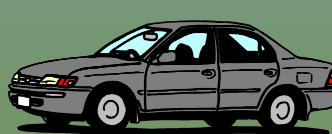
Nanotechnology and the New Energy Landscape

(A confluence of influences)



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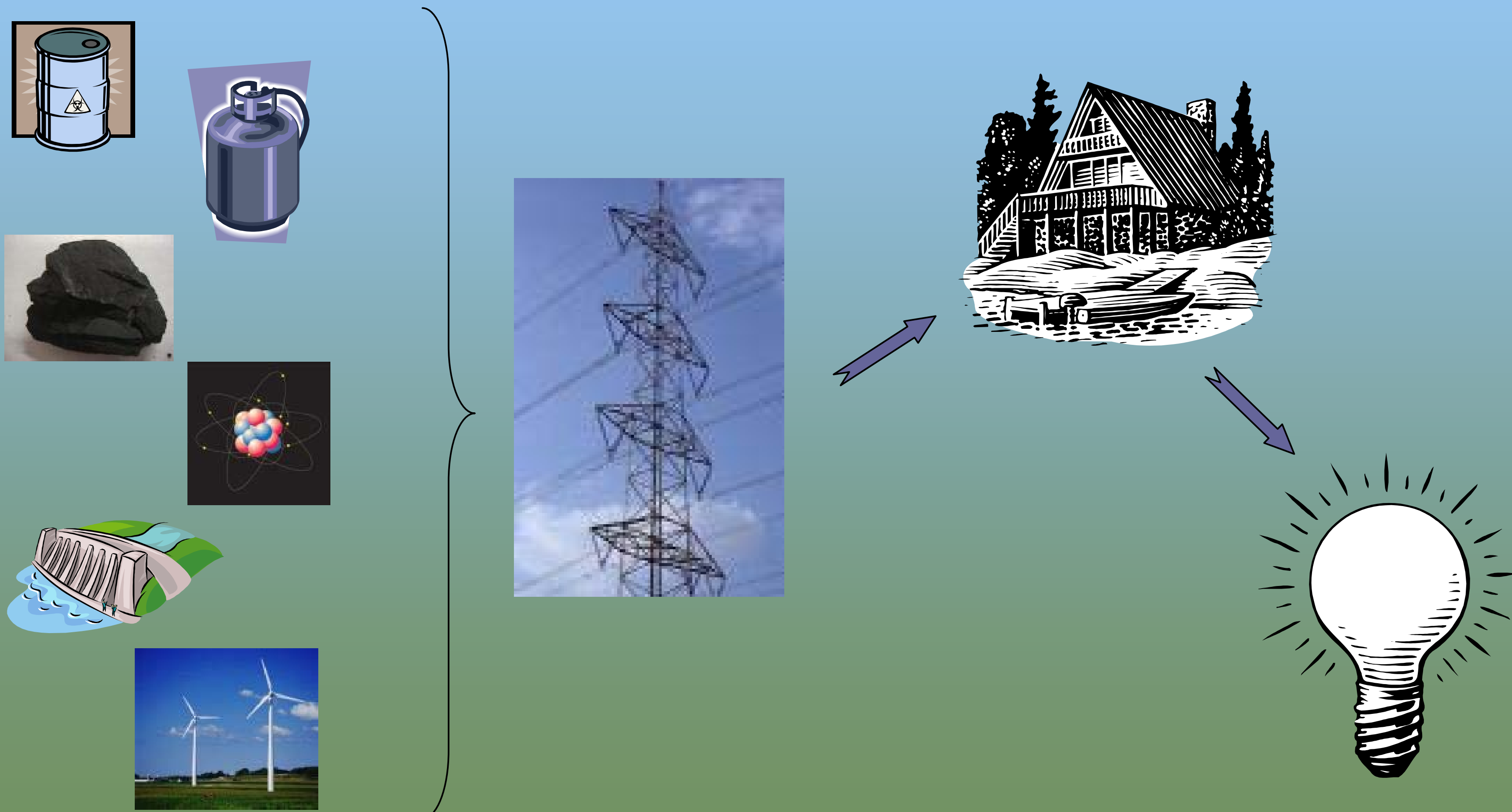
Why nanotech and energy?

