillion = 10^{18} power*

Rosillo-Calle & Johnson (2010)

Current global energy use

Estimated RE Share of Global Final Energy Consumption



http://www.renewableenergyworld.com/articles/2015/02/outlook-for-bioenergy-2015-whats-in-store-for-this-versatile-renewable-energy-feedstock.html

Breakdown of biomass use in US

In 2010, US biomass use looked like this:

- 46% was **wood** or wood-derived
- 43% was **biofuel**, mainly ethanol
- 11% was derived from **municipal waste**

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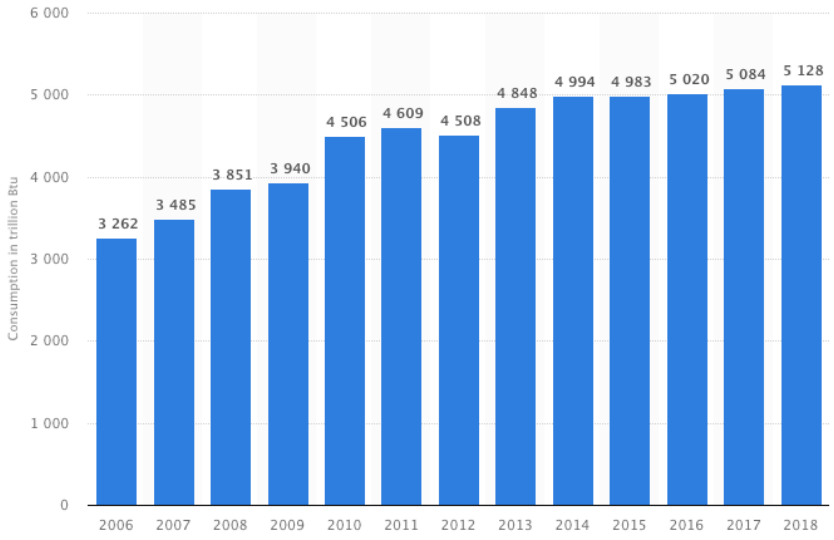
EIA @www.eia.doe.gov and www.repp.org/bioenergy/link6.htm;
www.extension.org/pages/Biomass_Feedstocks_and_Energy_Independence

Biomass energy use is static in the US

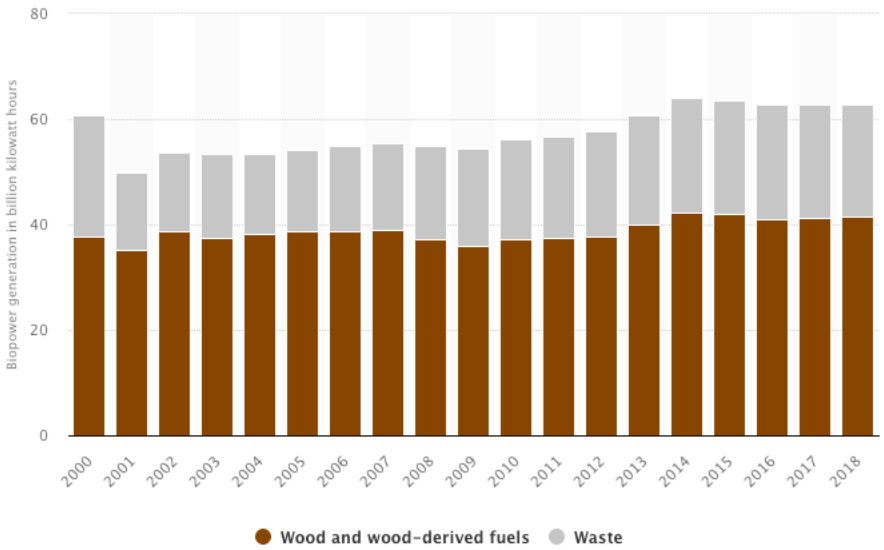
From 2000 to 2018, electricity produced from biomass hasn't increased.



https://www.statista.com/statistics/183429/biopower-generation-by-source-in-the-united-states-from-2000/

Biopower is static in the US

From 2000 to 2018, electricity produced from biomass hasn't increased.



https://www.statista.com/statistics/183429/biopower-generation-by-source-in-the-united-states-from-2000/

How will US energy use change?

If recent changes to state & federal policies[1] hold, then by **2035**:

- Total energy use will increase;
- Fossil fuel use will decrease from 84 to 78%; and
- Renewable energy use will increase from 10 to 14%.

Natural gas use will increase as we exploit shale gas deposits via fracking.

- NG prices are forecast to fall and stay low for some time.

Coal will continue to dominate electric generation, though new plants are not likely to be built.

Renewable energy targets have been set by 29 states and include wind, solar, hydropower and biomass (though biomass targets are very small).

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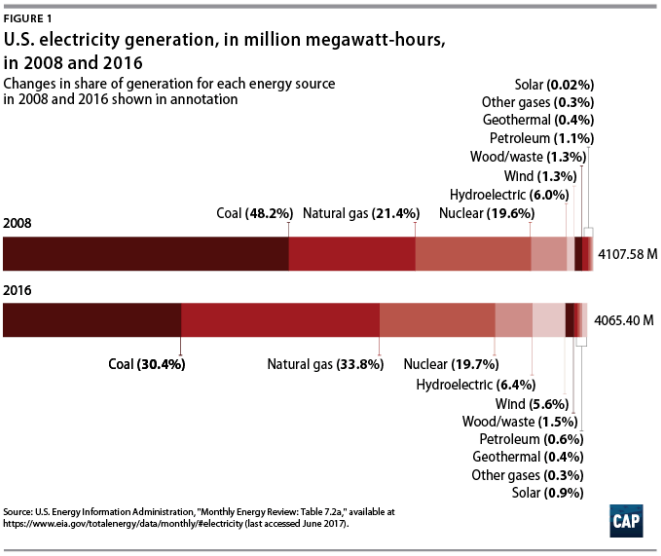
1 = CAFÉ standards, EISA, RFS, RFP, ARRA

Obama administration on biofuels?

Under the Obama administration, **renewable energy and natural gas** made great gains.

Biomass gains were more modest:

- Renewable Fuel Standard (RFS)
- Biomass Crop Assistance program
- Biofuels Working Group



https://www.americanprogress.org/issues/green/reports/2017/06/29/435281/americas-clean-energy-success-numbers/
https://en.wikipedia.org/wiki/Energy_policy_of_the_Barack_Obama_administration

Trump administration on biofuels?

August 2019: granted exemptions from the requirement for adding bioethanol to 31 of 40 small refineries.

> ***"Iowa's Republican Senator Chuck Grassley said the EPA had "screwed" the U.S. ethanol industry and farmers by granting the waivers."***
>
> - Reuters

December 2018: reauthorization of the Farm Bill, including Rural Energy for American Program (REAP) and Biomass Crop Assistance Program

