15-830 – Computational Methods in Sustainable Energy: Introduction

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September 11, 2012

- Why sustainable energy?

- Why computation?

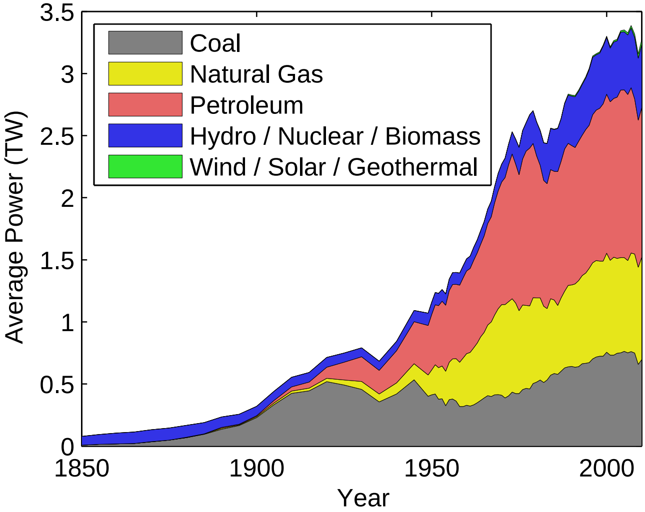
- What we will cover in this class

“Sustainable energy”

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

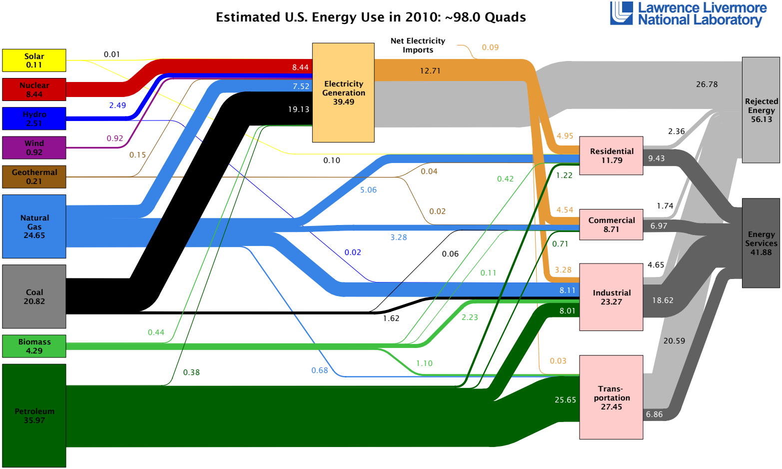
– UN Report “Our Common Future”, 1987

U.S. energy consumption



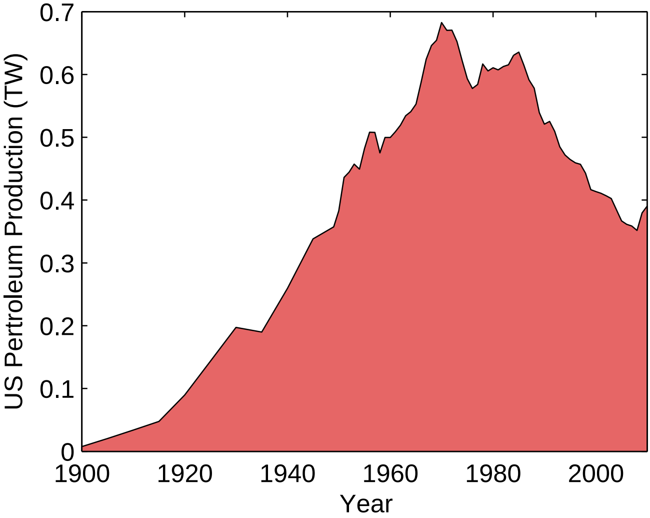
Data: U.S. Energy Information Administration

