GEOS 24705 / ENST 24705
Lecture 16: Transportation
History of oil usage: beginning of modern era

Wells (mostly hand-dug) and distilleries in Azerbaijan in 1830s, for making kerosene – centuries of history, descriptions as early as Middle Ages

-> Discovery of petroleum in U.S. (Oil Creek, Titusville, PA) in 1859 – first U.S. drilled oil well gave 20 bbl/day (market for oil in U.S. was lamp oil and lubricating oil)

Oil production boomed by x 1500 in 4 yrs, eight refineries built by 1868, x 5000 in 15 years

First international oil shipments, U.S -> London

Pipelines by 1870s (Rockefeller’s Standard Oil founded 1870)

– market still only for kerosene – gasoline was being disposed of as waste product

Oil production booms in Azerbaijan 1880s

Oil Creek (Lower Pioneer Run) in Titusville, 1860s (L), oil barrels (1860s?) Titusville (R). Price:~ $100/barrel 2006 doll.
History of oil usage: beginning of modern era (PA)

Phillips (R) and Woodford (L) wells, Oil Creek Valley, Titusville PA, ca. 1861. Phillips well gave 4000 bbl/day. From: From Pennsylvania Historical & Museum Commission, Drake Well Museum Collection, Titusville, PA
History of oil usage: beginning of modern era (PA)

Transport of oil in barrels from Titusville to Pittsburgh refineries, 1864. Estimated leakage & loss: 50%.
From Pennsylvania Historical & Museum Commission, Drake Well Museum Collection, Titusville, PA
History of oil usage: beginning of modern era (Azerbaijan)

Beginning of modern era: production in Baku, Azerbaijan

Nobel oil field in Balakhani, Azerbaijan, 1890s – Swedish-owned by Nobel brothers, one of whom goes on to invent dynamite and found a famous prize…From: San Joaquin Geological Society
History of oil usage: beginning of modern era (Azerbaijan)

Baku, Azerbaijan, 1890, building levees to try to save oil from gusher.
From: San Joaquin Geological Society
History of oil usage: beginning of modern era (Azerbaijan)

Horrible environmental standards – modern production far cleaner per barrel. It is the *scale* of the modern energy industry, not the practices, that makes it more environmentally harmful than in the past.

_Baku, Azerbaijan, 1890s? Wells pumping into oil-filled reservoirs for storage._
_From: Azer.com_
History of oil usage:
beginning of modern era

Opening of first Texas and then California oilfields

Highly recommended
Oil is now 1/3 of U.S. primary energy use

U.S. energy use, 2005 from LLNL, in quads/yr: 1 Q / yr ~ $10^{18}$ J / yr ~ 30 GW

Estimated Future U.S. Energy Requirements ≈ 96.8 Quads

Projection Year 2005
From Year 2005
Efficiency Year 2005
Energy Distribution Year 2005
Why are liquid fuels so important?

....Because they are primary transportation fuel

1. Allow internal combustion engine which is intrinsically lighter than external combustion engine (W/kg)  
   *determines how fast you go*

2. Fuel has high mass energy density so range is high (J/kg)  
   *determines how far you go*

3. Fuel has high volume energy density so again, easy to bring enough to get high range (J/m³)
Reciprocating internal combustion engines

.... Power nearly everything that runs on liquid fuel
.... Consume nearly all oil used
.... Make up 1/3 of U.S. primary energy consumption

Automobiles and trucks
Motorcycles
Locomotives
Boat engines
Propeller airplanes
Diesel generators
Riding lawnmowers
Outboard motors
Chainsaws (the non-electric kind)
Weed-whackers

*Uses: things that need to be mobile, where power-to-mass matters*
Transportation: early attempts with steam

Nicolas Cugnot, steam-powered automobile
First car (1769), military tractor for carrying artillery, 2.5 mph
First car accident (1771)
Transportation: **steam used mainly for locomotives**

First full-scale steam rail locomotive in Britain in 1804

First U.S. railroad in 1829

Adjust power via cut-off valve that changes steam intake to piston

Stephenson’s Rocket, 1829, winner of Rainhill Trials race between Liverpool and Manchester.
Internal combustion engine history: early history in France

1680: Christian Huygens (Holland) designs (*but doesn’t build*) an internal combustion engine driven by gunpowder

1690: Denis Papin designs (*but doesn’t build*) an internal combustion engine driven by gunpowder. Gives us an *invents* steam engine instead (design actually built by Newcomen).

Early-mid 1800’s: experiments with modifying steam engines to run on coal gas (i.e. natural gas)

1858: Jean Joseph Étienne Lenoir patents spark-ignition ICE running on coal gas. In 1863 drives hydrogen-powered vehicle 9 km in 3 hours (1.8 mph). Also drives vehicle with engine modified to run on liquid petroleum 7 miles at 4.5 mph.

1862: Alphonse Eugène Beau de Rochas, French engineer, designs and patents (*but doesn’t build*) the first four-stroke engine with compression cycle

*Hippomobile, ~400 sold*
Internal combustion engine

President Obama, State of the Union speech, Feb. 2009, on bailing out Detroit automakers:

“The nation that invented the automobile cannot walk away from it.”
“In what will surely be seen as a provocative move by the new administration, President Barack Obama announced last night in a televised address to the U.S. Congress that all inventions of note from at least the last 200 years will now be credited to Americans.