- The patterns of energy generation and use that have been dominant for close to a century are under threat. Timescale: somewhere between a few decades (global demand exceeds supply) and overnight (instability precipitates resource wars)
- Nanotech is promising to affect every part of the energy landscape in multiple ways, often with multiple candidate technologies
- Looking at the energy landscape from the nanotech perspective forces a fresh look at the whole system – thinking ‘outside the box’
- A fresh look at the whole system is probably very advisable (and it is what this presentation will try to encourage)

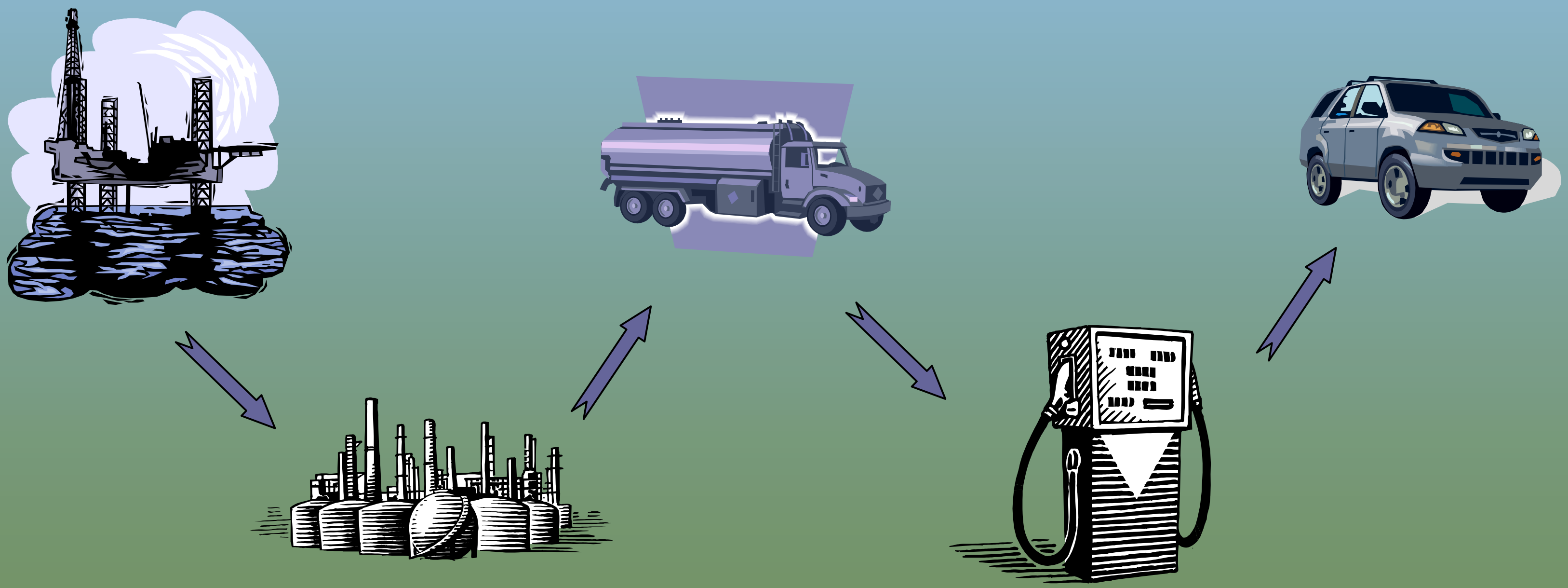
The traditional model - home and work

Powering our homes and businesses (and manufacturing base) - multiple energy sources, though largely fossil, all but the largest arteries of distribution based on the electrical grid.



The traditional model - transport

Planes, trains and automobiles (okay, maybe not trains)



The traditional, very dominant, models of energy supply for just about everything we do were just summed up in two slides.

