ENERGY in the 21st Century: Need for bold thinking & action

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Special thanks to
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The scale of global energy needs and the associated infrastructure is mind-boggling.

The pace of change of resource availability and competition necessitates new paradigms.
Energy and potable water are two key resources necessary not just for development but for preserving the modern way of life itself.
Correlation between energy use and wealth

Mean Power Consumption Per Capita, kW/person

Mean Gross Domestic Product Per Capita ($/yr•person)

POVERTY

AFFLUENCE

SLOPE = 23¢/kW•hr

Bangladesh

U.K.

Japan

France

U.S.A.

U.S.S.R.

Poland

Mexico

South Korea

China

SLOPE = 23¢/kW•hr
NEED 3X

To sustain 8 billion people expected by 2025 @ 5 kw/person we will need >3 times today’s (12Tw) power
2% growth in world primary energy consumption

World primary energy consumption grew by 2.9% in 2003, well above the 10-year trend growth rate of 1.7% per annum. As in 2002, the global figure was heavily influenced by China, where reported energy use increased by almost 14%.

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# Energy Profile
*(Share of total energy)*

<table>
<thead>
<tr>
<th>Country Region</th>
<th>Oil %</th>
<th>Gas %</th>
<th>Coal %</th>
<th>Hydro %</th>
<th>Nuclear %</th>
<th>Other %</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>19.9</td>
<td>2.8</td>
<td>55.9</td>
<td>2.1</td>
<td>0.4</td>
<td>18.9</td>
</tr>
<tr>
<td>India</td>
<td>21.1</td>
<td>4.4</td>
<td>33.8</td>
<td>1.2</td>
<td>0.9</td>
<td>38.6</td>
</tr>
<tr>
<td>EU</td>
<td>40.6</td>
<td>23.2</td>
<td>14.6</td>
<td>2</td>
<td>15.6</td>
<td>4.0</td>
</tr>
<tr>
<td>USA</td>
<td>39</td>
<td>24</td>
<td>23</td>
<td>3</td>
<td>8</td>
<td>3.0</td>
</tr>
</tbody>
</table>

1 ton of oil (7.33 barrels) → 4.5 megawatt hour in modern plants
1 ton of hard coal → 3.0 megawatt hour
1 ton of gas (1380 m³) → 9.0 megawatt hour in CCPP

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**21st century: a time of transition**

- Fossil fuels, along with hydro and nuclear, fueled the 20th century.
- The “other” fuels of 20th century are going to be the fuels by the 22nd century (possibly well before).
- The first half of 21st century is key to this transition.
- The questions today are
  - What is the “other”
  - How to pick winners in the mix that defines “other”
  - How to grow these within the context of the existing enormous fossil energy infrastructure.
Consumption of fossil fuels: The holes we are digging

- **OIL**: 82 million barrels/day
- **GAS**: 260 billion cubic feet/day
- **Coal**: 13.7 million tons/day

- **OIL**: $1.7 \times 1.7 \times 1.7$ km³/year
- **GAS**: $1.7 \times 1.7 \times 1.7$ km³/year (as liquid)
- **COAL**: $1.6 \times 1.6 \times 1.6$ km³/year

**CO₂ Sequestration needs roughly 3 times the mass/volume**
What is driving change

- **OIL**: Global oil production is expected to peak by 2010 while demand is increasing at ~2%!
- **NATURAL GAS**: expected to peak by 2025
- **COAL**: pollution → global climate change
- > 65% of remaining oil and gas reserves are in the Middle East and Russia
- USA will face increasing competition for oil and gas from China, India, Europe, …
- Business as usual: nuclear+solar+wind cannot cover expected shortfall in next 10 years

No good alternative to oil for Transportation
Huge inertia in energy sector

- Oil contracts, rigs, exploration technology
- Tankers and pipelines
- Refineries
- Auto industry
- 600 million cars running on gasoline
- Service stations and gasoline stations
- Existing coal/gas electricity generation plants

The existing investment of >$10 trillion in oil cannot be changed overnight
US Oil Consumption (million barrels per day)

EIA, Annual Energy Outlook 2001; "Potential Oil Production from the Coastal Plain of ANWR," - EIA Reserves & Production Division

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Energy Use


Largest increase is in transportation, where there is scope for very significant increase in efficiency.
The problem: R/P timeline

At current production levels U.S. proved coal reserves would last over 250 years

Data Source: BP, 2004
We are increasingly dependent on imports for both oil and gas.