The president revealed last evening that credit for the invention of the automobile will be transferred from one Karl Benz of Germany to an unspecified American.”
Internal combustion engine history:
development in German-speaking countries

1876: Nicolaus Otto builds workable, commercial version of 4-stroke gasoline engine, patents it (again). Now known as “Otto cycle”.

1885: Gottlieb Daimler invents prototype of modern engine

1885: Karl Benz invents 3-wheeled car with gasoline engine

1886: Daimler (who works for Otto) and Maybach build 4-wheeled car

1889: Daimler-Maybach car w/ 4 speed transmission hits 10 mph

1890: Wilhelm Maybach builds first 4-cylinder engine

1893: First auto manufacturing in U.S. (Duryea company, MA)

1896: Henry Ford starts auto company in Detroit

1908: Mass production of Ford Model Ts
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*Daimler-Maybach, 1886. From VintageWeb*
Internal combustion engine history:
2 other famous German-speaking auto inventors: who were they?

Both exhibited at the 1900 Paris Exposition

One (former electric shop worker) won the speed competition with an **all-electric car** carrying 1800 pounds of batteries and with a top speed of 37 mph.

The other (former steam engine designer) won the Grand Prix of the whole Exposition for a new **biofueled engine** running on peanut oil, operating on a new thermodynamic cycle he’d invented from 1st principles.

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*Lohner-Porsche Elektromobil,*  
designer: *Ferdinand Porsche,*  
Austrian, age 24. Note electric motors in front wheels.

*Diesel engine,* invented 1893,  
17% efficient.  
*Designer:*  
*Rudolf Diesel,* German-trained
Transportation: hybrid electric motor-driven cars not new

First hybrid 1901: to extend range, gasoline engine added to charge battery

Lohner-Porsche, hybrid “Mixte”, top speed 35 mph. In-wheel motors on all four wheels – first four-wheel drive vehicle. 83% efficient at conversion of electrical-mechanical energy.

Figure: jalopnik.com
Transportation: hybrid technology used for large vehicles

Hybrid technology in “land trains”: gasoline engine in lead car drives generator; electricity carried to each car to drive separate electric motors

Porsche “Landwehr”, post-1905 (while Porsche employed by Daimler), used by Emperor Joseph’s military to bring supplies to troops..

Figure: hybrid-vehicle.org
Transportation: last gasp for steam in personal vehicles

Stanley Steamer: biggest selling U.S. car by 1899 (200 sold) in production til 1927, typically
Set world speed record in 1906 (128 mph)
Burned gasoline or kerosene externally & made steam in vertical-tube boiler

1911
Model 72
20 hp
Roadster,
Stanley
Corp.
(Photo: Ken
Hand)
Why did the internal combustion engine win out?
In part, because fuel became cheap...

Production of Model T
Fords begins 1908

Oops! Compact cars are nice after all

Figure from: Wikimedia Commons
Four-stroke engine
driver of most transportation

One preparation cycle and one power cycle
1. Intake
2. Compression
3. Combustion
4. Expansion

Note need for spark plug to set off combustion

Note means of converting linear motion to rotational – looks similar to “sun and planet” gearing from Watt’s steam engine
Four-stroke engine
driver of most transportation

Advantages:
Produces heated, compressed, very dense fuel/air mixture

Disadvantages:
“off” half the time – half the power-to-mass ratio that it might have

Must have at least two cylinders, since when one is “off” the other must be providing the push to keep rotating the shaft
Four-stroke engines: must have pairs of cylinders

In practice, gasoline engines typically have from 4-8 cylinders. Out-of-phase cylinders must provide required force to drive pistons through compression phase and yield balanced power.

Note central crankshaft allowing pistons to turn linear motion into rotational motion and to put work into the same shaft.
Four-stroke engines: must have pairs of cylinders

High-power automobile engines have 8 cylinders, hence “V8”
Two-stroke engine
Simpler, cheaper

Advantages:
Higher power-to-mass since is never “off” – each stroke is power stroke
Can have only one cylinder
Therefore: engine of choice for cheap or hand-carried applications

Disadvantages:
Some unburned fuel escapes – very polluting
Since fuel fills crankcase, lubricating oil must be mixed into fuel mixture – even more polluting
Two-stroke and four-stroke engine comparison

Four Stroke Engine Animation

Two Stroke Engine Animation

See: www.animatedengines.com
Torque-speed: a drawback of internal combustion engines

Torque-speed curve produces low torque at low rpm
How do you start the car from a standstill? How do you accelerate?

