Energy Options
For each energy source—
We need to understand:

What is the resource base?
What are the economic costs?
What are the geopolitical consequences?
What are the environmental consequences?
What is the role of public policy to ensure a sustainable outcome?
What are the world’s largest energy sources?

- Oil: 39%
- Coal: 25%
- Natural Gas: 22%
- Nuclear: 6%
- Hydroelectric: 4%
- Renewables: 2%
Worldwide Energy Consumption
Projected by Source - 2020

Today
- Petroleum: 39%
- Natural Gas: 22%
- Nuclear: 6%
- Coal: 8%
- All Renewables: 25%

2020
- Natural Gas: 26%
- All Renewables: 23%
- Petroleum: 38%
- Coal: 8%
- Nuclear: 5%

Fossil and Nuclear Power Remain as World’s Primary Energy Sources
Growing Electric Demand by World Region

Annual Generation

Source: UDI, IEA, EM Forecast

Fuel Inputs

2030 Share

Source: UDI, IEA, EM Forecast
Petroleum

Remember these words:
Geopolitics
Depletion
The scale of the world’s fossil fuel infrastructure is vast.
Energy is the largest, most capital-intensive industry in the world.
Global Conventional Oil Reserves (2004 %)

Source: Oil and Gas Journal, 2005
Access to World’s Proved Oil and Natural Gas Reserves

- **65%** Controlled by governments; not open to Western companies
- **16%** Russian reserves, held by Russian companies
- **12%** Controlled by governments; limited access for Western companies
- **7%** Open to any oil company

Source: PFC Energy research, based on BP’s 2005 Statistical Review of World Energy
From Ball (2006)
map of proved oil reserves at end 2001

Thousand million barrels

Middle East 685.6

Europe 18.7
Asia Pacific 43.8
North America 63.9
Former Soviet Union 65.4
Africa 76.7
S. & Cent. America 96.0

bp statistical review of world energy 2002
Worldwide Oil Production

- Discoveries in billions of barrels:
  - 1930: 10
  - 1940: 15
  - 1950: 20
  - 1960: 25
  - 1970: 30
  - 1980: 35
  - 1990: 40
  - 2000: 45
  - 2010: 50

- Production in billions of barrels:
  - 1930: -10
  - 1940: -15
  - 1950: -20
  - 1960: -25
  - 1970: -30
  - 1980: -35
  - 1990: -40
  - 2000: -45
  - 2010: -50

We Are Here
GONE: 70% OF U.S. OIL HAS BEEN USED.
IT'S HISTORY.
US Oil - If you think of the original U.S. oil endowment as a six pack, four of the cans are empty. Two remain for all future generations of Americans.
When considering unconventional oil

- Oil shale ("Colorado has more fossil fuel than Saudi Arabia")
- Tar sands (Canada)
- Heavy oil (Venezuela)
- Coal to liquids (US, China, South Africa, etc.)

Consider:

Energy Return on Energy Investment?
Carbon dioxide?
Capital required?
Environmental outcome?
Resource Triangle

Conventional Reservoirs
Small volumes that are easy to develop

Unconventional
Large volumes that are difficult to develop

Increased pricing
Improved technology

High-Medium Quality

Low Perm Oil
Gas Shales
Heavy Oil

Tight Gas Sands
Coalbed Methane
Oil Shale

Gas Hydrates
Tar Sands
Tar Sands
Big “public education” campaign under way by corn growers in the US
Coal provides 25% of the world’s energy
We have 250 years of domestic coal!

• And in the small print:

  – “At the current level of consumption.”

• Oh….. Okay.

