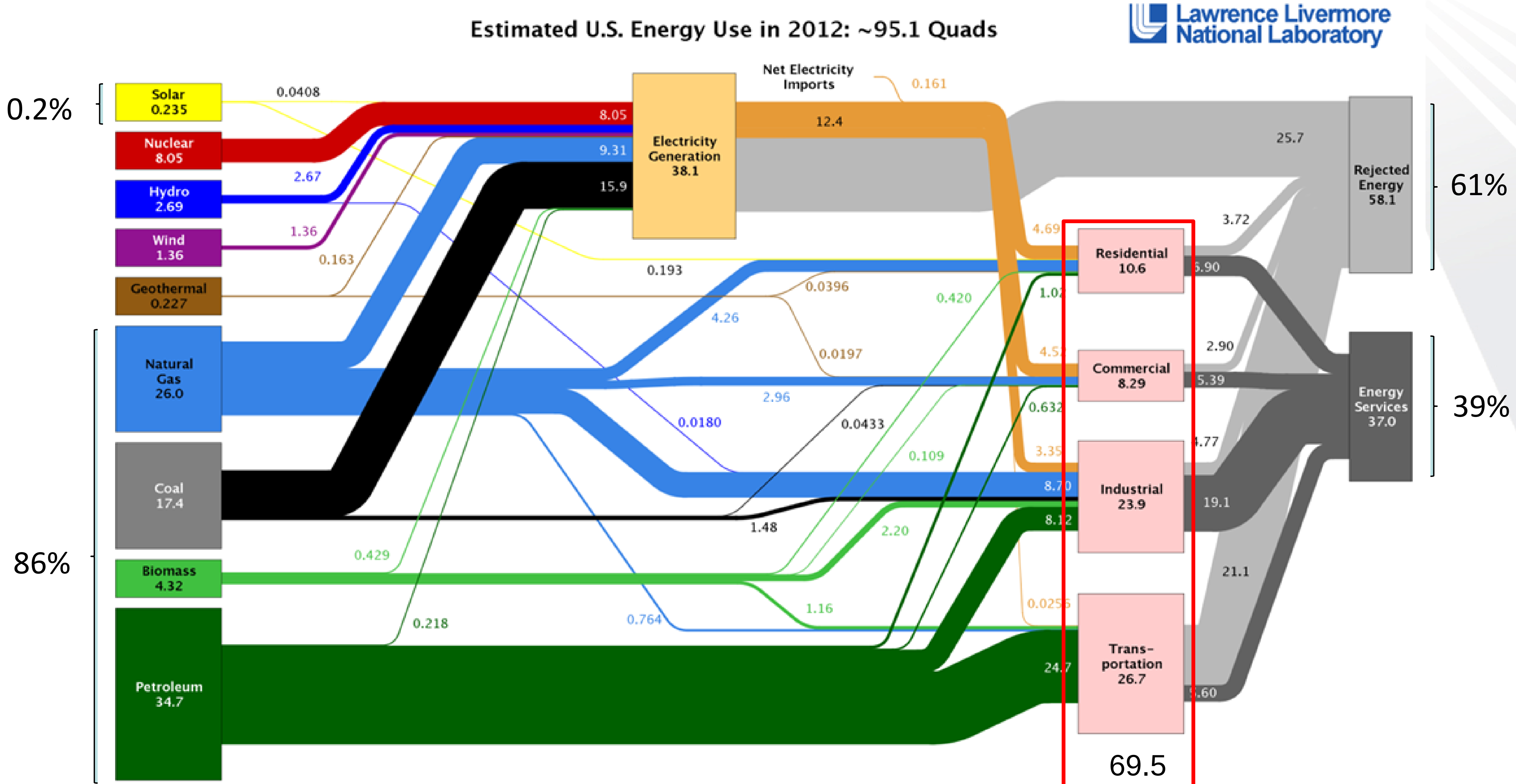
Should America Launch a Major Push Into Solar Energy?

Philip Dowd

For
Wanger Institute for Sustainable Energy Research
Chicago Council on Science and Technology
Chemical and Biological Engineering Dept, IIT

"The world receives more energy from the sun in one hour than the global economy uses in one year."