U.S. energy consumption



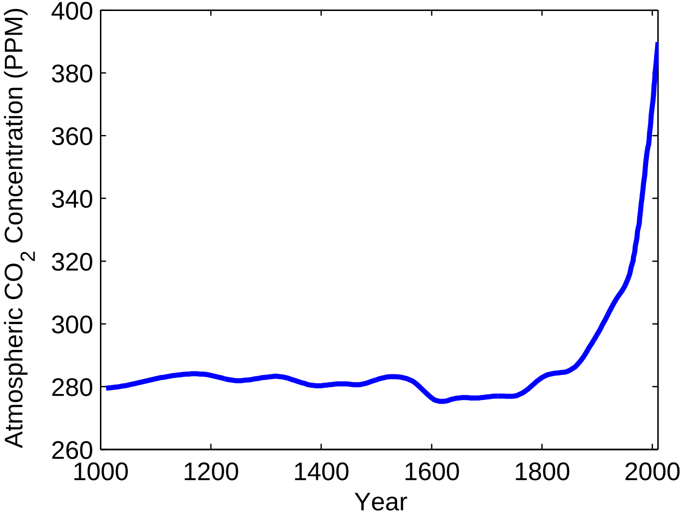
Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

U.S. petroleum production



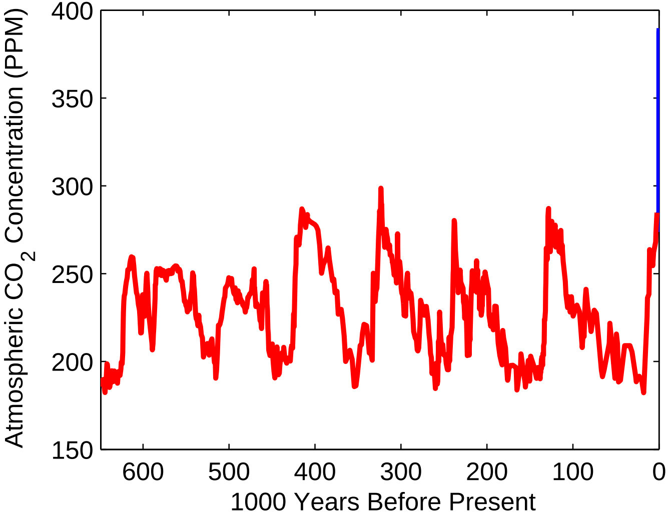
Data: U.S. Energy Information Administration

Atmospheric carbon dioxide



Data: NOAA and Eteridge et al., 1998

Atmospheric carbon dioxide



Data: Barnola et al., 2003, Siegenthaler et al., 2005

Climate change

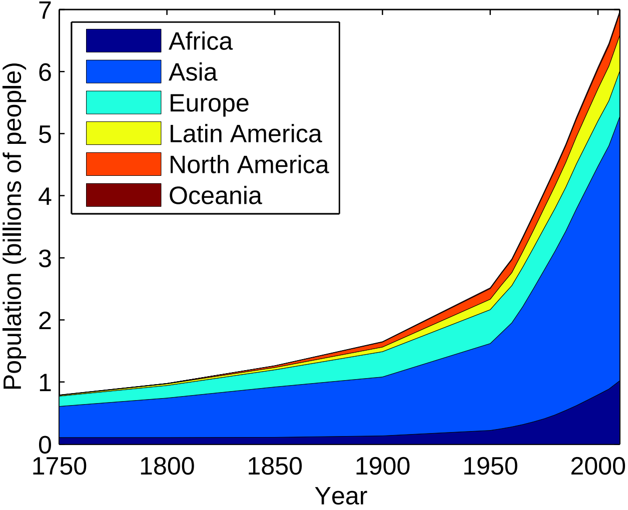
- Climate sensitivity

$$\Delta T_{2x} \equiv \text{"Temperature increase from doubling } CO_2\text{"}$$

- "Climate sensitivity is likely to be in the range of 2 to 4.5°C with a best estimate of about 3°C and is very unlikely to be less than 1.5°C" — IPCC 2007 Synthesis Report

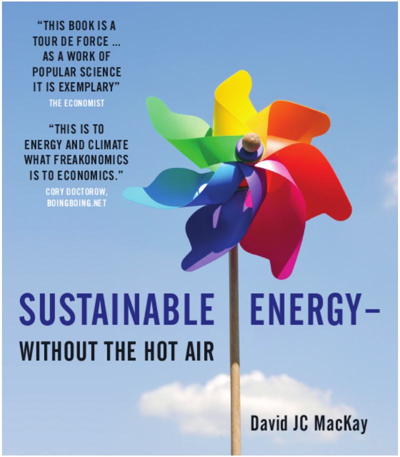
- $\Delta T_{2x} \begin{cases} \text{33-50\% from } CO_2 \\ \text{50-66\% from feedbacks (largely water vapor)} \end{cases}$