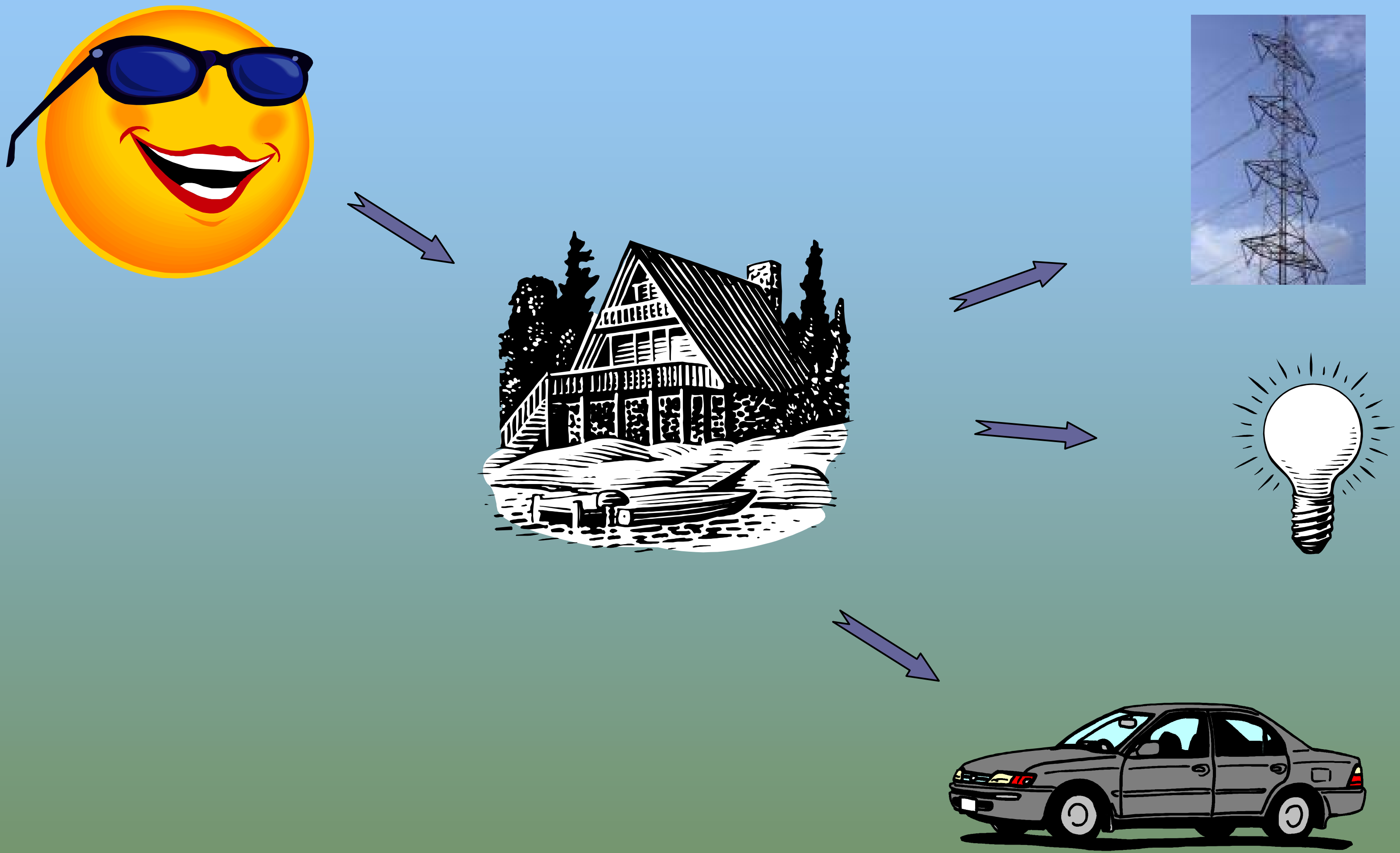
Maybe we should find that scary.

A couple of alternatives to consider…

Gridless…

It is worth noting that the grid is assumed by most in the developed world but is a high-loss distribution system that might make no sense give a few parameter changes. In countries such as India, large-scale grid infrastructure is highly questionable.

