Path Dependence in Energy Systems

Lecture 5

What determines which energy technologies are in use?

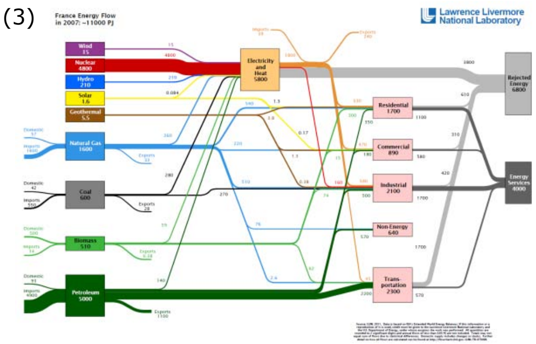
- Technically best choices from technologies available?

Some different rich-country energy choices

(1)

(2)

(3)



Energy flow diagram for countries in 2007 removed due to copyright restrictions.
Source: LLNL-TR-473098: 2007 Estimated International Energy Flows.

(4)

(5)

(6)

What determines which energy technologies are in use?

- Technically best choices from technologies available?
  - Probably not: different rich countries make different choices – French nuclear, EU v. US rail & transit systems…
  - Surely incomplete: What determines rate/direction of innovation and thus the set of available technologies at any time?
- <u>People</u> make choices – individual & collective – not always “optimal”; the market just coordinates
- History: culture shapes individual & collective choices
  - Chinese failure to exploit massive advantages in many areas
  - Dutch/Danish decision to retain reliance on bicycles
- Main focus today: three ways past energy decisions shape future ones -- versions of path dependence

1. Cost of durable capital is important in many energy technologies/systems

(1)

(2)

(3)

(4)

(5)

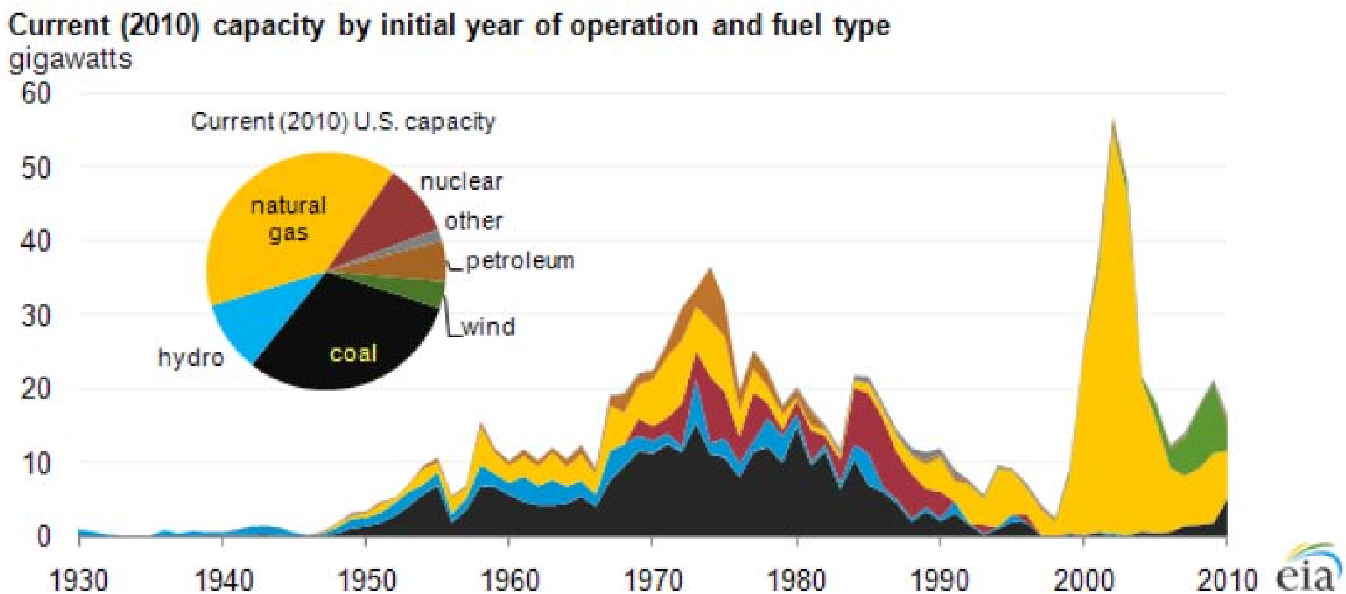
(6)