• So, it’s more like 75 years, right?
Natural Gas supplies 22% of world energy
“The Rockies are the Saudi Arabia of Natural Gas”
Global Natural Gas Reserves

- Former Soviet Union: 41%
- United States: 3%
- Arab Nations: 32%
- Mexico: 1%
- Rest of World: 22%
- Canada: 1%

Global Natural Gas

![Graph showing the production of conventional and non-conventional natural gas over time from 1930 to 2050. The graph indicates a significant rise in production from 1970 onwards, with a peak around 2010, followed by a decline towards 2050. The areas under the curves represent the cumulative production of conventional and non-conventional natural gas. The legend indicates that the lighter shaded area represents conventional natural gas, and the darker shaded area represents non-conventional natural gas.]
So, your curve:

**U.S. NATURAL GAS PRODUCTION**

Source: Solar Today Jul-Aug 01

![Graph showing U.S. Natural Gas Production](image)

- Peak 1973
- All this gas is gone

Trillion Cubic Feet/Year

1949 54 59 64 69 74 79 84 89 94 1999
Qatar has more natural gas reserves than North America. With proven reserves of 509 trillion cubic feet (Tcf), Qatar 's natural gas resources rank third in size behind Russia 's and Iran 's.
Import our gas from Russia and the Middle East? What choice do we have?
Proposed US Regasification Terminals

Source: FERC
Gas resource and transport issues

*Figure 3.12: Net Inter-regional Natural Gas Trade Flows, 2000 (bcm)*

Gas resource and transport issues

Figure 3.13: Net Inter-Regional Natural Gas Trade Flows, 2030 (bcm)
Hydroelectric
Hydroelectric plants provide 6% of the world’s energy supply.
Nuclear Fission
Nuclear fission provides 6% of the world’s energy.
Concerns

Accidents
- Chernobyl, Three Mile Island

Diversion of nuclear fuel for nuclear weapons
- North Korea, Iraq, Iran

Disposition of spent fuel
- Yucca Mountain

Financial Cost
Major Uranium Producers

Australia, Canada, China, Kazakhstan, Namibia, Niger, Russia, Uzbekistan
Welcome to Peak Uranium

- World uranium production is expected to peak in the next 15 years.
- After that--- welcome to the plutonium economy.
Nuclear power has gone from:

- "too cheap to meter," starting in the 1950s
- "too expensive to matter," since the 1980s

**NOW:**
Xcel Energy CEO Richard Kelly 2/24/07:

"Comparing a new nuclear plant to Xcel’s new Comanche unit near Pueblo, which will cost about $1 billion, a new nuclear plant could cost seven times that amount and take as many as a dozen years to complete."
Geothermal Power
Ocean Power Concept
Tidal Power Concept
Australia and California have recently introduced legislation to ban the incandescent light.
Renewable Energy
Renewable Energy Resources

Solar

Wind

Biomass

Geothermal

- Wind Speeds:
  - 6.0-6.5 m/s: 13.4-14.6 mph
  - 6.5-7.0 m/s: 14.6-15.7 mph
  - >7.0 m/s: >15.7 mph

- Solar Energy:
  - Megajoules/m²

- Biomass:
  - Agricultural resources
  - Agricultural & wood residues Low inventory

- Geothermal:
  - Temperature <90°C
  - Temperature >90°C
  - Geopressed resources
Renewable Energy Cost Trends

Levelized cents/kWh in constant $2000¹

Wind

PV

Geothermal

Solar thermal

Biomass

Source: NREL Energy Analysis Office
¹See attached slides for background information.
Updated: June 2002
Cost of Wind Energy Trend

1979: 40 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

2000: 4 - 6 cents/kWh

NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

2004: 3 - 5 cents/kWh
GE WindEnergy
3.6 MW
Prototype
Turbine in Spain
Each day, more energy falls to the earth from the sun's rays than the total amount of energy the planet's 6.3 billion inhabitants would consume in 27 years.
Concentrating Solar Power

In the Mohave Desert since 1995, and within five years, likely coming to the San Luis Valley
Photovoltaics: From Space to Earth

From $100/watt in 1970 to $4/watt today.
Needs to get to $1/watt
to get to the proverbial “tipping point.”
Look where they placed this 1.4 MW installation in Neustadt, Germany..............
Neatly tucked in next to a runway at a regional airport
Kyocera’s roof mount type (for the Japanese market)
9 x 175 W modules = 1,575kW

Up 28.0 percent

HEYBAN (for the Japanese market)
16 x 51 W modules, plus
30 x 40 W modules = 2,016kW
The Renewable Hydrogen Economy
Intermittent Renewables

Constant Demand
Energy storage can mitigate intermittency

Any renewable based energy scheme must have integrated energy storage before it can become a viable, sustainable energy system.