Self-sufficient…



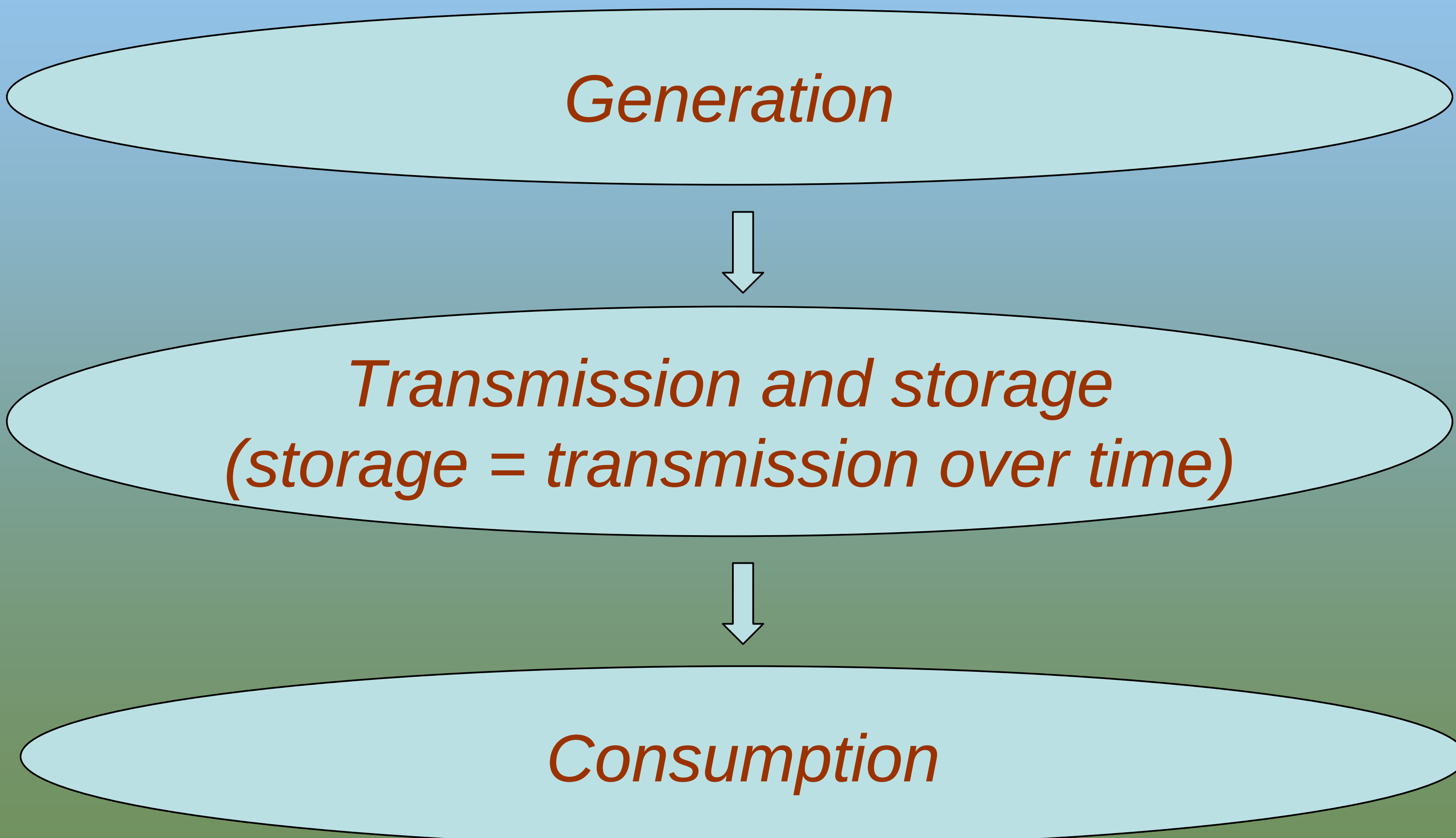
The point being…

There are many different generation and distribution models possible, and no reason that we shouldn't have quite a variety of them active at the same time.