**U.S. Oil Consumption Will Continue to Exceed Production**
(Millions of Barrels per Day)

Over the next 20 years, U.S. oil consumption will grow by over 6 million barrels per day. If U.S. oil production follows the same historical pattern of the last 10 years, it will decline by 1.5 million barrels per day. To meet U.S. oil demand, oil and product imports would have to grow by a combined 7.5 million barrels per day. In 2020, U.S. oil production would supply less than 30 percent of U.S. oil needs.

Source: NEP May 2001

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Key Questions

• Can we continue to consume and assume that alternatives will be in place in time?

• Should change be left to market forces?
  – Higher gas prices → people buy more fuel efficient cars and drive less
  – Declining oil and gas → switch to [clean] coal and non fossil sources

• What new technology should we push?

• How real are the possibilities of major disruptions due to global climate change?
Overall Message

A national “Manhattan/Man on the Moon” program to

• Switch power generation to clean coal & gas, nuclear and renewables
• Develop carbon capture and storage
• Improve fuel efficiency in transport
• Modernize transmission infrastructure
• Develop alternate storage technology
• Preserve oil for future needs in industrial processes and petrochemicals
**Message**

- There is no one solution
- There is no easy solution
- Solution: accumulation of many changes

The important question is whether we want a planned solution or a forced upon solution.

*Source: An and Sauer, Pew Center*
KEY IMMEDIATE QUESTION?
Is there abundant oil remaining?

Or are alarmists crying wolf again?
If oil reserves are finite, has time run out?

Debate: are there 1.0 or 1.7 tera barrels of recoverable oil remaining globally?

Unfortunately, the difference buys the world only 20 more years at current rates of withdrawal!
What has changed since 1970s

• Much more of the world has been surveyed extensively for oil and gas
• Many large oil fields are in decline.
• Saturation of refining and shipping capacity
• Recent rapid growth and competition from China, India, and other developing regions
• Most of the excess capacity is in very unstable and volatile parts of the world – Middle East, Russia, Central Asia, Africa, Latin America
Are oil and gas reservoirs finite?
Biotic formation of oil and gas

• Animal and plant biomass collected over 100s of millions of years in sedimentary layers
• Biomass in source rock between 7500 (82°C) - 15000 (145°C) feet depth “cracks” into oil. At further depth it gets cooked into methane.
• Source rock must be porous and permeable
• Cap rocks prevent oil from seeping up → Fields

Except for South China sea, most regions very well mapped
Recovery of oil/gas is not a mystery

We know the initial part of the curve for most fields/regions

We don’t fully know the area under the curve = Total oil

Technology, $, Economics can extend the peak by boosting recovery rates
A nation can buy some time only if there is excess capacity globally.
Demand is increasing at ~2%
Many fields/regions are in decline
Supply gap will open after peak
Production decreases rapidly after Hubbert’s Peak (2005-09)
A well understood example: North Sea Oil

Peaked in 1999 at 5.94 million bbl/day.
1999-2003: average decline at 2.8% to 5.33 million bbl/day

Source: EIA North Sea summary, BP statistical review 2004
How long will the fuels last?

**R/P method**
- OIL: 40 years
- GAS: 65 years
- COAL: 200 years
- Uranium: 5-25 years if used to supply all the power (10 Twatts)

**Hubbert’s Peak**
- OIL: Decline after ~2006
- GAS: Decline after ~ 2025
- COAL:
- Uranium:

• What will be the impact on the environment?
• What will be the geopolitical implications?
• How to preserve quality of life post oil & gas?

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Reserves/Production timeline

January 1, 2004 Crude Oil Reserves and 2003 Crude Oil Production

Source: EIA

*includes non-conventional
Nations will face decline in production and not an sharp cutoff
Depletion of reserves by 2030

- **OIL:** 84%
- **GAS:** 64%
- **Coal:** 25%

US accounts for ~25% of world consumption

Source: EIA 2003
Tough questions for policy makers

• When will a given fossil fuel end?
• When will production decline?
• What alternate sources can cover the decline?
• What new technologies will come into play?
• What policies and incentives will facilitate a smooth transition? Spur new technologies?
• Can we simultaneously have more energy, less pollution and prevent global climate change?
• What patterns of consumption will we need to change? Forgo?
Examine energy futures from three perspectives

• National and International security
• Economic development
• Environment

**NEED for timely action:** Investment in power systems is recuperated over 40-70 years. It takes 10-15 years to change the system or develop new capacity. Planning and execution has to happen decades before need.
National and International Security
National and International Security

• Energy is essential for economic development
• Predictable access to energy is key to long term stability, security, prosperity of nations
• Geographical location of energy matters ⇒ treaties and cooperation or war between nations
Key Factors in Energy Security