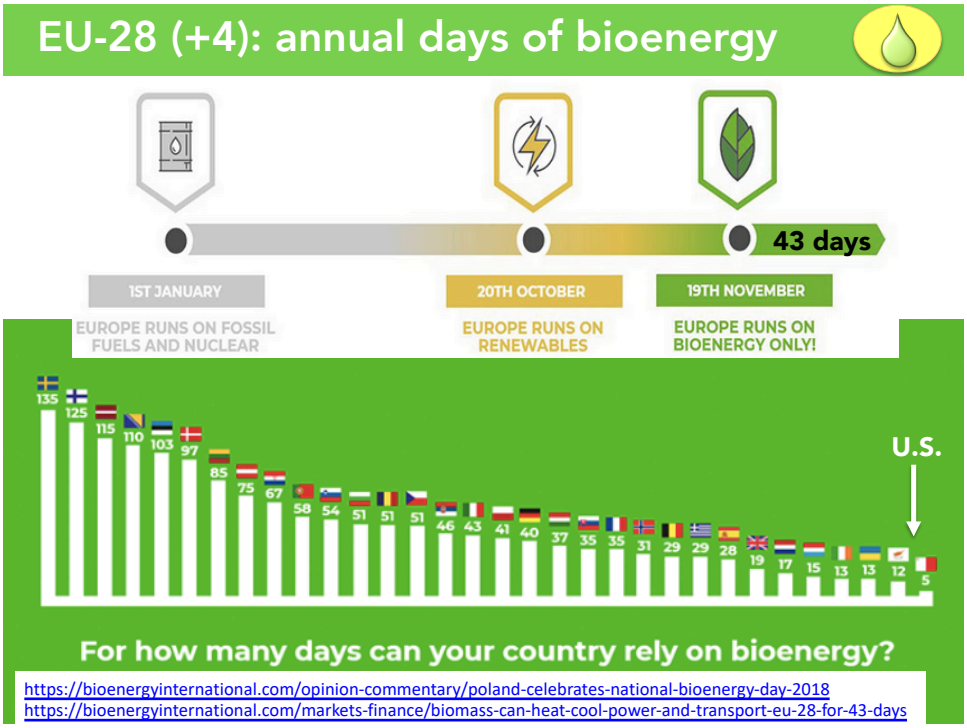
- Established Interagency Biogas Opportunities Task Force
- But didn't fund several of these programs as suggested

> ***"The Trump administration endorsed burning trees and other biomass to produce energy on Thursday, vowing to promote a practice some scientists have declared more environmentally devastating than coal-fired power."***
>
> – Bloomberg News

April 2018: replaced Clean Power Plan with the Affordable Clean Energy Rule

- Allows co-gen (addition of biomass to coal) to 'reduce emissions'

http://biomassmagazine.com/articles/15838/trump-signs-2018-farm-bill



https://bioenergyinternational.com/opinion-commentary/poland-celebrates-national-bioenergy-day-2018
https://bioenergyinternational.com/markets-finance/biomass-can-heat-cool-power-and-transport-eu-28-for-43-days

1.3: Forms of bioenergy

Three forms of bioenergy

Bioenergy can take many forms:

1. Biopower;
2. Bio-heat; &
3. Biofuel

Energy products

Biopower

Bio-heat

Biofuels

Dahiya (2015)

Three forms of bioenergy

Bioenergy can take many forms:

1. Biopower;
2. Bio-heat; &
3. Biofuel

Energy products

Biopower — Electricity, Mechanical

Bio-heat — Heating, Cooling

Biofuels — Gas, Liquid, Solid

Dahiya (2015)

Three forms of bioenergy

Bioenergy can take many forms:

1. Biopower;
2. Bio-heat; &
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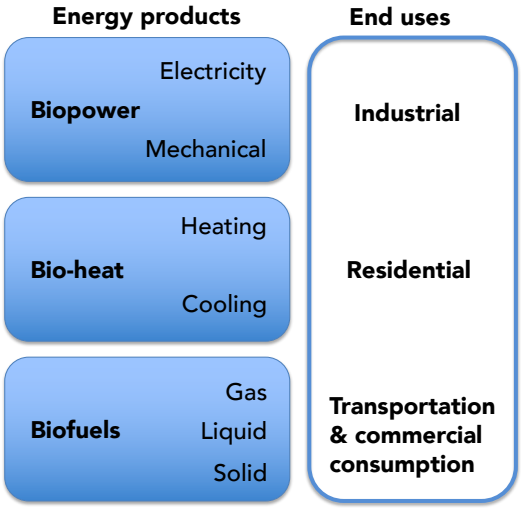

Dahiya (2015)

Three forms of bioenergy

Bioenergy can take many forms:

1. Biopower;
2. Bio-heat; &
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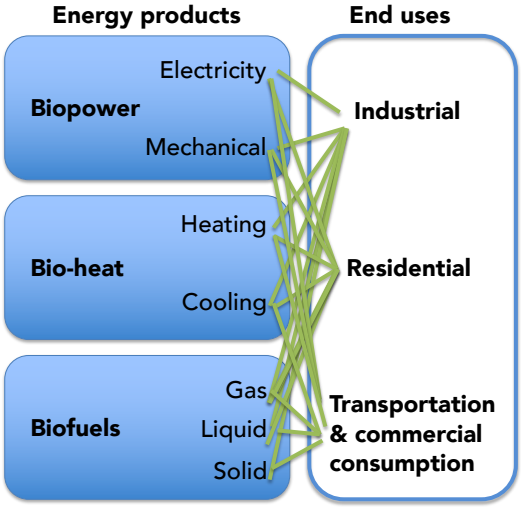


Dahiya (2015)

Biopower

Biopower: electricity generated from combustion of biofuels

- Sometimes co-fired with fossil fuels
- Moisture in biofuel may slightly decrease efficiency of power production…
- … but co-firing can help fossil fuel plants meet renewable energy standards. *Is co-firing a bridge to RE?*

Biopower
- Electricity
- Mechanical

Most biopower plants are **direct fire**: fuel is combusted to create steam.

- Most often, the steam is used to turn turbines & generate electricity.
- But the steam can be used to do mechanical work.

Challenges:

- Feedstock quality;
- Boiler chemistry; &
- Ash deposition & ash disposal.

Dahiya (2015)

Biofuels

Biofuel: fuels produced by biological means; renewable

- Solids combusted for heating
- Liquids / gases can be used for heat or as transportation fuels
  - Produced by:
    - Fermentation (bioethanol)
    - Gasification
    - Pyrolysis
    - Torrefaction

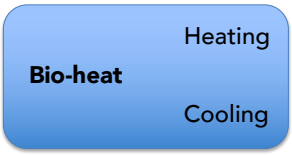
Biofuels
- Gas
- Liquid
- Solid

Rudolph Diesel's original 'diesel' fuel was derived from peanut oil. Ford's model T could run on ethanol.

Dahiya (2015)

Bio-heat

Aka thermal energy: generally refers to waste heat generated by biopower production or combustion of biofuels



Co-generation: is the simultaneous production of both power and heat from a single fuel source

Use of internal combustion engines converts the majority of energy in a fuel source to heat rather than power:

- 30% power (like electricity)
- 70% heat

Dahiya (2015)

'Generational' categories of biofuels

First generation biofuels:
Derived from oils, sugars and starches in food crops:

- Corn ethanol, soy biodiesel, etc,.,

Second generation biofuels:
Derived from food crop waste and crop residues; leftovers:

- Biodiesel from waste oil; &
- Biogas from organic wastes.

Third generation biofuels:

- Produced from algae, perennial grass & fast growing trees:
  - Energy crops; &
  - Algae for oil-based fuels.

Dahiya (2015)

Bioenergy vs. fossil fuels

Generally, bioenergy is seen as less advanced or less efficient than fossil fuels.

	Bioenergy	Fossil fuels
advantages	• Renewable • May be carbon neutral • Widely available (energy security)	• Energy dense • Supported by current energy infrastructure

Relative energy densities

Energy density is an expression of the energy content of a type of fuel per volume.

Fossil fuels convenience and widespread use can be attributed to their **high energy densities** and to the universal availability of fossil fuel-based energy infrastructure.