ICEs do not run well at low speeds – neither torque nor power nor efficiency (not shown) are high at low speed

For V6 Cologne engine
Torque-speed: a drawback of internal combustion engines

Transmission – required to allow gasoline engine to operate at high speed when wheels are low speed
**Thermodynamic cycles: Otto cycle**

*Fast combustion + valve opening = 2 constant-volume legs. Sparkplug to ignite quickly and completely.*

Efficiency $= 1 - 1/r_k^{\gamma-1}$ where $r_k = \text{compression ratio } V_1/V_2$
Thermodynamic cycles: Otto cycle

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Efficiency = $1 - 1/r_k^{\gamma-1}$ where $r_k =$ compression ratio $V_1/V_2$

Since efficiency is a function of compression ratio, engineer for high ratios, typ. ~ 10:1 in cars

Figure: web.mit.edu
Thermodynamic cycles: Otto cycle

But do you need a constant-volume leg on combustion?

Since efficiency is a function of compression ratio, engineer for high ratios, typ. ~ 10:1 in cars

Efficiency = 1 – 1/$r_k^{\gamma-1}$ where $r_k$ = compression ratio $V_1/V_2$
Thermodynamic cycles: **Diesel cycle**

Cycle designed for higher efficiencies, achievable only if fuel can withstand higher pressures. Fuel must be sprayed in to compressed air to control ignition.

What we call Diesel fuel is a petroleum-based fuel designed for the Diesel cycle. Peanut oil worked perfectly well at first!

Diesel fuel less volatile, ignites on compression but only at very high $P$

Compression ratios always $> 14$, can be $> 22$

Efficiency = \[1 - 1/(r_k \gamma^{-1}) * (\alpha^\gamma - 1)/(\gamma(\alpha - 1))\], where $\alpha$ is the "cutoff ratio" $V_4/V_3$
Thermodynamic cycles: of course in practice, aren’t ideal

No engine can really achieve the ideal PV cycle, so real-world efficiencies are lower

Figure: web.mit.edu
Diesel: advantages

1. Higher compression ratios = higher temperatures = higher efficiency (theoretically up to 75%, in practice 40%, up to 55% in some demonstrated engines)

   Fuel efficiency greater than with gasoline hybrids

2. More torque at low speeds (will discuss later – very useful for pushing big loads. But has high torque ONLY at low speed – poor acceleration at speed.)

3. Reliability: no sparkplugs – ignition occurs from compressional heating alone

4. Lubrication: fuel is better lubricant than gasoline, so piston rings and cylinder bores last longer
Diesel: disadvantages

1. **Weight** – longer pistons to get bigger compression ratio, heavier engine materials

2. **Poor torque at high speeds** – bad acceleration when at cruising speed

3. **Inherently polluting** - incomplete combustion gives sooty particulates (injected just before combustion, after compression, not mixed throughout cylinder stroke)

*Pollution problem greatly fixed in recent engines*
**Torque-speed:** Diesel better at low speed than Otto

Note that Diesel engine has flatter torque-speed curve
(Red on L, Green on R)

Otto engine torque-speed
For V6 Cologne engine

Diesel engine torque-speed
Torque-speed: an advantage of DC electric motors

Torque-speed curve produces high torque at low rpm

Figure: ELMO
What is each engine type best for?

**Gasoline**: poor torque at low speed, good torque (acceleration) when at cruising spd., light weight

**Diesel**: higher torque at low speed, less torque at cruise, heavy weight but high power

**Electric**: max torque at low speed, very little torque once at cruise, requires generator (or heavy battery) to drive
**Locomotives:** all diesel-electric series hybrids

Hybrid technology: gasoline engine drives generator; electricity carried to each wheel to drive separate electric motors

General motors EMD 710 series engine. Each cylinder of the engine has a displacement twice that of the biggest gasoline engines (11.6 liters). 3200 hp (2.4 MW) with 16:1 compression ratio. The generator is 6 feet in diameter and weighs nearly 18,000 pounds. 904 rpm (very slow).

Two-stroke diesel requires compressed air to force out exhaust, produces greater power.

Figure: howstuffworks.com
**Locomotives:** all diesel-electric series hybrids

Electric motors driving wheels have single fixed gear

Individual motors weigh 6000 pounds and draw over 1000 amps. Braking energy recovered “regenerative braking”: electric motors act as generators and torque applied to motors slows train.

Figure: howstuffworks.com
Hybrid automobiles: all are parallel hybrids

Toyota Prius uses AC motors and generators, requiring 2 inverters, + power split device to allow power from both gasoline and electric motors simultaneously, same drivetrain and transmission as gasoline car.

Figure: CleanGreenCar
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Hybrid automobiles: all are parallel hybrids

“So the choice seems clear. If you want a product that's easy on the environment, gets great fuel economy and has good performance, the only reasonable choice is Hybrid Synergy Drive. You can buy a vehicle powered by the system right now, today. But if you want a series hybrid, well – you can cross your fingers and wait for a few years until some difficult engineering and production problems are solved. Or, you can look into buying a locomotive.”

Irv Miller, Group Vice President, Corporate Communications, Toyota

defending Toyota’s choice of parallel vs. series hybrid for the Prius
Fuel usage in transportation: where does energy go?

1. Thermodynamic losses in engine (typically Otto cycle in real engines gives ~ 75% losses)

2. Braking (kinetic energy must be replaced later on acceleration)

3. Frictional losses in gears, bearings

4. Rolling resistance

5. Air resistance (aerodynamic drag)