- Domestic production capacity and mix
- Dependence on imports
- Degree of import concentration
- Stocks and strategic petroleum reserves
- World excess capacity
- Geographical distribution & competition
- Improving efficiency

Source: James L. Williams and A.F. Alhajji, www.wtrg.com
OIL

No viable substitute yet for oil in transportation sector

Light oil is mostly alkanes $C_nH_{2n+2}$ and alkenes $C_nH_{2n}$
Top World Oil Producers (>2 M bpd), 2003**  
*(OPEC members in red)*

<table>
<thead>
<tr>
<th>Country</th>
<th>million bpd</th>
<th>Export</th>
<th>Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Saudi Arabia</td>
<td>9.95</td>
<td>8.38</td>
<td></td>
</tr>
<tr>
<td>2) United States</td>
<td>8.84</td>
<td></td>
<td>11.1</td>
</tr>
<tr>
<td>3) Russia</td>
<td>8.44</td>
<td>5.81</td>
<td></td>
</tr>
<tr>
<td>4) Iran</td>
<td>3.87</td>
<td>2.48</td>
<td></td>
</tr>
<tr>
<td>5) Mexico</td>
<td>3.79</td>
<td>1.74</td>
<td></td>
</tr>
<tr>
<td>6) China</td>
<td>3.54</td>
<td></td>
<td>2.00</td>
</tr>
<tr>
<td>7) Norway</td>
<td>3.27</td>
<td>3.02</td>
<td></td>
</tr>
<tr>
<td>8) Canada</td>
<td>3.11</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>9) United Arab Emirates</td>
<td>2.66</td>
<td>2.29</td>
<td></td>
</tr>
<tr>
<td>10) Venezuela</td>
<td>2.58</td>
<td>2.23</td>
<td></td>
</tr>
<tr>
<td>11) United Kingdom</td>
<td>2.39</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>12) Kuwait</td>
<td>2.32</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>13) Nigeria</td>
<td>2.25</td>
<td>1.93</td>
<td></td>
</tr>
</tbody>
</table>

Source: EIA, BP

**Total Oil Production includes crude oil, natural gas liquids, condensate, refinery gain, and other liquids
<table>
<thead>
<tr>
<th>2002 rank</th>
<th>Country</th>
<th>2002 proved OIL reserves (billion barrels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Saudi Arabia</td>
<td>261.7</td>
</tr>
<tr>
<td>2.</td>
<td>Iraq</td>
<td>115.0</td>
</tr>
<tr>
<td>3.</td>
<td>Iran</td>
<td>99.1</td>
</tr>
<tr>
<td>4.</td>
<td>Kuwait</td>
<td>98.9</td>
</tr>
<tr>
<td>5.</td>
<td>United Arab Emirates</td>
<td>62.8</td>
</tr>
<tr>
<td>6.</td>
<td>Russia</td>
<td>53.9</td>
</tr>
<tr>
<td>7.</td>
<td>Venezuela</td>
<td>50.2</td>
</tr>
<tr>
<td>8.</td>
<td>Libya</td>
<td>30.0</td>
</tr>
<tr>
<td>9.</td>
<td>Nigeria</td>
<td>30.0</td>
</tr>
<tr>
<td>10.</td>
<td>China</td>
<td>29.5</td>
</tr>
<tr>
<td>11.</td>
<td>USA</td>
<td>22 (2004 end)</td>
</tr>
</tbody>
</table>

Source: EIA, BP

- Middle East
- Exporters
- Importers
Middle East: 2.5 M barrels  
Africa: 2.0 M barrels  
Venezuela: 1.5 M barrels  
Canada: 1.8 M barrels  
Mexico: 1.4 M barrels  
North Sea: 0.9 M barrels  
Far East: 0.4 M barrels  
Soviet Union: 0.1 M barrels
Production, Discovery, Excess

- Many of the larger oil fields are in decline
- Discovery is of smaller fields and in less accessible areas
- World consumption is increasing at ~2%
- In early Sept. 2004, excess world oil production capacity fell to 0.5-1.0 M b/d, all of which was in Saudi Arabia.
Production, Discovery, Excess

The price of all oil is decided by the last barrel sold

Past discovery based on ExxonMobil (2002). Revisions backdated

C. Campbell
Crude oil prices since 1861

Source: BP 2004

1861-1944 US average.
1945-1983 Arabian Light posted at Ras Tanura.
1984-2003 Brent dated.
Increased volatility and high prices post 2004?