In fact, it is arguable that the future energy landscape will be far more varied (heterogenous, if you prefer) than the current one.

A whistle-stop tour of the nanotech impact, grouped according to the diagram below.

(Don’t expect to absorb too much of this unless you’re really into this stuff already.)



Generation – the nano-impact
Fossil fuels

- Nanocatalysis
  - Gas to liquid and coal liquefaction
  - Fuel cells
  - Catalytic converters
  - Nanostructured catalyst support materials
- Nanoporous materials
  - Fuel cell PEMs, esp. to prevent poisoning in DMFCs
  - Gas separation (CO2 sequestration, hydrogen production)
- Other nanomaterials
  - Improved fuel cell electrodes (increased surface area and good conductivity, e.g. buckypaper)
  - Conducting composites for fuel cell bipolar plates
  - Nanocrystalline metals for drilling

Generation – the nano-impact Solar

- Improved / more flexible photon capture / electron generation
  - Nanoparticulate TiO_2 ‘paint’ (e.g. on buildings)
  - Nanoparticulate TiO_2 for dye-sensitised cells – dyes allow broad wavelength capture, nanoparticles have upped efficiency
  - Semiconductor nanorods, nanowires and other novel semiconductors
  - Thin film approaches
  - Organic approaches (roll technology possible for mass production)
  - Quantum dots – multiple electrons per photon
- Improved electron transport
  - Various conducting nanostructures, including buckyballs and nanotubes
  - Organic photoreceptor/transport complexes
- Direct production of hydrogen from solar
  - E.g. nanocrystalline metal oxides reaching 10% efficiency for this direct photochemical conversion
- Biomimetic / bioinspired photochemical systems (i.e. artificial photosynthesis)
  - ‘Spinach cells’ approaching 12% efficiency
- Encapsulation / protection materials for sensitive new organic (thin film / roll process) PV materials
- Self-cleaning coatings

Note: Enough solar energy hits the Earth in a day (or less) to satisfy our energy needs for one year.

Generation – the nano-impact
Wind

- Not much: stronger turbine blades (NT composites offer greatest promise) – efficiency of turbines increases exponentially with blade radius.
- **BUT**, for any intermittent source, developments in batteries, hydrogen generation and fuel cells can greatly improve economics.

Generation – the nano-impact
Wave / tidal

- Minor impact but anti-fouling nanoparticulate paints would likely see use.

Generation – the nano-impact Geothermal

- Improved drilling materials (nanocrystalline metals, ceramics)
- Low-grade heat to electricity through thermoelectrics. This is potentially very big for geothermal and waste heat. Recent breakthroughs show great promise.

Generation – the nano-impact Biomass and waste

- Nanocatalysis
- Bio fuel cells (same advantages as previously noted for fuel cells for fossil use)

Note: Primary biomass is popular (especially with farmers) but intrinsically inefficient – photosynthesis efficiency is maximum 8-9% ***before processing for fuel***, which compares badly with PV of 15-50%. Waste biomass is another matter, especially when you consider that much biomass ends up putting methane (potent greenhouse gas) into the atmosphere.

Generation – the nano-impact
Fission and fusion

- Primarily: nanostructured materials for radiation tolerance

Generation – the nano-impact General / other

- Improved (and directional) thermal conductivity
- Stronger nanocrystalline metals, less brittle nanoceramics, in machine parts (especially likely to be seen in the new generation of mini- and micro-turbines)

Transmission and storage – the nano-impact

- Fuel cells (nano-impact as mentioned previously) – actually a generation technology but a key ‘bridge’ technology for transmission, especially for automotive (e.g. using locally-generated hydrogen)
- Hydrogen storage materials (CNTs, ‘nanopyramids’, nanostructured metal hydrides)
- Batteries / supercapacitors – improved electrodes through various nanomaterials (main benefits: increased surface area; improved conductivity / charge retention with lower weight – higher energy and power densities)
- Gas-to-liquid technology (mentioned under fossils) allows access to ‘stranded’ gas
- New synthesis pathways for liquid (or near-liquid) fuels to bypass hydrogen transport problems
- CNT superconducting grid (electrical transmission losses run from around 5-15% and are prohibitive over great distances)
- Improved efficiency of electrolysis (e.g. using ‘broken’ CNTs)