Fuel	GJ/metric tonne	
natural gas	55	fossil fuel
oil	42	fossil fuel
coal	28	fossil fuel
biogas	~33	bioenergy
charcoal	30	bioenergy
wood, dried	15 - 18	bioenergy
paper	17	bioenergy
bagasse	17	bioenergy
MSW, commercial	16	bioenergy
manure, dried	16	bioenergy
straw	15	bioenergy
MSW, residential	9	bioenergy
wood, green	6	bioenergy
grass, fresh	4	bioenergy

municipal solid waste

Boyle (2004) RE

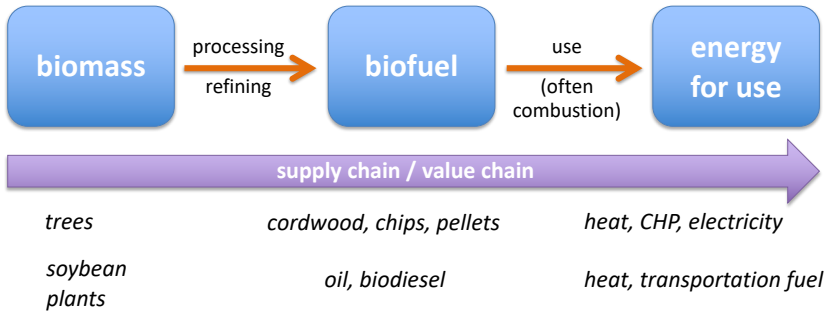
1.4: Bioenergy feedstock materials

Bioenergy feedstock & supply chain

Bioenergy feedstock: biomass-derived material that can be converted to energy using microbes, heat, chemicals or some combination thereof

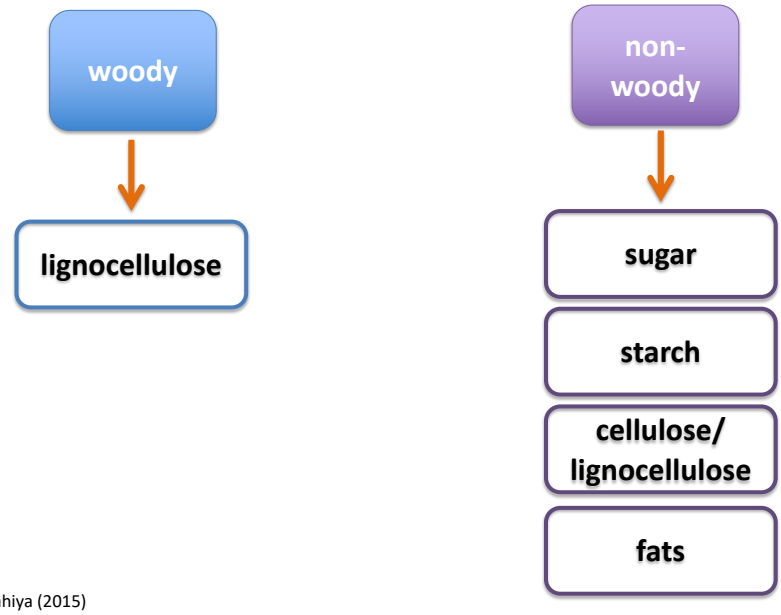
- Some amount of conversion (aka 'refining') is usually required to turn feedstock into use-ready biofuel.

Processing (refining) often involves **densification** (or aggregation) to make transport of feedstock easier and cheaper.



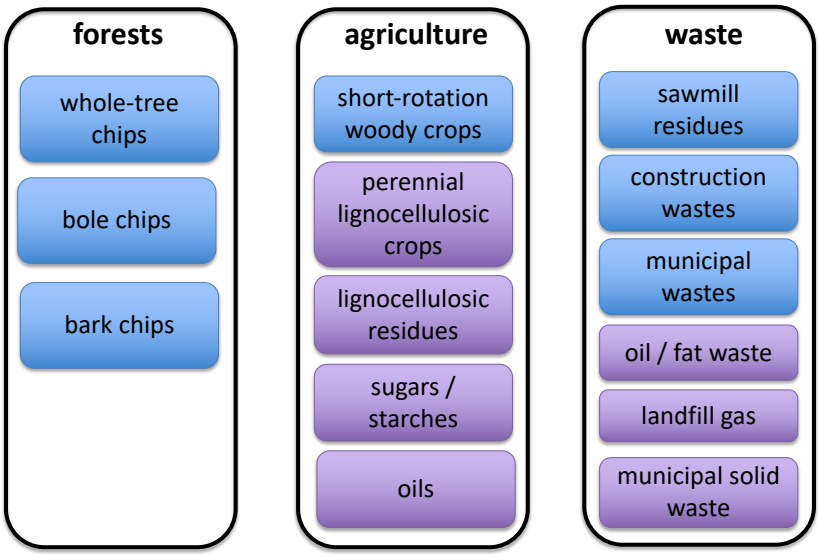
Dahiya (2015)

Types of bioenergy feedstock materials



Dahiya (2015)

Feedstock sources



Dahiya (2015)

Biomass feedstock availability

We'll discuss each feedstock material in more detail as this course proceeds, but let's look at some general conclusions about biomass availability here.

The 2005 report, '*Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply*' prepared by DOE & USDA made these conclusions:

- We have enough biomass to replace **30% of US petroleum use by 2030**.
- Biomass harvests could be increased from 2005's 473 million to **1.1 billion dry tons annually** with modest changes to land management practices.
- 2011 update decreased estimates of forest & crop residue resources, but increased the potential of energy crops.

Because biomass feedstock materials are not energy dense, **transportation** to processing plants affects the cost of feedstock and profitability of growing bioenergy feedstock.

- Willingness to grow bioenergy crops may be limited by distance from processing plants.

Ethanol feedstock availability

The 2008 report, '*90-Billion Gallon Biofuel Deployment Study*' prepared by Sandia National Lab and General Motors R&D Center looked at availability of feedstock for ethanol production.

hitectransportation.org/news/2009/Exec_Summary02-2009.pdf

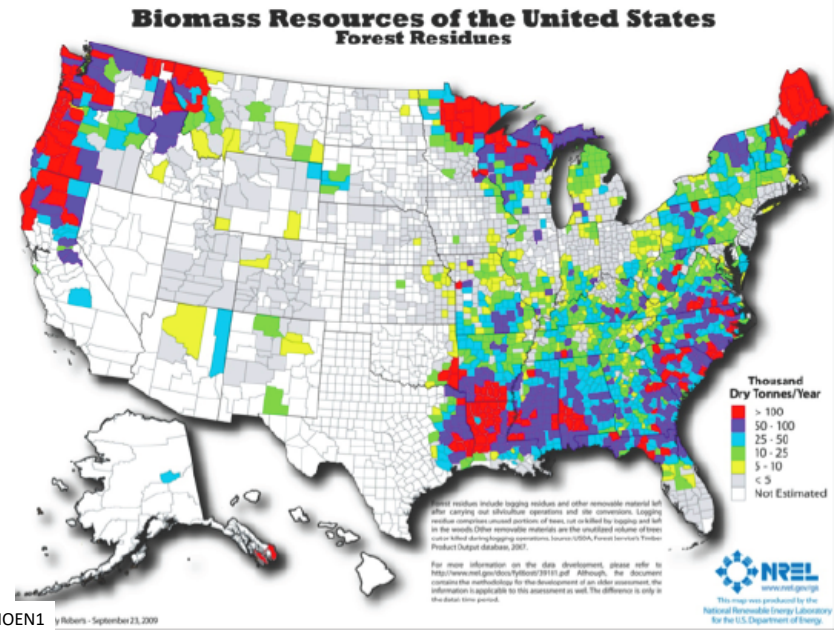
- **90 billion gallons** of biomass ethanol could be produced annually.
- 15 billion gallons from **corn**; and
- 75 billion gallons from **cellulosic biomass**, mainly perennial energy crops
  - Requiring 48 million acres of land now characterized as 'idle, pasture of non-grazed forest'.

In order for **cellulosic ethanol** to become commercially viable:

- Biomass producers will need consistent & reliable markets;
- Production contracts to help ensure supply; &
- Supportive policy to encourage development.

While cellulosic biomass doesn't take food from the hungry, farmers can't sell cellulosic biomass crops for food if the energy demand / market drops.