US dollars per barrel

World events

- Sumatra production begins
- Russian oil exports begin
- Growth of Venezuelan production
- Fears of shortage in USA
- Loss of Iranian supplies
- Post-war reconstruction
- BP 2004

- Discovery of Spindletop, Texas
- East Texas field discovered

BP 2004

1861-1944 US average.
1945-1983 Arabian Light posted at Ras Tanura.
1984-2003 Brent dated.
Natural Gas

- Methane \( \text{CH}_4 \)
- Ethane \( \text{C}_2\text{H}_6 \)
- Propane \( \text{C}_3\text{H}_8 \)
- Butane \( \text{C}_4\text{H}_{10} \)
<table>
<thead>
<tr>
<th>2002 rank</th>
<th>Country</th>
<th>2002 proved GAS reserves (trillion cubic feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Russia</td>
<td>1,700.0</td>
</tr>
<tr>
<td>2.</td>
<td>Iran</td>
<td>939.4</td>
</tr>
<tr>
<td>3.</td>
<td>Qatar</td>
<td>757.7</td>
</tr>
<tr>
<td>4.</td>
<td>Saudi Arabia</td>
<td>228.2</td>
</tr>
<tr>
<td>5.</td>
<td>United Arab Emirates</td>
<td>204.1</td>
</tr>
<tr>
<td>6.</td>
<td>United States</td>
<td>183.5 @ 22Tcf /per year</td>
</tr>
<tr>
<td>7.</td>
<td>Algeria</td>
<td>175.0</td>
</tr>
<tr>
<td>8.</td>
<td>Nigeria</td>
<td>159.0</td>
</tr>
<tr>
<td>9.</td>
<td>Venezuela</td>
<td>149.2</td>
</tr>
<tr>
<td>10.</td>
<td>Iraq</td>
<td>112.6</td>
</tr>
</tbody>
</table>
Geographical distribution of oil, gas, and coal reserves matters and will matter more with time as reserves dwindle.
But by 2020

USA -,-,1
Russia -,-,1,2
China -,-,3
India -,-,4
EU -,-,6

Persian Gulf
OIL 1,2,3,4,5
GAS 2,3,4,5,10
No Coal

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Increasing competition for oil and gas

China and India are making deals with Iran, Sudan, …

Chinese imports jumped by ~1Mbo/per day in 2004!
Major oil trade movements

Trade flows worldwide (million tonnes)

USA  Canada  Mexico  S. & Cent. America  Europe & Eurasia  Middle East  Africa  Asia Pacific

BP 2004

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Major natural gas trade movements
Where will Russian oil and gas go?

- Center of oil field
- Center of gas field


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Energy
Which countries will get oil/gas in 10 years
The natural destination for Persian gulf, Caspian Sea and Russian oil and gas is EURASIA

But the US needs them too!

What role will pipeline, tanker, refining capacity play?
Without the infrastructure to liquefy Natural Gas (LNG) and ship it, the US cannot access global gas reserves.

At current rate of use (22 Tcf in 2003) the US reserves \(~(200+200)\) Tcf will last only 20 years by the R/P criteria.

New LNG facilities start operating in 2008.
Figure 42. Existing U.S. LNG Terminals and New Terminals Planned in North America

Source: Energy Information Administration.

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This global oil and gas situation has been anticipated by the US and it has guided its policies since WWII
Oil: key driver of foreign policy

• 1945
  – F. Roosevelt and King Abdel Aziz “oil for security”
• 1947: Truman Doctrine
  – Stop the spread of communism (Greece, Turkey, Iran)
• 1957: Eisenhower Doctrine
  – Protect friendly interests
• 1969: Nixon
  – Protect interests through surrogate friendly rulers
• 1980: Carter Doctrine
  – To protect Saudi Arabia and the free flow of oil from the Persian Gulf
• 1983: Establishment of Central Command
  – Protecting the free flow of oil from the Middle East and Central Asia
US bases in Middle East and Central Asia.
A very successful but costly military investment.
What is the true cost of USA’s thirst for oil?

• Should we continue to demand more?
• Use our military to guarantee supplies?
• Or use innovation (R&D) to reduce dependence on imported oil and gas and preserve reserves in our protected lands for the future?
• Or burn more coal?
COAL

• Mostly carbon
  – composition varies between C and CH
  – produces most CO$_2$ on burning
• Contains many pollutants
  – Sulfur $\rightarrow$ SO$_2$ $\rightarrow$ H$_2$SO$_3$
  – NO$_x$
  – Mercury
  – Arsenic
COAL is abundant

Based on 2001 production figures, global coal reserves will last about

- 207 years for hard coal
- 198 years for soft brown coal

We can lead the world by innovating clean coal technology for generating electricity

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90% of global coal reserves are in 10 countries.