Consumption – the nano-impact

- Lighter materials for cars and (especially) planes, e.g. nanoclay, nanocrystalline steel, CNT composites
- Waste heat conversion to electricity using thermoelectrics - around 10 terawatts electricity generated through heat engines globally but 15 terawatts is lost as waste heat
- More efficient cooling technologies using above in reverse
- Thermal insulation through anti-IR coatings, (super-strong) aerogels (transparent: double-glazing) and other nanoporous materials
- Efficient LED/OLED (even CNT) lighting (widespread adoption could cut 10% of global energy consumption)

What developments are interesting near-term ?

- Solar
  - multiple novel approaches, especially in PV, maximising potential
  - cheap, roll-based manufacture possible, though organics usually used (stability issues) but not always
  - real estate not necessarily a big issue (rooftops)
  - particularly attractive for local generation, avoiding cost of grid infrastructure (China, India, even remote US) – potentially revolutionary for poor, remote communities
- Coal gasification & liquefaction
  - Synthetic diesel economically competitive at oil price of approx. $45 / bbl
  - Between 50 and 300 years supply
  - Radically shifts global energy picture (geopolitical)
- Fuel cells
  - Broad applications, covering everything from electronics to cars to factories.
  - Capable of using a variety of fuels, cleanly
  - Good potential to exploit local generation of hydrogen, bypassing need for distribution network and offering unusual prospects such as powering your car from the solar panels on your roof (batteries could offer similar)

Interesting speculative developments

- Efficient synthesis of liquid fuel from renewables (e.g. direct from solar, à la photosynthesis, or indirectly)
- Lossless or near-lossless electrical transmission.

Reason these are interesting – they both allow efficient transport of renewable energy over great distances.

Generation – energy sources

Source	***Annual capacity***	***Lifetime***	***Drawbacks?***	***Technological obstacles***	***Nanotech impact***
Natural hydrocarbons (fossil fuels) • oil • gas • coal • methane hydrates	Ample (potentially)	Centuries (but increasingly costly)	Major	Moderate	Major
Solar (thermal, photovoltaic, photochemical)	Ample	Indefinite	Insignificant	Moderate	Major
Wind	Limited	Indefinite	Minor	Minor	Moderate
Tidal/Wave	Limited	Indefinite	Insignificant	Minor	Minor
Hydroelectric	Limited	Indefinite	Significant	Insignificant	Minor
Geothermal / hydrothermal	Ample	Indefinite	Minor	Significant	Moderate to major
Biomass (waste and primary)	Limited	Indefinite	Minor	Moderate	Moderate
Waste	Limited	Quasi-indefinite	Minor	Moderate	Moderate
Fission	Ample	Centuries?	Major (currently)	Minor	Minor
Fusion	Ample	Indefinite	Minor	Major	Minor

Common errors from thinking in a straightjacket

- The hydrogen economy won’t happen because of the massive cost of building the distribtion network. False assumption: hydrogen needs to be delivered rather than produced at supply points
- The hydrogen economy is the ‘ideal’ future. Actually, hydrogen’s a pain to transport and store, and may even damage the ozone layer. A liquid or near-liquid fule would be much better
- Even with oil at $100 / bbl it is cheaper than various renewables such as solar, so these are not likely to be widely adopted for many decades (unjustified assumptions: 1 - new technologies won’t bring down the cost of alternatives; 2 - oil won’t get much more expensive than this; 3 – oil supplies will remain adequate)
- One bonus of oil running out is that our transport will emit less CO2 and maybe save the planet from global warming. Missed fact: coal and natural gas can produce synthetic diesel, and we have up to 300 years of coal left. Then there’s methane hydrates.
- Renewables such as wind and solar can only ever be **supplementary** sources because they are intermittent. Missed fact: energy from solar and wind can be stored and transported in several ways, with improving technoliges.
- Biofuels are a good source of energy. No, as said before, primary biomass is a horribly inefficient way to use solar energy. However, the results can be put straight into our existing cars (hence the attraction). Waste biomass okay.