Forest-based feedstock sources



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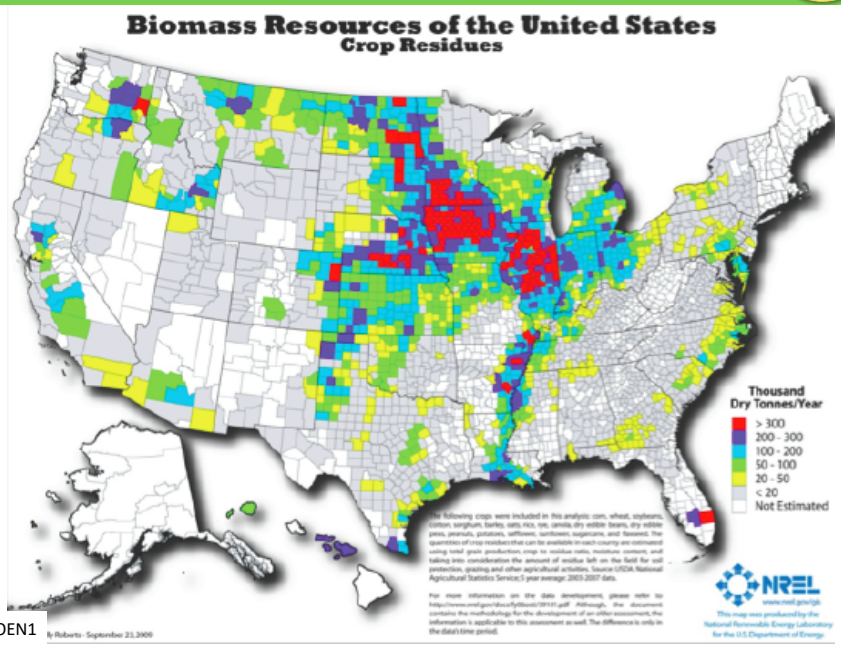
Agricultural residue sources



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Agricultural sources: perennial crops

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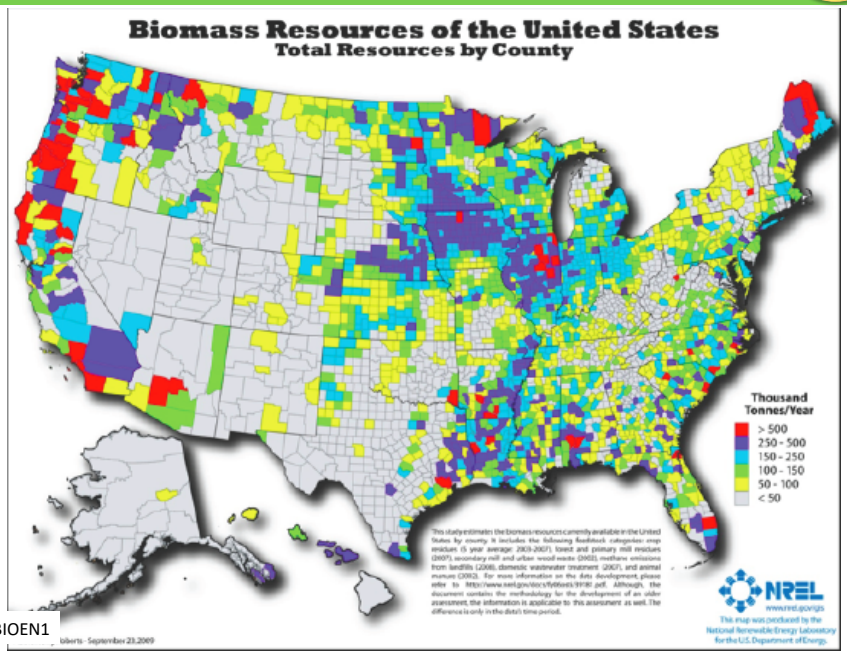
Total biomass sources



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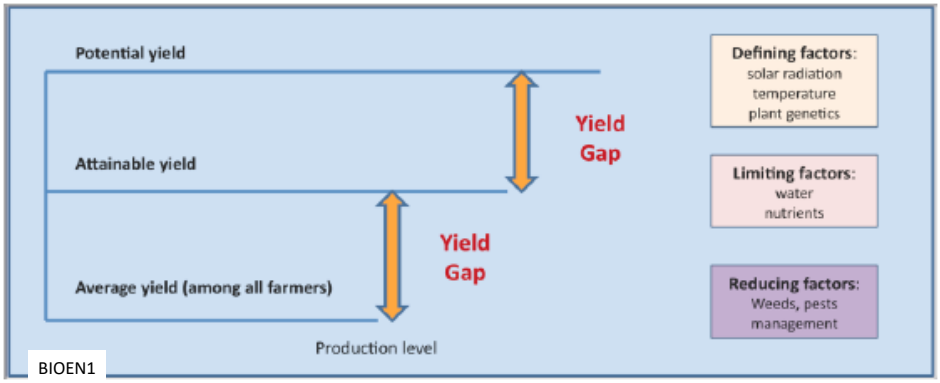
Biomass yields

The term yield can mean different things. **Average yields** are conservative estimates based on averages across producers and years. **Attainable yields** & **potential yields** can be obtained if all factors are optimized:

- Nutrients (can be controlled to some extent)
- Water
- Weather
- Pests & management



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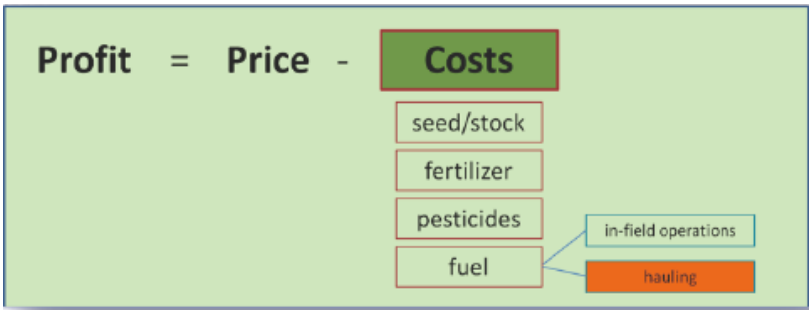
Biomass profits?

Typically, agricultural profits depend on the price paid for the crop and the combined cost of producing that crop.

The costs of **hauling** the crop to the buyer / processor must also be considered as a cost to the producer. So, producers will choose their crops, in part, on their distance from buyers or processing plants.

- Biomass is an attractive crop to produce only **when processing plants are close enough** to limit the costs of hauling and allow profit.



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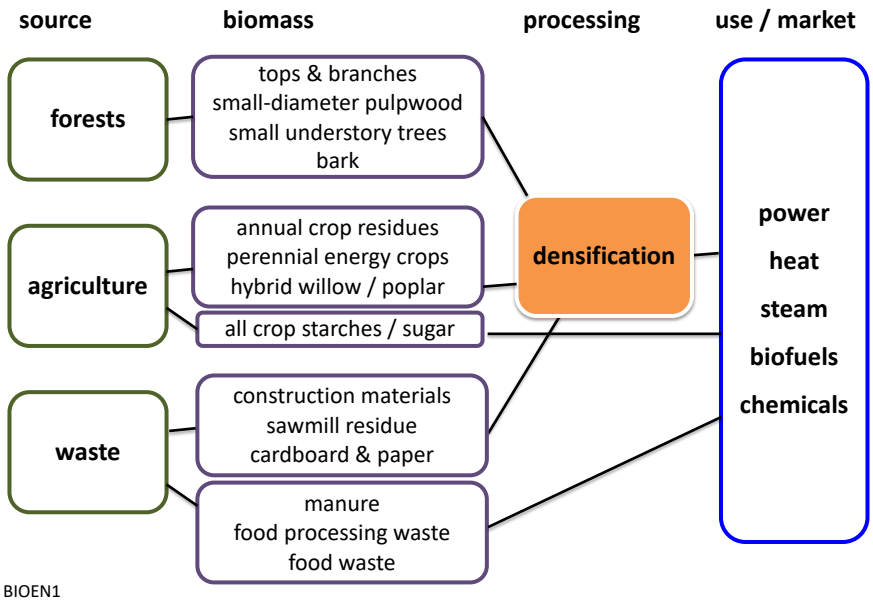
Biomass supply chain