- Hydrogen
- Biofuels
- Batteries
- Pumped Hydro

- Compressed air
- Flywheels
- Superconductivity
- ....
Hydrogen Economy
Closed Energy Cycle

Inputs:
Solar Energy and Water

Outputs:
Electricity, Heat and Water

Oxygen

Stored Hydrogen

Water
Renewable Hydrogen Production

- H₂ from Algae
- H₂ from Bacteria
- H₂ from Bio-Oil Reforming
- H₂ from Solar Electric Chemical
- H₂ from Solar Thermal Decomposition of CH₄
- H₂ Storage
Illustrative Hydrogen Content of Fuels

- **Wood**
  - Carbon
  - Hydrogen ($H_2$)

- **Coal**
  - Carbon
  - Hydrogen ($H_2$)

- **Oil**
  - Carbon
  - Hydrogen ($H_2$)

- **Gas**
  - Carbon
  - Hydrogen ($H_2$)

- **Hydrogen**
  - Carbon
  - Hydrogen ($H_2$)
Burn the hydrogen, not the carbon.
Sustainable Paths to Hydrogen

- Solar Energy
  - Heat
  - Mechanical Energy
  - Electricity
  - Conversion
- Biomass
- Thermolysis
- Electrolysis
- Photolysis

Hydrogen
Can we meet the challenge?
1830: “Rail travel at high speeds is not possible because passengers, unable to breathe, would die of asphyxia.”

– Dionysius Lardner, Professor of Natural Philosophy and Astronomy at University College, London, and author of “The Steam Engine Explained and Illustrated”
1864: “No one will pay good money to get from Berlin to Potsdam in one hour when he can ride his horse there in one day for free.”

–Kaiser Wilhelm I of Prussia
1933: “There will never be a bigger plane built.”

– A Boeing engineer at the launch of the ten-seater Boeing 247
1977: “There is no reason anyone would want a computer in their home.”

– Ken Olson, president, chairman and founder of Digital Equipment Corp.
The Only Constant is Change
The calculator retailed for $400 when first introduced.
Things Change
Change is created through:

Leapfrog Technology
Honda Motor Enters Solar Cell Market

“We are serious about solar cells, and in the future will be making hydrogen with them,” said Takeo Fukui, president and chief executive officer (CEO) of Honda Motor Co Ltd of Japan.
Plug in hybrid vehicle powered up by a green grid (dominated by wind power)

Breakthroughs are needed in advanced battery technology
The Founders of Apple Computer:

Steve Wozniak and Steve Jobs
in Jobs’ garage - 1976
Google co-founders Larry Page and Sergey Brin
Conclusion:

Crash Program Needed: Renewable Economy
The Apollo Project

On July 20, 1969, the impossible dream came true. After 8 years, and $24,000,000,000, the Apollo XI landing craft made a perfect landing on the moon in the Sea of Tranquility.
Kissinger: “Strategy, Mr. President. Strategy.”
The Lessons of History.....

• “We can no longer afford to ignore the reality that we have fixed resource boundaries, and that radical changes in our oil-based economy cannot be denied any longer. The era of cheap, abundant oil is over, and the sooner we accept this fact, the sooner we can get on with the task of developing alternative energy sources.”

• Former Secretary of Defense William Cohen, December 22, 1973
It has been done before. We can do it now.
Thank you!