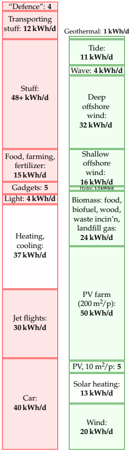
World population



Data: U.S. Census Office, 2010

For additional discussion...



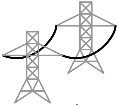


http://www.withouthotair.com

Why computation?

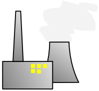
83m residential and
5m commerical/
industrial buildings
(768 GW peak
demand)

30m installed
smart meters

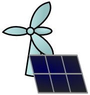


172k miles of
transmission
lines

You: need to
supply power
to the country



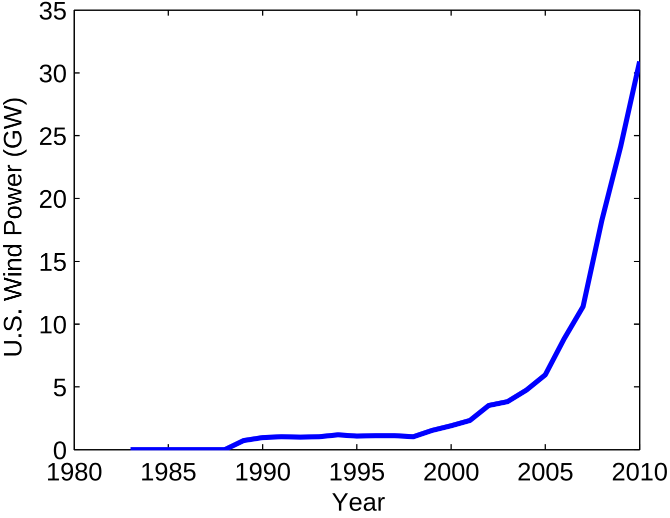
5,500 power
plants (925
GW capacity)



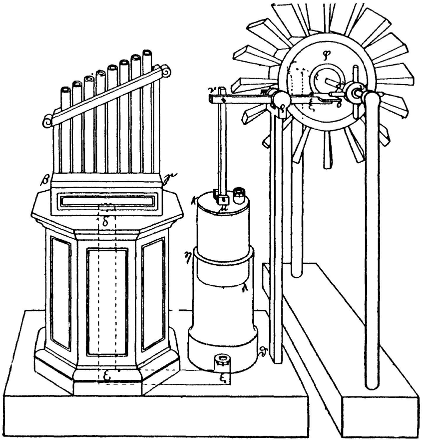
49 GW of
installed wind/
solar capcity

Data: U.S. Energy Informational Administration, 2010 U.S. Census, Institute for Electric Efficiency, Argonne National Labs

The rise of wind power



Data: U.S. Energy Information Administration



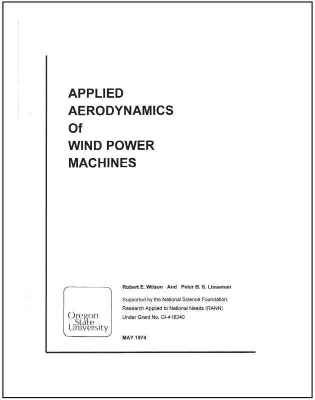
Heron's Windwheel, 1st century AD

Smock Mill, 1802; Photo: L. Chatfield

Smith-Putnam 1.25 MW Turbine, 1941-1945

UMass WF-1 Turbine, 1975

- Optimal blade shape
- Variable speed operation
- Power control via pitch
- Computer controlled


APPLIED
AERODYNAMICS
Of
WIND POWER
MACHINES

Oregon State University

Robert E. Wilson And Peter B. S. Lissaman

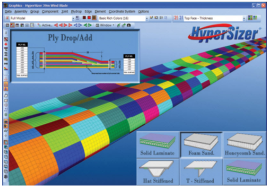
Supported by the National Science Foundation,
Research Applied to National Needs (RANN)
Under Grant No. GI-418340

MAY 1974

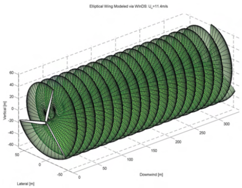
Wilson and Lissaman, 1974

"The advent of the digital computer makes the task of preparing general performance plots of wind machines easy."