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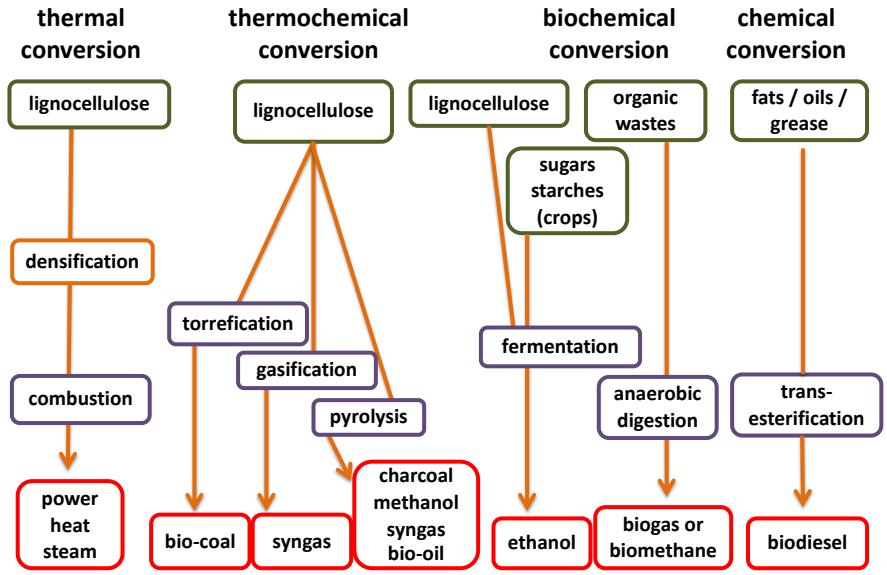
Feedstock by conversion process



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1.5: Bioenergy co- & by-products

Bioenergy co-products

Co-products: non-energy products of bioenergy processing or use that have economic value

We will discuss more co-products as the course proceeds, but a few of the most valued co-products are listed here.

Distillers grains: grain after ethanol production
- DDG (dry distillers grains) & WDG (wet distillers grains)
- Produced by 60% of ethanol plants: dry-mill plants
- Animal feed; AD feedstock

Bagasse: the fibrous material remaining when sugarcane is crushed
- Combusted, cellulosic ethanol feedstock; AD feedstock

Glycerol (aka glycerin): high-energy liquid co-product of biodiesel production
- Used by cosmetic & food industries if purified
- Combusted & used for AD feedstock
- 950,000 tons produced per year with surplus above market demand

Biochar: co-product of gasification or pyrolysis
- Used as a soil amendment: holds nutrients & sequesters carbon in soil

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Bioenergy by-products

By-products: non-energy products of bioenergy processing or use that do not have significant economic value
A few of significant by-products are listed here.

Fly ash: fine particulate matter from combustion of solid fuels; silica-rich
- Air pollutant & health hazard regulated by EPA
- Less than half of US fly ash is recycled as amendment to Portand cement

Waste water: water containing biomolecules
- Regulated and cannot be dicharged into waterways without treatment
- Liquid remainder from distillation of grains for ethanol
  - 4-6 gallons of wastewater are produced per gallon of ethanol
- Water used to 'wash' alcohol and glycerol from biodiesel
- Can be treated via anaerobic digestion though it has a low energy content

Carbon dioxide: produced by combustion of biofuels
- Will be regulated by EPA
- *We need to make CO_2 into a co-product*!

BIOEN1

1.6: Drivers of bioenergy development

What drives use of bioenergy?

The current interest in expanding use of bioenergy is driven by a number of factors.

- Desire for energy independence or **energy security**
- Local energy sourcing can provide **local economic growth & development**
- **Renewable energy**
- **Carbon neutrality** (less impact on global climate change)
- **Recycling of nutrients** – in biogas and to some extent biomass

Recent surge of interest seems to relate most strongly to:

1. The potential for sustainability!
2. The potential for disseminated global economic development & local energy security

Dahiya (2015)

Policy influences use of bioenergy

Since 1918, **US** governmental policy has provided the fossil fuel industry with substantial support in the form of subsidies and drilling rights. In comparison, support for renewable energy has been insignificant, and has become a political football.

- **Fossil fuels** **$446.96 b**
- **Renewable energy** **$5.93 b**

In 2011, **worldwide**, fossil fuel subsidies:

- **$480 b** pre-tax
- **$1.9 t** on a post-tax basis including externalities like carbon, environmental impacts and public health

Eliminating the US's 12 fossil fuel subsidies would save **$41.4 b over a decade** without increasing fuel prices, reducing unemployment or weakening energy security.

www.energyfactcheck.org; bit.ly/N9lsin; bit.ly/1coLJmn; bit.ly/1h3mDhB

Recent bioenergy incentives

Ethanol production from corn has been supported by:

- State & federal tax subsidies
- Mandated use of 'high oxygen' gasoline
- the Clean Air Act Amendments of 1990

2006: Advanced Energy Initiative had funding for biofuel production processes
2007: "20-in-10" plan to reduce gasoline consumption by 20% in a decade
2007: Renewable Fuel Standard passed as part of the Energy Independence & Security Act of 2007
- 36 b gallons of biofuel by 2022
- Provisions for advanced biofuels

2008: Farm Bill included mandatory USDA funding for bioenergy activities.

August 2019: granted exemptions from the requirement for adding bioethanol to 31 of 40 small refineries.

"Iowa's Republican Senator Chuck Grassley said the EPA had "screwed" the U.S. ethanol industry and farmers by granting the waivers."

- Reuters

Dahiya (2015); www.energyfactcheck.org/

Bioenergy research

In the US, some bioenergy research is supported by the federal government, mainly through two agencies:

U.S. Department of Energy (US DOE)

- Office of Energy Efficiency and Renewable Energy (EERE)
- National Energy Research Lab (NREL)
- Idaho National Lab
- Scandia National Lab
- Bioenergy research centers at:
  - Oak Ridge National Labs
  - Great Lakes Bioenergy Research Center
  - Joint BioEnergy Institute (Lawrence Berkeley National Labs)

U.S. Department of Agriculture (USDA)

- Biomass Crop Assistance Program
- *Renewable* Energy Assistance Program (REAP)

Dahiya (2015)

Overcoming market inertia

Like other new or emerging technology, development and implementation of bioenergy requires the active participation of the market.

'The market' likes to make investments when returns are **assured**.

At this point, RE incentives, and falling prices of equipment, are beginning to push the market for some technologies like solar.

However, **development of bioenergy lags behind**.

Major investments in bioenergy crop production, processing facilities, heating or combustion infrastructure will probably require:

- Increased demand (ie higher energy prices or a booming economy);
- Increased incentives (price supports for farmers trying new crops); &
- Legislation limiting or penalizing carbon emissions.

Dahiya (2015)

The chicken or egg dilemma

Energy companies, biomass producers, bioenergy refiners, electric utilities, vehicle manufacturers and others don't want to invest in bioenergy infrastructure, or even research, until there is both feedstock supply and demand for bioenergy.

But the demand won't increase until users are that the bioenergy is truly available, proven, and widespread enough to lower the price.

'Development vs. demand' can be seen as a 'chicken or egg' dilemma.

Energy prices, policy and support / incentive will be key to resolving this dilemma.

Dahiya (2015)

'Roadmaps' for biofuel development

US DOE (EERE), UDSA and EPA have released 'roadmaps' for bioenergy:

- A vision backed up by information;
- A promise to look for and provide some funding; and
- An attempt to shake market inertia.

August 2014 **Biogas Opportunities Roadmap**
www.usda.gov/oce/reports/energyBiogas_Opportunities_Roadmap_8-1-14.pdf
Advocates for increasing the number of US AD facilities from 240 to 11,000 over the next decade.

- Urges voluntary action
- Leverages $10 million of funding

2010 **National Algal Biofuels Technology Roadmap**
www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf

2011 IEA **Biofuels for Transport Roadmap**
www.iea.org/publications/freepublications/publication/biofuels_roadmap_web.pdf

- Biofuel could power 27% of the transport sector by 2050

1.7: Bioenergy debate

Major issues in the bioenergy debate

While there is disagreement about whether specific and overall impacts of bioenergy will be positive or negative, there is no doubt about the issues of being discussed and debated.