Source: International Energy Outlook 2004
Clean Coal Initiatives

- Integrated Gasification Combined Cycle (IGCC)
- FutureGen
- Vision 21

- Multiple feedstock
- Higher efficiency (CC)
- Multiple products (modular)
- Zero CO2 and polluting emissions

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Energy
Clean coal technology has yet to be implemented.

What happens if conventional oil peaks in 2005, demand continues, and coal is used to cover the shortage?
Oil demand growth 2% /per year  
coal demand growth 1%  
Oil production decline 2%  
coal to oil to cover shortfall  

Oil produced = 1.05 trillion barrels between 2005-2055
The magnitudes are staggering but without clean coal we have an even bigger problem

Pollution and global climate change
Energy and Environment

Climate change is the largest and costliest uncontrolled experiment being done.
CO$_2$ concentrations over the last 1000 years. The rise since 1850 parallels the increase in emissions from fossil fuels.
CO₂ & Temperature History

Source: Petit et al., Nature 399 Vostok, Antarctica Ice Core data

Industrial age CO₂ increase

Temperature Changes (ºC)

CO₂ (ppmV)

Age (years)

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“Simulations of the response to natural forcings alone … do not explain the warming in the second half of the century”

“..model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this*period” - IPCC 2001
Thermohaline
Paleoclimatet
Can we reduce use of fossil fuel without stalling economic development?

Where are we headed?
World energy use?

- World energy use $\approx 1.2 \times 10^{17}$ watt-hour
- Per capita energy $\approx 2 \times 10^7$ watt-hour

- World Power $\approx 1.4 \times 10^{13}$ watts
- Per-capita power $\approx 2000$ watts

Total Electricity Use would be

$\approx 5$ times @ <USA>
$\approx 4$ times @ <G7>
$\approx 3.5$ times @ <OECD>

1 BTU = 1055 joules = 0.293 watt-hour
China and India are developing

<table>
<thead>
<tr>
<th>Year</th>
<th>China GDP (T)</th>
<th>India GDP (T)</th>
<th>China Oil (Mbo)</th>
<th>India Oil (Mbo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>$1.3T</td>
<td>$0.51T</td>
<td>4.92</td>
<td>2.3</td>
</tr>
<tr>
<td>2003</td>
<td>$1.4T</td>
<td>$0.6T</td>
<td>5.55</td>
<td>2.4</td>
</tr>
<tr>
<td>2004</td>
<td>$1.6T</td>
<td>$0.64T</td>
<td>6.63</td>
<td>2.6</td>
</tr>
</tbody>
</table>

And they want more oil and gas
Motor Vehicle Sales per Capita

Sales per Thousand People

- 1980
- 1990
- 1996
- 2001

China, India, South Korea, Brazil, United Kingdom, Germany, France, Japan, United States

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If we don’t want China, Pakistan, India, Bangladesh, Central Asia, Africa, … to fail, they need to develop

• If we want them to develop they must have energy!
• How much energy?
• How can we help them get clean energy?
What is the global mean energy/per capita we should aim for?

Japan, Germany, UK, France show a plateau at ~165 M btu/per capita → 5.5 kilowatt. The current global mean is ~2 kilowatt. How do we get it to 5.5kw?
NEED

- Cheap
- Clean
- Copious

ENERGY

How do we help tailor the right mix for a given nation?
In short all three

• National and International security
• Economic development
• Environment

Point to the same thing

1. Need to increase non-fossil sources in the mix
2. Clean use of fossil fuels
3. More efficient use of energy
4. Conservation of fossil fuels

Start major implementations of 1-4 now
Long term musts

We must have an alternate energy carrier/storage to fossil fuels that is fully functional by 2030

Carbon sequestration by 2020
Short term Options: Transportation

- Change lifestyles
- Clean (coal → oil)
- Unconventional oil
Achilles Heel: Transportation

- Current alternatives can replace gas and oil for electricity generation
- The problem is in transportation. There does not exist a viable alternative to gasoline yet!
Fuel efficiency: a case for hybrids

Projected Growth in Daily U.S. Oil Demand by 2025 Under Various Fuel Economy Scenarios

New passenger vehicle fuel economy standards will help reduce projected growth in U.S. petroleum demand.

We have lagged on CAFÉ

Has cheap gasoline and electricity lead to complacency?

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Energy
Coal → Oil

- 1 ton of coal → 5.5 barrels of oil = 0.75 ton of oil
- To replace 10% of world crude by synthetic from coal would need processing 1.54 million tons of coal a day (USA daily production is ~3 M tons)
- 72% more CO₂ is emitted when gasoline is produced from coal than from crude
- Costs $15/barrel to produce oil from coal versus $1-2 for Saudi oil. Syn oil becomes economical for > $30.
- Need to remove sulphur, mercury, arsenic, ….

