GEOS 24705 / ENST 24705
Lecture 18A: Fossil fuels III – alternative liquid fuels
**Fossil fuels:**  Readily extractable oil will run out. Even tar sands + shale oil will not be enough

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Fuel Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 bboe/yr</td>
<td>World coal</td>
<td>4,500</td>
</tr>
<tr>
<td></td>
<td>U.S. coal</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>World oil (no oil sands)</td>
<td>1,000</td>
</tr>
<tr>
<td>30 bboe/yr</td>
<td>World oil (w/ oil sands)</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>Shale oil (most U.S.)</td>
<td>~1000</td>
</tr>
<tr>
<td>19 bboe/yr</td>
<td>World gas</td>
<td>1,100</td>
</tr>
</tbody>
</table>

1 barrel of oil equivalent = 6.1 GJ

Data: EIA

That’s at current rate of consumption.. growth in energy usage is ~ 2 %/yr

= lifetime of 40 years?
Fossil fuels  Scarcity helps drive prices up?

From: Wikimedia Commons
Fossil fuels: why not turn coal we have into gas or liquid?

Liquifying is three-step process: Solid -> gas -> liquid

Gasification

*Syngas production:*

Steam reforming: combine hydrocarbon with water to make hydrogen and CO (combustible gases):

\[
CH_x + H_2O \rightarrow (1+0.5x)H_2 + CO
\]

*Can just burn these products – that’s what an IGCC plant does. Or proceed to:*

Water-shift reaction (also called “steam reforming”)

Combine CO with steam (and catalyst) to boost hydrogen concentration. Energy intensive: Rxn stages at 350 C and ~ 200 C, exothermic rxn

\[
H_2O + CO \rightarrow H_2 + CO_2
\]

Liquification

*Fischer-Tropsch process:*

Catalytic conversion of hydrogen and CO to liquid hydrocarbon, requires temperatures 150-300C, best lower T, higher P, highly energy intensive

\[
(2n+1)H_2 + nCO \rightarrow CnH(2n+2) + nH_2O
\]
Fossil fuels: syngas production

Combine hydrocarbon with water to make hydrogen and CO (combustible gases):
$$\text{CH}_x + \text{H}_2\text{O} \rightarrow (1+0.5x)\text{H}_2 + \text{CO}$$

Earliest use: lighting (“coal gas”) ca. 1800
Current main use: “integrated gasification / combined cycle” or IGCC

Figure: Energy Northwest
Fossil fuels: syngas production

Combine hydrocarbon with water to make hydrogen and CO (combustible gases):

German syngas plant. Figure: Linde Engineering
Fossil fuels: liquid fuel production from coal

History

Syngas: as early as 1800. Used to make “coal gas” for lighting *(slightly diff. process)*
Liquids by Fischer-Tropsch: invented by German chemists in 1920s
South Africa pioneered commercial coal-to-liquids in 1970s
Now many plants in Europe
First U.S. commercial plant will be in W. Illinois

Pluses

Minimize refining – hydrocarbon output easier to convert to liquid fuel
For national security, world peace: use homegrown fuel
For environment: perhaps paves way for using biomass instead (can’t run world on biomass alone but could maybe run transportation sector)

Minuses

Increased CO2 emissions – high energy consumption to produce. Use a lot of cheap fuel (coal) to get a high-value fuel (synthetic oil). Also coal has high carbon per energy content so emissions even worse.
*Hope: energy penalty might be reduced with better heat recovery*
Non-fossil options: liquid fuels can be made from biomass via:

**Gasification to syngas and on to liquid fuel via Fischer-Tropsch**
*Can use virtually any biomass, but highly energy intensive (i.e. efficiency is low: 75% effective losses in conversion)*

or turn it into:

**Biodiesel**: from fats (e.g. vegetable oil)
*Efficient but sources of pure fats are small – meat byproducts/waste or oil-producing seeds. Fats are a very small fraction of total biomass.*

**Ethanol**: from carbohydrates (usually sugars): ~\(\text{C}_6\text{H}_{12}\text{O}_6\)
*Good if you have easily grown biomass that has high sugar concentration (e.g. sugarcane). Not good if sugar concentration is low and energy required to grow and harvest is high (corn). Competes with food uses.*

**Cellulosic ethanol**: from non-sugar carbohydrates (lignins)
*Feedstock is much more abundant, tougher to break down – can’t be done now with positive energy return, but hopefully can be someday.*
Non-fossil biofuels: history of use