- Social & economic development
- Energy independence
- Land use / sustainable practices
- Ecology: environmental quality; biodiversity; habitat conservation
- Energy balance
- Greenhouse gas (GHG) emissions
- Subsidies
- Food prices

BIOEN1; Rosillo-Calle & Johnson (2010)

Biofuels are controversial

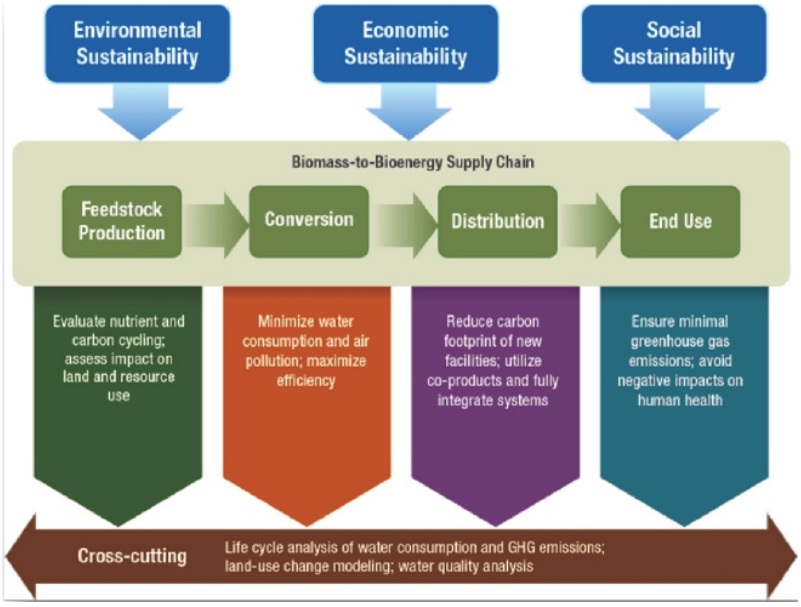
PRO

- There is sufficient land to produce both needed food & a significant amount of biofuel.
- Food insecure countries don't have access to fossil fuels, but could produce biofuels.
- More than 2.5 billion people don't have access to modern energy systems. Bioenergy can be developed as rural countries also develop food production.
- These countries already have multi-functional agricultural systems that can be developed to provide more food and fuel.
- The social & economic benefits of biofuels can outweigh the costs if good management is applied to food and biofuel production.

Rosillo-Calle & Johnson (2010)

Critical thinking about bioenergy

How do we rationally assess the value and potential downsides of bioenergy?



BIOEN1

Life cycle analysis

Life cycle analysis or assessment (LCA): an approach to evaluating the direct & indirect effects associated with a product or process on human health and the environment in a 'cradle-to-grave' (or better yet, 'cradle-to-cradle) analysis of the benefits and costs of a process or product.

- LCA can be used to measure the effects of bioenergy production and use across the supply chain.
- LCA allows for comparison of different products and processes.
- LCA is a ***systems* analysis**; it examines a series of components, the processes that link those components, and the interactive effects of those processes on one another.

LCA analysis of bioenergy technologies is far from complete, but this approach is promising and essential.

For more on LCA, see BIOEN2: http://blogs.extension.org/bioen2/

BIOEN1

1.8: Is bioenergy sustainable?

Sustainability

Sustainability can be viewed through several lenses:

1. A set of goals;
2. Practices and behaviors that support those goals; or
3. A branch of science.

"Human actions that support and enhance human well being derived through interaction with the environment and its components, and which supports the ability of the environment and human society to interact in ways that discourage reduced benefits."

"An emerging academic discipline that integrates scholarship and practice, and disciplines across the natural and social sciences, engineering and medicine to advance both knowledge and action to evaluate, mitigate, and minimize the consequences of human impacts on planetary systems and societies."

The sustainability of bioenergy depends on policy goals & human behavior.

Concerns & solutions?

Concerns about the sustainability of bioenergy include:

- Water use;
- Impacts on soil;
- Loss of biodiversity as more land is used to grow or harvest feedstock; &
- Reductions in food production or food prices.

Guidelines and best management practices (BMPs) are needed, though few have been issued:

- Forest Biomass Retention & Harvesting Guidelines for the Northeast
- There are some third-party verifiers for sustainable forestry.
- WI (& only that state) has guidelines for sustainable harvest & production of non-forest biomass.

Conclusion?

Bioenergy ***can be*** part of a sustainable approach to energy production ***if*** it is done well. That will require widespread, clear guidelines and follow through.

BIOEN1

Energy balance

Energy balance (or **energy return on investment, EROI**) is a measure of the ratio of energy produced to energy invested:

$$\text{EROI (energy return on investment)} = \frac{\text{energy produced}}{\text{energy invested to produce energy}}$$

Traditionally the energy balance of first generation biofuels, like American biodiesel, has not been impressive.

However, continuous refinement & other technological improvements have improved energy balance.

- Brazilian biofuel has improved five-fold in the last 20 years.

Rosillo-Calle & Johnson (2010)

Energy balance (EROI) values

EROI values aren't easy to come by, but here are a few examples.

Fossil fuel	EROI
coal	80
nuclear	10 - 75
oil	20 - 35
natural gas	10
tar sands	3

Bioenergy fuel	EROI
hydropower	100
geothermal	10 - 32
wind	18
PV	6.8
tar sands	3
ethanol	1.3 – 5.0
biogas	2
biodiesel	1.3

Rosillo-Calle & Johnson (2010)

Land use concerns

Land use is influence by many **factors** including:

- Policy / regulation;
- Economic returns / subsidies; and
- Local traditions & ethos.

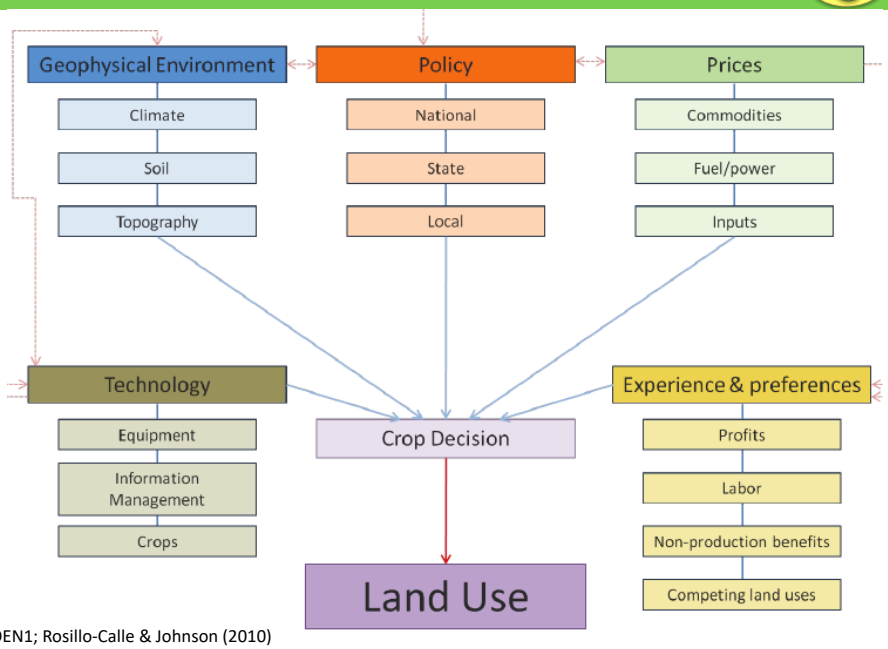
Land use for bioenergy production generally involves **change**:

- From one agricultural use to another (food to energy);
- From managed forest to cropland; or
- From ecosystems to agriculture.

The nature of change can dictate the effect of environmental impacts. Sadly, our society generally does not consider the costs and benefits of ecosystem services (like cleaning air and water, providing resources & biodiversity). Until we consider **externalities** in LCA analysis, we will never understand the true costs of bioenergy or any other human activity.