Needs CO₂ sequestration
Unconventional sources

- Extra-heavy oil (Orinoco oil belt in Venezuela)
- Tar sands (Athabaska Canada, in-situ mining)
- Shale oil (most resources in North America)
- Synthetic crude (from tar, gas, coal)
- Coal bed methane
- Methane hydrates

Need more R&D to scale up
Unconventional sources

• Need more **energy** and **water** to extract
• Are more polluting
• Have larger **environmental impact**

**Consequences of production at 10s of megatons a day are unknown**
Example: Tar Sands

- 2 tons bitumen + energy + 3 barrels of water $\rightarrow$ 1 barrel oil
- Much more sulphur, mercury, ...... have to be captured and processed.
- Tailings slurry contains heavy metals, inorganic salts and hydrocarbons
- Production cost: Syncrude Canada = $12 per barrel of oil versus $1-2 for Saudi oil.
- Commercially viable for > $25/barrel
Power generation
Short term Options

• Clean coal
• Nuclear
• Wind
• Solar and Biomass
• Hydro

What does the market say?
Cost of power generation

US Electricity Production Costs

Declining Costs of Wind Power

These costs do not include capital costs or cost of waste management

Does not include cost of backup

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Energy
### 2004 cost of generating UK electricity (p/kWh) from a new plant

<table>
<thead>
<tr>
<th>Basic cost pence/kWh</th>
<th>With back-up</th>
<th>With £30/t CO₂ £110/t C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>2.3</td>
<td>n/a</td>
</tr>
<tr>
<td>Gas-fired CCGT</td>
<td>2.2</td>
<td>n/a</td>
</tr>
<tr>
<td>Coal pulverised fuel</td>
<td>2.5</td>
<td>n/a</td>
</tr>
<tr>
<td>Coal fluidised bed</td>
<td>2.6</td>
<td>n/a</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>3.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>5.5</td>
<td>7.2</td>
</tr>
</tbody>
</table>
# Installation cost and time for a new plant

<table>
<thead>
<tr>
<th>Energy</th>
<th>Installation Cost</th>
<th>Installation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>$2 / watt</td>
<td>7-10 years</td>
</tr>
<tr>
<td>Coal</td>
<td>$1 / watt</td>
<td>3-5 years</td>
</tr>
<tr>
<td>Gas</td>
<td>$0.6 / watt</td>
<td>2-3 years</td>
</tr>
<tr>
<td>Wind</td>
<td>$0.7-1.0 / watt</td>
<td>months</td>
</tr>
<tr>
<td>PV</td>
<td>$8 / watt</td>
<td>weeks</td>
</tr>
</tbody>
</table>
The hidden and ignored environmental cost of CO2 emissions from fossil fuels

Clean Coal Initiatives

- Integrated Gasification Combined Cycle (IGCC)
- FutureGen
- Vision 21

When?

- Multiple feedstock
- Higher efficiency (CC)
- Multiple products (modular)
- Zero polluting emissions
Nuclear power
“CO2 clean”

- Principles of nuclear fission are known
- Natural $^{235}\text{U}$ is a limited resource
- Issue of HEU and $^{239}\text{Pu}$
- Generation IV reactors
- Breeder reactors?
  - $^{232}\text{Th} \rightarrow ^{233}\text{U}$
  - $^{238}\text{U} \rightarrow ^{239}\text{Pu}$

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Energy

• 442 plants in 32 countries produce $\sim 0.2$ Terawatts. This represents 6.7% (18%) of world energy (electricity) use.
• No new plants in the US since 1978
• Typical lifetime of operation $\sim 40$ years
• 442 plants produce $\sim 2000$ tons of highly radioactive waste fuel per year
• Issues of proliferation of HEU and Pu$^{239}$ and diversion to nuclear weapons
USA is not even at the table