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. 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 consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." 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 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Objective

- Design a solar power plant that reliably delivers the electric energy equivalent of 70 quads to run the US economy for one year, or $56*10^{12}$ Wh (56 Terawatt hours) of electricity per day.
- That consists of
  - PV Power Plant
  - Battery
- Estimate cost of building the whole thing

The PV Power Plant

Assumptions:

- Locate in the Southwest
- Add a 50% safety factor, so

24 hour demand = 83 TWh/day

- Night time demand = ½ of 24 hour demand, or

41 TWh

Typical Solar Power Plant

Examples of Existing PV Power Plants

Facility	Location	Electricity Output/sq meter
Nellis AFB	Nevada	150 Wh/day
Beneixama	Spain	160
Serpa	Portugal	90
Solarpark Mühlhausen	Bavaria	68
Kagoshima Nanatsujima	Japan	170

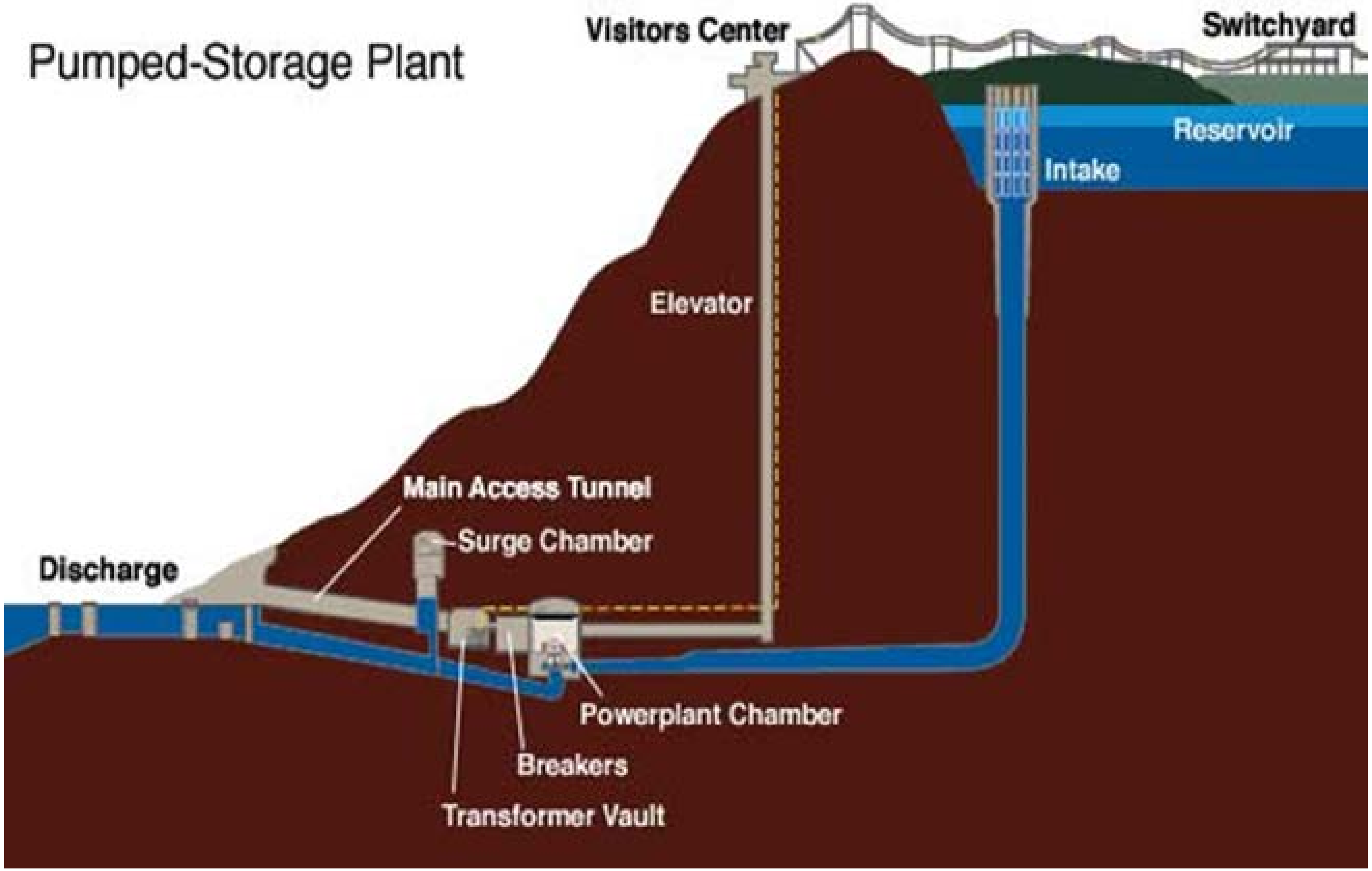
PV Power Plant Footprint

If assume 150 Wh/day-sq meter

Then, footprint = 83 TWh/day ÷ 150Wh/day-sq m

Which = **210,000 sq mi**

The Battery



Pumped-Storage Plant
Visitors Center
Switchyard
Reservoir
Intake
Elevator
Main Access Tunnel
Surge Chamber
Discharge
Powerplant Chamber
Breakers
Transformer Vault