BIOEN1; Rosillo-Calle & Johnson (2010)

Land use decision making



BIOEN1; Rosillo-Calle & Johnson (2010)

Use of 'marginal' lands for bioenergy

Typically, land is viewed as **'marginal'** when it:

- Is steep;
- Has shallow soils;
- Is prone to drought; or
- Is too wet.

Many propose that use of marginal lands for bioenergy production could provide energy security and avoid impacting agricultural food production.

- However, marginal lands are sometimes our best remaining 'reserves' of otherwise scarce ecosystems.

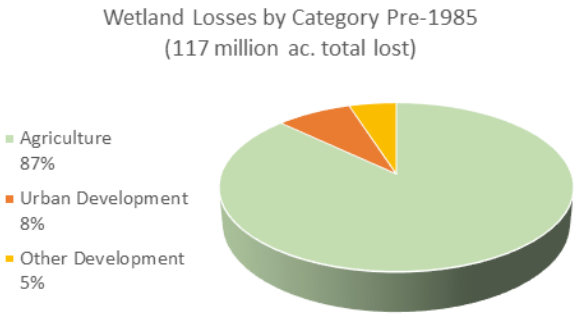
  Example: **Wetlands** are among the richest and most biodiverse of terrestrial ecosystems and provide critical ecosystem services. Most US wetlands have already been filled and converted for human use.

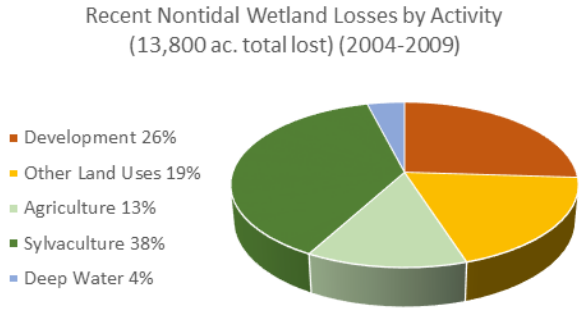
USDA's **Conservation Reserve Program** encourages farmers to set marginal lands aside; compensation is given for fallow land.

- The 2014 farm bill reduced the scope and effectiveness of this program.

BIOEN1; http://investigatemidwest.org/2015/02/21/conservation-program-isnt-what-it-used-to-be/

US wetlands: scarce & imperiled





http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/wetlands/

Deforestation / loss of biodiversity

One example of the negative impacts of bioenergy production on the environment is the massive increase in production of crops that can be used for bioenergy (though they are often also food crops).

Southeast Asia: Palm oil cultivation has boomed.

- 1990 – 2005
- 55 – 59% of the increased cultivation of oil palms involved clearing of forest

Argentina: from 1990 to 2009, soy bean cultivation, largely by clearing forest.

Brazil: in order to meet biofuel targets, forest will be converted to ag lands.

- 5.7 Mha for sugarcane
- 10.8 Mha for soybeans

As much as 12.2 Mha of forest in the **Amazon** and **Cerrado** river basins may be converted to pasture.

Both China and Brazil are interested in 'offshore' agricultural production in **Africa**. Brazil's interests are in bioenergy.

http://www.unep.org/bioenergy/Portals/48107/doc/issues/issuespaper/Issue%20Paper%207%20-%20REDD%20and%20Bioenergy.pdf
http://www.theguardian.com/global-development/poverty-matters/2013/aug/27/brazil-china-africa-agriculture

Use & spread of invasive species

The ideal bioenergy crop would have rapid rates of growth with little fertilizer input, would grow in a variety of conditions, and would have few predators or consumers. That sounds like an **invasive species!**

Invasive species are a growing global problem that has social, economic & environmental costs.

In fact, invasive species like the tropical elephant grass *Miscanthus* and eurasian Reed canary grass (*Phalaris arundinacea)* are being cultivated as bioenergy feedstock.

- **Sterile** Miscanthus hybrids spread less quickly.
- **Harvesting** invasives for bioenergy may contain them.

Miscanthus x giganteus

Water use & quality

Bioenergy uses water for:

1. Growth of bioenergy feedstock; and
2. Processing or conversion of feedstock..

When and where crops require **irrigation**, water uses rises sharply and can:

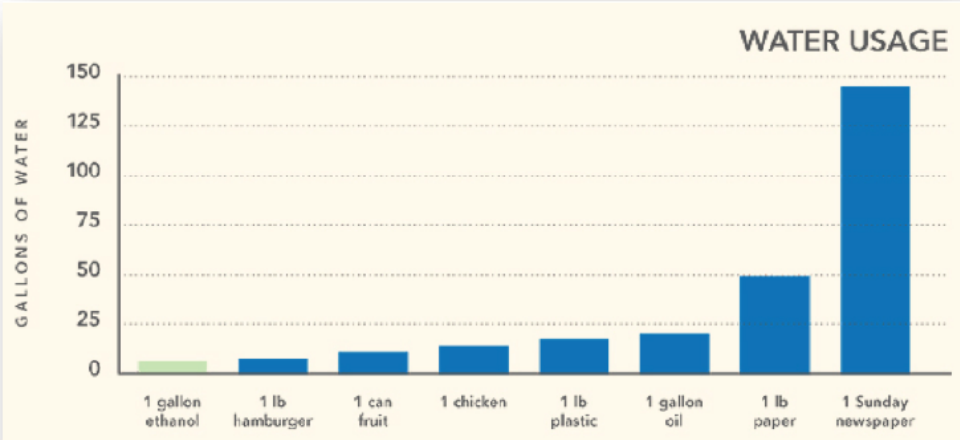
- Lower groundwater supplies;
- Steal water away from use in food-production; and
- Contribute to deposition of salts in soils.

Perennial crops (like grasses) uses less water and provide groundcover and filtration.

- Agricultural production can also pollute ground and surface waters with pesticides, herbicides and excess nutrients like nitrogen and phosphorous that promote eutrophication and oxygen depletion.

Water use for ethanol production

While we need to be concerned about use of water in bioenergy production, its helpful to put that into **context** with other activities we probably don't give much thought to.



BIOEN1

GHG and climate change

Greenhouse gases (GHG) absorb and emit heat from solar radiation. Increased levels of GHGs like water, carbon dioxide, methane and nitrous oxides can increase global temperatures and contribute to climate change.

Bioenergy combustion produces CO_2, but bioenergy has the potential to be **carbon neutral**:

- Bioenergy combustion releases CO_2 into the atmosphere.
- Growing plants (to be used as food, animal feed or energy crop) take up CO_2 from the atmosphere.
- Resulting crop residue, manure or energy crops are harvested and used as bioenergy feedstock.
- Feedstock is processed into bioenergy fuels.
- Rinse, repeat.

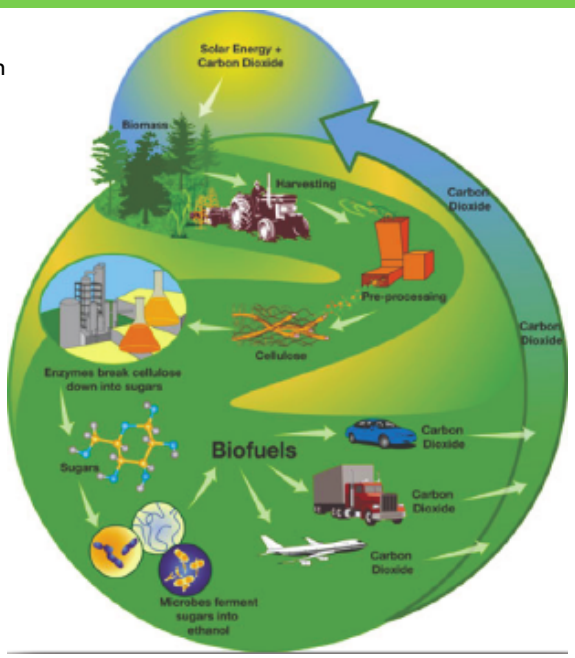
2009: **biofuel use prevented emission of 123.5 megatons of GHG globally**