GE 100-2.5 Turbine



Collier, 2010

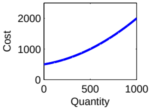
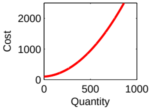


Sebastian and Lackner, 2010

The emergence of power markets

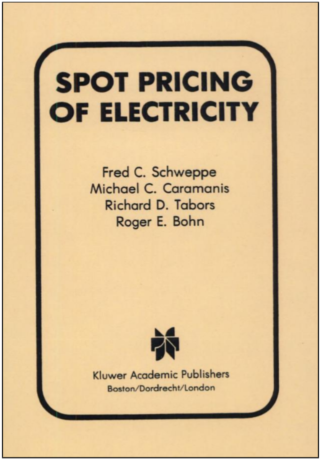
- 1935 – Public Utility Holding Company Act (PUHCA)
- 1992/2005 – PUHCA repealed, (ideally) opens competition in power generation

Typical Market

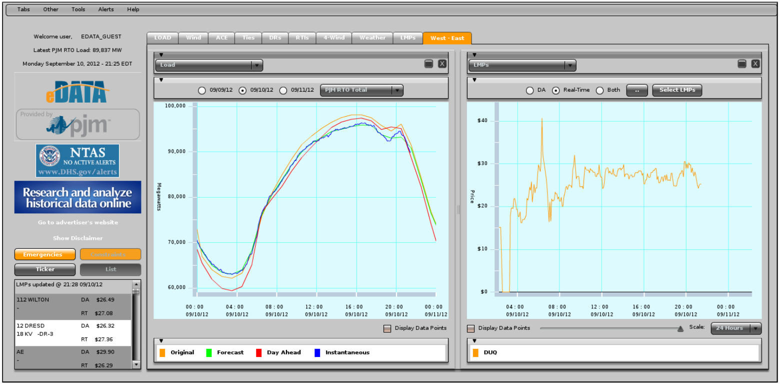
Producer 1	Producer 2
	
Consumer: wants 1000 units	

Power Market

- No time to wait for bidding system
- No way to store significant energy (yet?)
- Constraints of transmission grid



Schweppe et al., 1988



PJM (Pennsylvania's regional transmission operator) website

Solving large non-convex optimization problems once every five minutes to determine energy production/distribution

Overview of course topics

Modeling / prediction

Control

Unknown / hard to model elements: Machine learning

Physically well-understood elements: Electric power systems

- Applications
  - electrical demand prediction, renewable resource availability, building energy consumption, power flow, power markets and economics, distributed storage and control, ...
- Algorithms
  - linear and non-linear regression and classification, convex optimization, time series prediction, Newton's method, model predictive control, mixed-integer programming, ...
- Algorithms applied to *real-world* data in these domains, and a focus on *implementation*

Class prerequisites

- Some programming experience, ideally in MATLAB

```
P = [0 0; 0.5 1; 1 0];
X = zeros(50000,2);
for i=1:size(X,1)-1,
  X(i+1,:) = 0.5*X(i,:) + 0.5*P(ceil(3*rand),:);
end
plot(X(:,1), X(:,2), 'b.');
```

- Basic knowledge of linear algebra

$$Ax - b + x = c,$$
$$x, b, c \in \mathbb{R}^n, \quad A \in \mathbb{R}^{n \times n}$$

- Review notes for both of these posted to course web site

Class organization

- 4 problem sets
  - ~2 programming assignments per problem set
  - ~2 extensions / challenge problems
- Final project
  - Written report (max 5 pages) on topic in computational approach to energy
  - Done in groups of 2-3
  - For 830, must be original research project, for 630 can be survey
  - Come to office hours (soon!) to discuss possible topics