Impact scenario 1 – solar reigns (locally)

Technological circumstances:

- Oil effectively runs out, gas and coal provide expensive alternatives for some countries
- Photovoltaic energy costs drop 10-fold (more has been promised by some nano startups)
- Battery lifetime cost per unit energy drops 3-5 fold

Possible consequences:

- Rural India is supplied with ample electricity for lighting and computing – education can soar. Personal transport (electric cars and bikes) becomes widespread.
- Middle East remains awash with energy but exports lose out to local solar generation so income plummets. However, solar-powered desalination allows them to turn over large swathes of desert to food production, which can be exported.
- Highly-populated Northern European economies become highly energy-restricted (hydrogen imports being costly). Much industry shifts south, personal transport is prohibitively expensive for many.

Impact scenario 2 – solar goes global

Technological circumstances:

- Oil effectively runs out, gas and coal provide expensive alternatives for some countries
- Photovoltaic energy costs drop 10-fold (more has been promised by some nano startups)
- Efficient generation of transportable fuel from PV achieved

Possible consequences:

- Rural India is supplied with ample electricity for lighting and computing – education can soar. Country becomes a net exporter of energy (one among many in region)
- Middle East continues to be an energy exporter but much diminished, losing its stranglehold
- Highly-populated Northern areas become, or continue to be, net importers of energy, most seeing little change (exceptions being oil & gas producers such as Norway and the UK, which would lose their exports)

Impact scenario 3 – a fossil future

Technological circumstances:

- Oil effectively runs out, gas-to-liquid and coal reforming / gasification / liquefaction technologies provide ample, easily transported, fuel for cars and power stations at a reasonable price
- Photovoltaic energy fails (surprisingly) to live up to its promise and geothermal remains limited to areas such as Iceland

Possible consequences:

- Patterns of consumption worldwide are little affected
- Middle Eastern countries go into sharp decline
- North America becomes largely self-sufficient (but maybe not for long) while China and India become energy exporters. Russia and Europe see little change, with Russia a major supplier to Europe
- Man-made climate change continues or worsens, without action to combat it (sequestration)

Impact scenario 4 - nuclear

Technological circumstances:

- Oil effectively runs out, gas and coal only provide expensive alternatives for some countries
- Photovoltaic energy fails (surprisingly) to live up to its promise and geothermal remains limited to areas such as Iceland

Possible consequences:

- Nuclear energy is adopted on a large scale in many countries
- Middle Eastern countries go into sharp decline
- Transport becomes dominated by electrical systems and fuel cells burning hydrogen (produced locally from electricity grid) – the air in our cities gets clean
- Global CO_2 emissions go into steep decline
- Risks from nuclear weapons and ‘dirty nuclear’ attacks increase.

Summary of nanotech impact

Imagine a really big picture with *lots* of arrows….

Summary of nanotech impact (without graphics)

- Major exploitation of non-oil fossils very likely, with nanocatalysis playing a critical role.
- Increased reliance on nuclear power (for countries that are allowed) combined with fuel cell advances would strongly favour transport based on hydrogen fuel cells. The US especially seems interested in promoting this combination (moreso, surprisingly, than coal-to-liquids, though this may change).
- High probability of solar becoming a major energy source globally, with nanotechnology playing a crucial role. Developing nations may be most transformed, especially through access to global information (education) that electricity can bring.
- General diversification of sources and decentralisation of transmission systems.

When?

10-20 years, depending on economic and geopolitical pressures.

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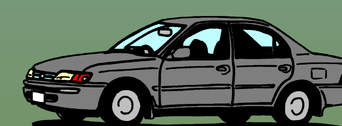

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