- That's 57% compared to fossil fuels
- Ethanol + biodiesel production = 100 billion liters
- Displaced 1.15 million barrels of crude each day

BIOEN1; Rosillo-Calle & Johnson (2010)

Carbon cycle & bioenergy

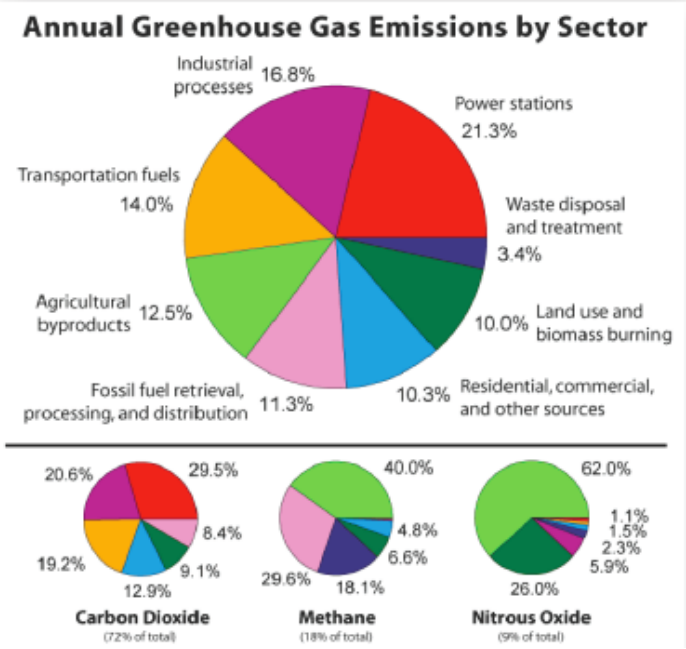
Carbon cycle & potential for carbon neutrality of bioenergy



BIOEN1

US GHG by sector

While bioenergy may recycle CO_2, it <u>doesn't recycle</u> other GHGs as readily.



BIOEN1

Community impacts of bioenergy

Because bioenergy feedstock is not as energy dense as fossil or nuclear fuels, the costs of transporting bioenergy feedstock materials is high. So feedstock processing plants tend to be constructed and operated close to biomass production.

- **Bioenergy tends to be more local than fossil fuel and nuclear energy.**
  - The less dense the biofuel, the more local it tends to be
- This can **focus the economic development** associated with bioenergy in the communities that produce the feedstock.
- The net effect of bioenergy on those communities is **not necessarily positive**, and must consider impacts on noise, traffic and other resource use.

BIOEN1

Conclusion

It's clear that first-generation bioenergy has had negative impacts on land use, habitat and biodiversity.

Other studies suggest that second- and third-generation bioenergy could have beneficial effects.

- It's clear that in order to make this so, **policies and standards** for production and processing of bioenergy feedstock must be created and implemented

Effective policies should:

- Minimize habitat loss;
- Prevent habitat fragmentation;
- Continue the Conservation Reserve Program;
- Ban use of persistent pesticides; and
- Protect waters from agricultural runoff.

BIOEN1

Waste biomass should be the focus

A 2019 study by researchers at UCLA concluded that US **waste biomass** could create enough energy to power the states of Oregon and Washington.

- **3.1 – 3.8 EJ/year from waste**

Enough energy to replace the GHG emissions (carbon) of 37 million cars.

- **= 105 – 178 million metric tons of carbon dioxide**

Waste?

- Agricultural waste
- Forestry waste
- Landfill waste
- Cow manure

Technology?

15 waste-to-energy technologies considered for…
29 types of local waste

While **European waste-to-energy processes > 106 million metric tons of waste each year**, the US produces bioenergy mainly from forest harvest and virgin crops (corn).

https://biofuels-news.com/news/ucla-study-encourages-us-to-maximise-benefits-of-waste-derived-fuels/

1.9: The food vs. fuels debate

Intersection of food & energy systems

In 2007 – 2008, crop and food prices soared around the globe, causing shortages in underprivileged areas. Why?

- Futures trading
- Higher fossil fuel prices
- Building of grain reserves
- Agricultural price supports & subsidies
- Growing demand / increased populations
- **Use of food crops for ethanol production**

Many food crops can be used as feedstock for bioenergy & chemical production.

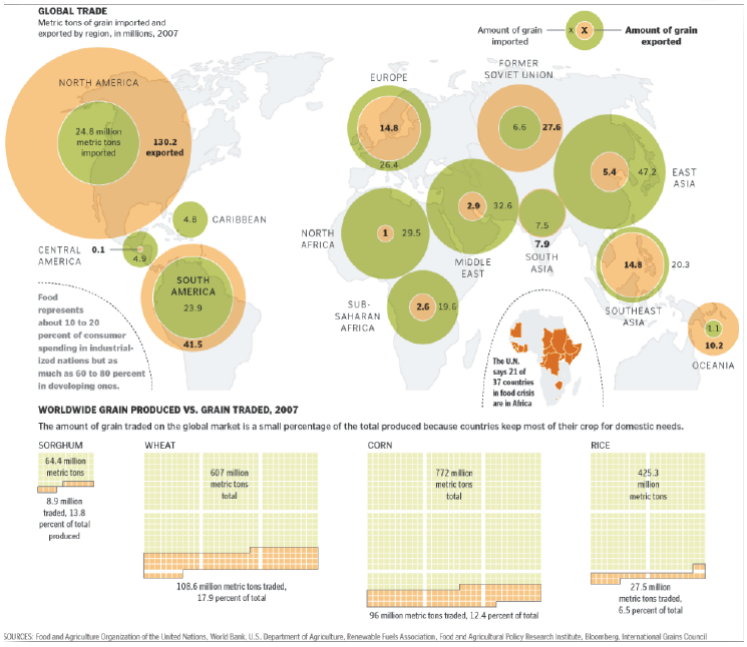
- Growing human populations increase the demand for food and energy..
  - *Should we increase the supply of these crops? Can we?*
  - *Should we decrease the demand for food or energy? Can we?*

As of 2009, **ethanol production consumed 30% of the US corn crop**, double the use of corn for fuel in 2006.

BIOEN1; Thurow & Kilman (2009)

Global grains trading

Global patterns of grain production vs. consumption

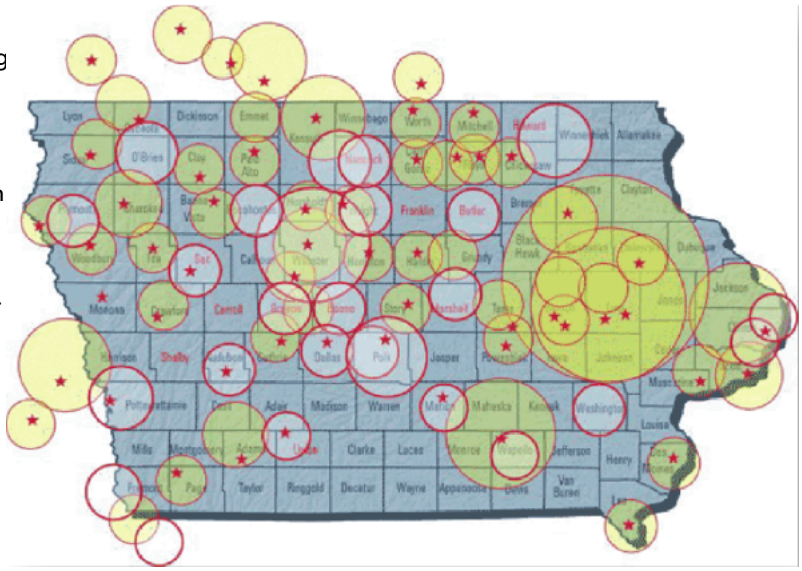


BIOEN1

Corn for food or ethanol?

Planned corn processing and ethanol plants (stars) and corn producing areas (circles) in Iowa (2006).

Overlapping circles indicate where competition may increase food prices.



BIOEN1

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