**Biodiesel:**
Rudolf Diesel demonstrates Diesel engine running on peanut oil in 1900
Much research in Europe during WWII (esp. Germany) when oil supplies cut off
South Africa again pioneers commercial use, first plant in 1987 *(Why S. Africa?)*
Now many plants in Europe and the U.S.
Minnesota first state to require biodiesel addition to diesel sold in state

**Ethanol**
Brazil is largest sugarcane producer, also mandated use of ethanol – Brazilian auto fleet runs primarily on 25% ethanol blend or straight ethanol. *(Ethanol is still < 20% of automotive energy use, though).*
U.S. ethanol subsidies meant boom in ethanol in last decade, though now plants are closing.
Barriers to ethanol import mean we have no access to cheap Brazilian product
Fossil fuels: another conundrum

If we run out of oil, but have enough coal, we can keep our transportation system running by liquifying it … but only at price of making climate change and damages worse

The environmental impacts of extracting unconventional fossil fuels are bad, but the bigger concern is accelerating climate change
Energy budgets: Energy Return on Energy Investment (EROEI)

EROEI = Energy extracted / “Process energy” lost in extraction

Sort of like an efficiency, but neglects the initial energy source, considers only process energy. Useful when discussing only extraction/conversion of primary energy, and only for:

- energy sources that would otherwise be untapped (wind, unextractable oil).
- ...in context of asking whether a system is a net energy producer (i.e. do you get out more than the process energy you put in?)

Notes:
If EROEI is < 1 in primary energy extraction, no sense to extract
If EROEI is < 1 in an energy conversion, may still make sense (might really want the converted form of energy) but you have net losses

Some rough EROEI estimates:
Middle East crude oil production: > 30
Coal mining: > 30
Commercial wind > 30
Oil sands recovery: ~ 4
Coal-to-liquids: ~ 1  

Note: this last is an inappropriate context for EROEI use, since the coal is not “free”
**EROEI:** useful for determining net energy extraction from renewables

---

**Example:** EROEI of wind turbines goes with size.
Larger turbines put out 30x more energy than it took to build them
Very small turbines put out less energy than it took to build them

*What doesn’t go into the EROEI? The energy of the wind itself. Only energy to build the turbine.*
EROEI: not the same thing as efficiency

EROEI = Energy out (other than waste heat) / process energy in

\[ \varepsilon = \frac{\text{Energy out (other than waste heat)}}{\text{total energy in}} \]

Consider the case of oil extraction. Process energy for drills, pumps

Fuel energy \( E_f \)  

\( \rightarrow \)  

Fuel energy \( E_f \)

Process energy \( E_p \)  

\( \rightarrow \)  

Waste heat
EROEI: not the same thing as efficiency

EROEI = Energy out (other than waste heat) / process energy in

\[ \varepsilon = \frac{\text{Energy out (other than waste heat)}}{\text{total energy in}} \]

Consider the case of oil extraction. Process energy for drills, pumps

Fuel energy \( E_f \)

Process energy \( E_p \)

Waste heat

\[ \text{EROEI} = \frac{E_f}{E_p} \quad \text{.... consider the fuel as free. Divide by process energy only} \]
EROEI: not the same thing as efficiency

EROEI = \frac{\text{Energy out (other than waste heat)}}{\text{Process energy in}}

\varepsilon = \frac{\text{Energy out (other than waste heat)}}{\text{Total energy in}}

Consider the case of oil extraction. Process energy for drills, pumps

Fuel energy $E_f$

Process energy $E_p$

Waste heat

EROEI = \frac{E_f}{E_p} \quad \text{... consider the fuel as free}

\varepsilon = \frac{E_f}{(E_p + E_f)} \quad \text{... count the fuel too}
EROEI: not the same thing as efficiency

EROEI = Energy out (other than waste heat) / process energy in

ε = Energy out (other than waste heat) / total energy in

Consider the case of oil extraction. Process energy for drills, pumps

EROEI = \( \frac{E_f}{E_p} \) .... consider the fuel as free

\( \varepsilon = \frac{E_f}{(E_p + E_f)} \) .... count the fuel too

Reduces to \( \varepsilon = \frac{1}{1 + \left(\frac{1}{\text{EROEI}}\right)} \)