Ludington Pumped Storage Plant, Ludington, MI

Seneca Pumped Storage Generating Station in Warren, PA

Yanbaru Seawater PSH Plant on Okinawa Island

Pumped Storage Hydro (PSH)

A proven technology

- 99% of bulk electric energy storage worldwide
- 50 currently operating around the world
- In 2009 US had 21 GW of PSH capacity
- Many operating more than 30 years

Examples of Existing PSH Facilities

	Capacity (MW)	Capital Cost ($2014/W)	Stored Energy (GWh)	Footprint (Acres)
Ludington, MI	1,872	0.98	25.5	1,000
Bath County, VA	3,000	1.40	43.0	820

The Battery

Number of “Bath-like” Facilities = 41 TWh ÷ 43 GWh = 953 ≈ 1,000

Footprint = 1,000 x 820 acres/facility ≈ 1,300 sq mi

What Would It All Cost?

The PV Power Plant

Capacity Req'd = 17 TW

Cost = $3.90/W

PV Power Plat ≈ $66 trillion

The PSH Battery

Capacity Req'd = night time demand ÷ 12 hrs

= 41 TWh ÷ 12 h

= 3.4 TW

Cost = $0.98/W - $1.40/W

Battery ≈ $4 trillion

Total ≈ $70 trillion

Summary

The Solar Power Plant

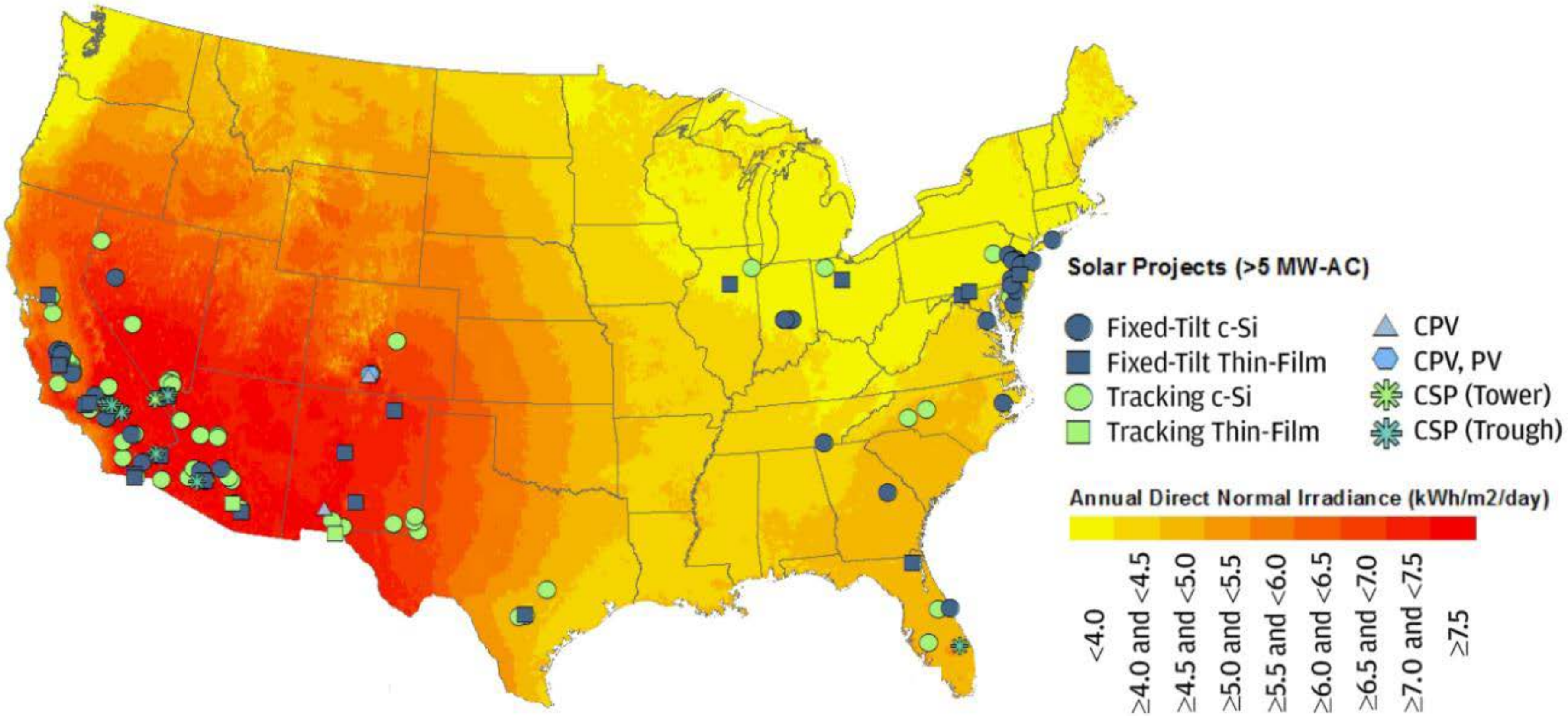
- Photovoltaic panels
- Approx 210,000 sq mi footprint
- $66 trillion to build (capex)