• 32 countries have nuclear energy as part of their energy portfolio.
• Many more want to, and will try to, get it!
• These countries are designing their own strategies and solutions.
• The US is not even at the table discussing the future of nuclear energy, non-proliferation and waste management with them.
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>Nuclear Reactors in Operation</th>
<th>Reactors under Construction</th>
<th>Nuclear Electricity Supplied in 2003</th>
<th>Total Operating Experience to June 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Units</td>
<td>Total MW(e)</td>
<td>No of Units</td>
<td>Total MW(e)</td>
</tr>
<tr>
<td>CANADA</td>
<td>17</td>
<td>12113</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHINA</td>
<td>9</td>
<td>6587</td>
<td>2</td>
<td>2000</td>
</tr>
<tr>
<td>FRANCE</td>
<td>59</td>
<td>63363</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GERMANY</td>
<td>18</td>
<td>20643</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INDIA</td>
<td>14</td>
<td>2550</td>
<td>8</td>
<td>3622</td>
</tr>
<tr>
<td>IRAN</td>
<td>2</td>
<td>2111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAPAN</td>
<td>54</td>
<td>45464</td>
<td>2</td>
<td>2371</td>
</tr>
<tr>
<td>KOREA, REPUBLIC OF</td>
<td>19</td>
<td>15850</td>
<td>1</td>
<td>960</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>2</td>
<td>425</td>
<td></td>
<td>1.81</td>
</tr>
<tr>
<td>RUSSIAN FEDERATION</td>
<td>30</td>
<td>20793</td>
<td>3</td>
<td>2825</td>
</tr>
<tr>
<td>SPAIN</td>
<td>9</td>
<td>7584</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWEDEN</td>
<td>11</td>
<td>9451</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UKRAINE</td>
<td>13</td>
<td>11207</td>
<td>4</td>
<td>3800</td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>27</td>
<td>12052</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>104</td>
<td>98298</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (15 countries)</td>
<td>386</td>
<td>326,380</td>
<td>22</td>
<td>17689</td>
</tr>
<tr>
<td>Total (32 countries)</td>
<td>442</td>
<td>363,380</td>
<td>27</td>
<td>22676</td>
</tr>
</tbody>
</table>
To replace 10 Terawatts by nuclear power would require 10,000 one GW plants – 1 new plant a day for 30 years
Renewables
Hydroelectric Dams

- Electricity generation
- Water management

NO significant growth

- Silting
- Ecological impact
- Large versus small dams

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Wind and Solar

Power input is intermittent → need ~3 times the demand OR storage to function without backup
Solar PV options reaching 15% efficiency
30-45 watts / sq. meter

Laminate

Troughs

Tiles /Shingles

PV polycrystalline

Thin films

rg@lanl.gov  http://t8web.lanl.gov/people/rajan/  Energy
Payback of PV: homes & buildings

For a 2 kilowatt system installed for $16000

My gas utility bill was $18000 for last 12 months
Wind 2003: Total=40 gigawatts peak

Worldwide, Europe and the U.S. account for 90% of cumulative capacity.

<table>
<thead>
<tr>
<th>Top five wind energy markets</th>
<th>2002 Additions</th>
<th>2002 Year End Total</th>
<th>2003 Additions</th>
<th>2003 Year End Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>3,247</td>
<td>12,001</td>
<td>2,645</td>
<td>14,609</td>
</tr>
<tr>
<td>United States</td>
<td>410</td>
<td>4,685</td>
<td>1,687</td>
<td>6,374</td>
</tr>
<tr>
<td>Spain</td>
<td>1,493</td>
<td>4,830</td>
<td>1,377</td>
<td>6,202</td>
</tr>
<tr>
<td>Denmark</td>
<td>407</td>
<td>2,880</td>
<td>243</td>
<td>3,110</td>
</tr>
<tr>
<td>India</td>
<td>195</td>
<td>1,702</td>
<td>408</td>
<td>2,110</td>
</tr>
</tbody>
</table>

Source: AWEA
International wind & PV growth

1995-2002 show ~30% growth

Log-linear plot for Wind & PV

Source: Ben Luce
Wind & PV: Long Way To Go (2003)

World energy use ~ 420 quads ~ $1.2 \times 10^{17}$ W hr

- Power from Wind ~ $3.5 \times 10^{14}$ W hr ($4 \times 10^{10}$ W)
- New capacity (2003) ~ $7 \times 10^{13}$ W hr ($8.2 \times 10^{9}$ W)
- Cost: 3-6 cents / kW hour
- Assuming growth at 30% ($10^{17}$ W hr in 22 years)

- Power from PV ~ $3 \times 10^{13}$ W hr ($3.2 \times 10^{9}$ W)
- PV added (2003) ~ $7.5 \times 10^{12}$ W hr ($8.5 \times 10^{8}$ W)
- Cost: $8$/watt (installed) in 2004 $\Rightarrow$ $0.20$/kWh
- Assuming growth at 30% ($10^{17}$ W hr in 31 years)

Can we sustain this growth or will it flatten out much sooner?
Biomass (land+water use)

- Ferment starch \((C_6H_{10}O_5)_x\) in grain into ethanol
  - Corn kernel → 1/3 ethanol + 1/3 distiller’s grain + 1/3 CO₂ (Starch → C₆H₁₂O₆ → 2C₂H₅OH + 2CO₂)
    - 1 hectare . 120 days → 9 tons corn → 800 gallons ethanol → 14 Million watt hours
    - 1 hectare PV farm (5000 m² . 10% . 200w . 24hrs . 120 days) → 288 Million watt hours

- Cellulosic biomass (waste, wood) is “free” but less efficient
Ethanol: goal 5 billion barrels

Graph 1. U.S. Fuel Ethanol Production * (R.F.A.)