(1) Photo by Walter Siegmund <http://upload.wikimedia.org/wikipedia/commons/5/51/Anacortes_Refinery_31904.JPG> on Wikimedia Commons.
(2) Photo by Michigan Department of Transportation <http://upload.wikimedia.org/wikipedia/commons/7/77/US_131%2C_M-6%2C_68th_St_interchange.jpg> on Wikimedia Commons.
(3) Photo by Marcus Winter <http://upload.wikimedia.org/wikipedia/commons/4/4a/Railroad_Tracks_-_Merritt_Island%2C_Florida.jpg> on Wikimedia Commons.
(4) Photo by Fletcher6 <http://upload.wikimedia.org/wikipedia/commons/6/64/Salem_Harbor_Station.jpg> on Wikimedia Commons.
(5) Photo by David R. Tribble <http://upload.wikimedia.org/wikipedia/commons/f/f3/PylonsSunset-5982.jpg> on Wikipedia Commons.
(6) Photo by Marshall Asstor <http://upload.wikimedia.org/wikipedia/commons/d/d7/Los_Angeles%2C_CA_from_the_air.jpg> on Wikipedia Commons.

Sunk costs don't matter, but…

- Suppose your plant produces Q units of output/ year.
  - Variable cost is v per unit.
  - Plant cost F to build, will last T years, interest rate is r
  - New plant: variable cost v*, costs F* to build, will last T years
  - When do you scrap the old plant & replace with the new one?
- Use continuous compounding: $1 in t years = e^{-rt}
  - Compound n times/year: $1/[(1 + r/n)^n]^t = 1/[(1+1/z)^z]^{rt}$, z=n/r
  - Lim $z \to \infty$ = lim $n \to \infty$ = e^{-rt}
- Compute unit capital cost c*: $F^* \equiv \int_0^T c^* Q e^{-rt} dt = \frac{c^* Q}{r}[1 - e^{-rT}].$
- c* falls with T, rises with F*; for T large, c* $\to$ rF*/Q
- F sunk, but only scrap if [v* + c*] < v; tougher the more important are capital costs in old (v low), new (c* high)
- **T is very large for institutions, know-how, policies…**

Old generating plants live on…



- Coal plants have large T, large c/v, large up-front cost
  - If replacement cost = R; economic cost of replacing x years early = $R[1 - e^{-rx}]$
- Clean Air Act $\Rightarrow$ EPA sets standards for new plants; raises their cost v. old (dirty) ones; slows replacement

Source: U.S. Energy Information Administration. *Today in Energy* (blog). http://www.eia.gov/todayinenergy/detail.cfm?id=1830.

2. Big changes in policy regimes often very disruptive – hence rare

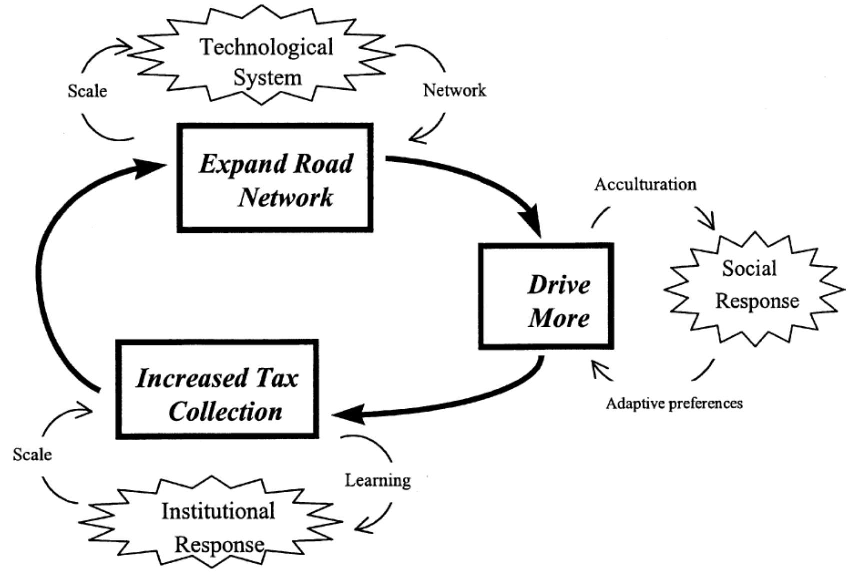
- Rational policy inertia (decades) $\rightarrow$ inertia in technologies used
  - Architecture of clean air act unchanged since 1970s; not up for debate absent serious problems
  - Ag price supports, tax subsidies for oil drilling seem immortal
  - London pre-WWI electricity system
- Gawande on health care reform: different universal health care systems because of inertia, different prior regimes:
  - UK: government ran health care during WWII (US ran many industries, but not health), easy to continue post-war
  - France: chaos post-WWII; built system on pre-war funds
  - Swiss: only had private insurance; universal system simply required purchase, subsidized low-income
  - US: got employer subsidies to get around WWII wage controls; tax-exemption an economic mistake, but immortal
  - MA: built on employer-based system, no change for most