The Battery

- Pumped Storage Hydro
- Approx 2,000 sq mi footprint
- $4 trillion to build

Total Cost ≈ $70 trillion

A Few Comments



The power plant would cover about 50% of the Southwest!

A Few Comments

PV Panels on Houses

- 89 million houses in the US
- Assume 1,000 sq ft on each (20 ft x 50 ft)
- Total area ≈ 3,200 sq mi

A small fraction of what's needed.

A Few Comments

PV Capex Costs are Falling

- PV panel cost today = $ 0.74/W about 1/100 th of cost in 1977
- But, non-module cost now = 2/3 of power plant

A Few Comments

Your Capex Cost for PV Is Too High

- My cost = $3.90/W
  - Source: US Energy Information Administration
  - Based On: projects completed in 2013
- Oft Quoted cost = $1.75/W
  - Source: Lazard
  - Based On: projections for projects started in 2014

This whole exercise is based on <u>today's technology</u> and <u>today's costs</u>

A Few Comments

The battery stores only one night's worth of electricity

- If covered by clouds, PV output can drop 80%
- If our system covered by clouds, what then?
- Answer, either:
  - More storage
  - A backup system
- Backup system must be able to run 70-80% of the economy
- Backup = today's power grid (?) X4 (?)

A Few Comments

Other Costs to Solarize the US

- Electrify the economy
  - Transportation = 38% of current energy
  - Abandon the internal combustion engine
- Re-build and expand the national electrical grid
  - US currently = 3 grids (interconnections)
  - Max transit distance for electricity ≈ 300 mi
- Develop a computer network to control the whole system (“smart grid”)

A Few Comments

The Competition Is Gas

- My back-of-envelope design for solar PV power plant
  - Electricity only when the sun shines
  - So, you need a battery
  - Susceptible to the weather
  - Total cost to build ≈ $70 trillion

- A gas-fired power plant
  - Electricity rain or shine, day or night
  - Total cost to build ≈ $ 4 trillion

- This proposal ≈ 17 X the cost of the gas alternative

So What? We Can Do This.

We've done big projects before, for example:

- The Manhattan Project
  - Build the first atomic bomb
  - 1942 – 1946
  - Cost ≈ $ 26 billion in 2014 dollars
- Project Apollo
  - First man on the moon
  - 1961 – 1972
  - Cost ≈ $ 130 billion in 2014 dollars
- Interstate Highway System
  - Build 41,000 mi of freeway
  - 1956 – 1991
  - Cost ≈ $ 500 billion in 2014

What Did We Learn?

Keys To Big Project Success

1. A perceived threat or reward

2. A clear goal

3. Government money

What To Do?

Plan A

1. More R&D
   a. Double the efficiency of PV panels
   b. Reduce by ½ the cost of building PV power plants

Result: reduce capex to ¼ of original estimate or about $15 trillion

Then, and only then:

2. Raise capital to build with carbon tax of $ 1.25/gal of gasoline
   a. Currently burn about 135 billion gal

Result: $ 170 bil/yr or about 1% of current GDP

Assuming no further improvements in tech and cost, time to build ≈ 100 yrs

A Final Comment

Solar is good bet for the future, because the sun is:

1. An inexhaustible source of energy

2. Free

3. Available to everyone

A Final Comment

But, to get there, to move solar energy from 0.2 % of all energy use to almost 100%

- Much better solar tech
- Much lower costs to build it
- Electrify the entire economy, incl transportation
- National grid w/ long distance electricity transport
- Smart grid that cannot be hacked

Against

- stiff competition from low-cost fossilized carbon alternatives (e.g. gas)
- the public's lack of interest
- the government's lack of money

Questions?

http://www.iit.edu/wiser/news/seminar.shtml