Energy input in corn and ethanol production ≈ stored!
→ Ethanol: a way to convert coal and gas into liquid fuel!
Summary of non-fossil

- **Nuclear:** bogged down by proliferation and waste issues
- **Biomass:** small and will peak at ~1%
- **Hydro:** most rivers tapped
- **Solar:** tiny but will grow as cost ↓
- **Wind:** small but has potential for rapid growth
Transition to non-fossil

- **Mixed News (will buy US some time):**
  - Coal is abundant in large economies
  - Synthetic oil and gas is profitable for crude oil > $30 per barrel
- **CO2:** Sequestration or move away from fossil fuels
- **Nuclear:** Not yet a global solution
- **Renewables:** Small. Exploit potential for rapid growth of wind and solar

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Energy
What I will bet on

- Oil (will peak at ~86 million barrels/day: 2006)
- Gas (will peak around 2025. Fuel for Eurasia)
- Coal (will grow. Zero emissions only >> 2025)
- Nuclear (proliferation issues will limit growth)
- Hydro (no significant growth)
- Wind (will grow driven by market)
- Solar (will grow driven by home & building use)
- Biomass (useful for excess “corn” & waste disposal)

Long term vision: Dominant power will be electric with $H_2$ or $CH_4$ the intermediate carrier/storage
Electricity and gasoline in the US is cheap!

MANUFACTURE
World leader in photovoltaic production is Japan

U.S. SLIPS
Production, export of photovoltaics decline

APPLICATION
Japan leads in annual photovoltaic installations

MOSTLY ROOFTOPS
Residences use most of the photovoltaic-generated electricity

Jeff Johnson, Chemical and Engineering News: June 21, 2004 Volume 82, Number 25 pp25-28
Recommendations

• Education to change behavior: the oil and gas crisis is not a ploy by producing countries or companies. Global production is approaching its peak.

• Improve efficiency and conserve fossil fuels

• Increase CAFÉ standards by 1 mile / year for next 15 years and classify SUVs as automobiles

• Accelerate development of clean coal technology

• Accelerate development of solar and wind

• Reinvest in nuclear power. R&D in waste management

• Upgrade electric transmission grid

Enlightened policy, incentives (rebates, credits) can have a major impact
Recognize inertia in energy sector

• Oil contracts, rigs, exploration technology
• Tankers and pipelines
• Refineries
• Auto industry
• 600 million cars running on gasoline
• Service stations and gasoline stations
• Existing coal electricity generation plants

The existing investment of >$10 trillion in oil cannot be changed overnight
Remember oil shocks, windows of opportunity, and lessons not learned

• Pre 1973
  – Controlled exploration & production, source nations just got royalty

• 1973 - 2001:
  – We don’t own energy sources but dominate exploration & recovery
  – We bought it (traded for it) on favorable terms by providing security

• 2001 – 2020:
  – OCED does not own oil or gas reserves. Share of companies decreasing
  – many other nations are competing/trading for resources and rights
  – All cheap oil & gas reserves outside the Middle East are in decline

• 2020 –
  – Middle East (if stable) holds the trump cards OR
  – Middle East is unstable & oil supplies insecure → development stalls
  – Middle East is occupied (Iraq is step one)
Promote American innovation and ingenuity. Reduce oil and gas imports by 1% every year!

- Switch electricity generation to clean coal, nuclear and renewables. Share of renewables will increase as costs come down.
- Improve fuel efficiency in transport. In short term switch to efficient hybrid automobiles
- Re-examine centralized versus distributed power generation as clean coal and fuel cells technology develops
- Invest in broad based R&D
Make New Mexico a prototype for

- Intelligent, designed, evolving mix
- Empowering incentives, credits, regulations
- Power grids that facilitate/embrace distributed and intermittent generation with attractive buy back offerings.
Hope for the future!

Wind and solar are the most abundant sources of energy in poor countries lying within the tropics. Having exhausted oil and gas we owe them a clean, copious and cheap source.
Further reading and Sources

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- http://www.energycrisis.org/
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- “Blood and Oil”, Michael T. Klare, 2004