3. Early choices can fix later path because of +interactions on the path

- Classic definition (Mahoney): initial choice, not inevitable (“contingent”), fixes later path – for a while
- Classic example: QWERTY keyboard chosen to minimize jamming on old mechanical typewriters
  - Some say endured beyond technology even though inferior to Dvorak because of mass training, value of standard; hard to change
  - Evidence of inferiority weak, and could buy Dvorak keyboards for a while – *arbitrary* choice can persist if performs OK, change hard
- Second example: Swiss watch-making, started early on because Swiss farmers had time in the winter
  - Over time built up design expertise, pool of skilled workers, training centers, distribution channels – tough to dislodge
  - Initial location somewhat arbitrary (why not Danish farmers?), but once set, advantages build, tough to dislodge

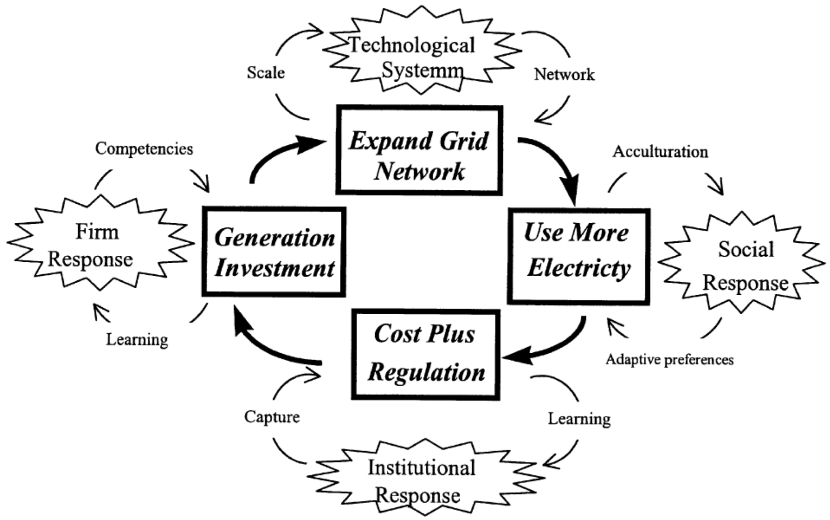
Energy Examples of +Interactions: Institutions & Physical Systems

- Caveat: Unruh has good framework but over-states – DC not superior to AC early; electric cars weak…
- Gasoline autos:
  - R&D, training
  - Jobs→clout
  - Road network
  - Culture adapts
  - Policy supports
  - Driving→taxes
  - Firm-level rigidities – companies tend to focus on getting better at what they are good at, not leaps (Palm, BlackBerry, GM)
  - “Historically derived subjective modeling of the issues” – autos as central to “the American lifestyle,” shapes debates



More examples of +interactions in energy systems – not all pro-carbon

- Electricity:
  - Appliances
  - Training
  - Jobs
  - Habits
  - …



- Air travel (planes, airports, training, legislation, jobs…)
- Natural gas for heating (wells, pipelines, laws, regs)
- Broadly, US on an energy-intensive path v. other countries with equivalent education, health, etc.
- But bicycles in Amsterdam? Subway in London?

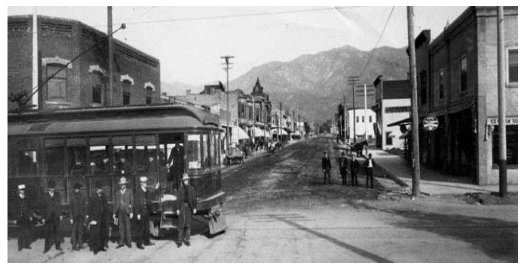
So energy systems can't be changed?

(1)

(2)

(3)

(4)



- Has been done, can be done, despite clear "lock-in" effects
  - Sometimes just takes R&D – sail to steam, gas to electric lights, coal to diesel locomotives
  - Sometimes takes changes in policy – interstate highway system, limited liability for nukes, environmental policy hitting coal generation
  - Often new systems face <u>chicken-egg problems</u>: lights for electricity, roads for cars, stations for natural gas cars

(1) Image by Fitz Hugh Lane http://upload.wikimedia.org/wikipedia/commons/f/f4/Clipper_Ship_Southern_Cross_Leaving_Boston_Harbor_1851.jpeg> on Wikimedia Commons.

(2) Photo by Schwede66 <http://upload.wikimedia.org/wikipedia/commons/2/22/Gas_Light_03.JPG> on Wikimedia Commons.

(3) Photo by NekoJaNekoJa <http://upload.wikimedia.org/wikipedia/commons/5/5a/C623_Express_Niseko.JPG> on Wikimedia Commons.

(4) Photo courtesy of Los Angeles Public Library's Photo http://upload.wikimedia.org/wikipedia/commons/d/d2/Monrovia-1903.jpg> on Wikimedia Commons.