# B2 Engineering, Sustainability and the Environment

Wei Huang, Michaelmas Term 2021

Lecture 4

## Sustainable energy and Scenario analysis

# Course outline

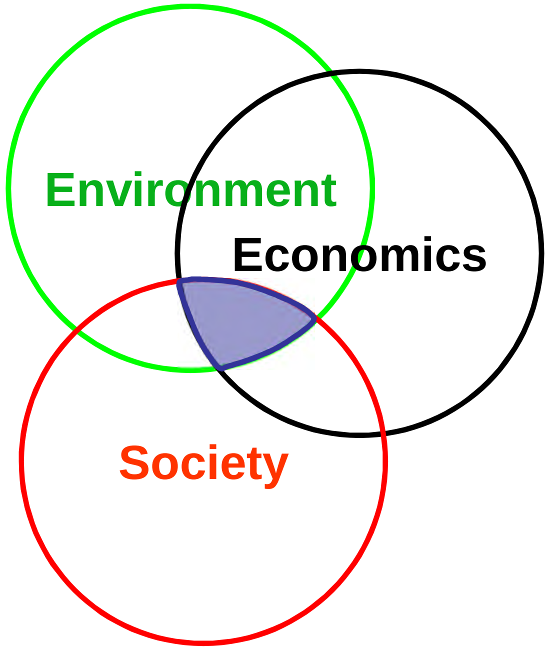
1. Why?
   - Global Issues
   - Why Engineering?

2. What?
   Brundtland Report
   Triple Bottom Line
   Stakeholders

3. How?
   - Legislation
   - Tools
   - Metrics

4. When?
   - Scenario Analysis
   - Structural Change?
   - A Sustainable Future

# A Sustainable Energy Future?




## Scenario analysis

**Example scenarios**

**Low carbon futures & making it happen**

**Energy company activities**

**Conclusions**

# Scenarios

**We cannot predict the future!**

**Many possible futures**

**Scenarios consider possible alternative futures**

**Plausible, internally consistent stories to aid strategic thinking**

**Need at least two scenarios**

**Not forecasts which extrapolate from the past**

THE DAILY TELEGRAPH


I predict that futurologists will keep on getting it wrong

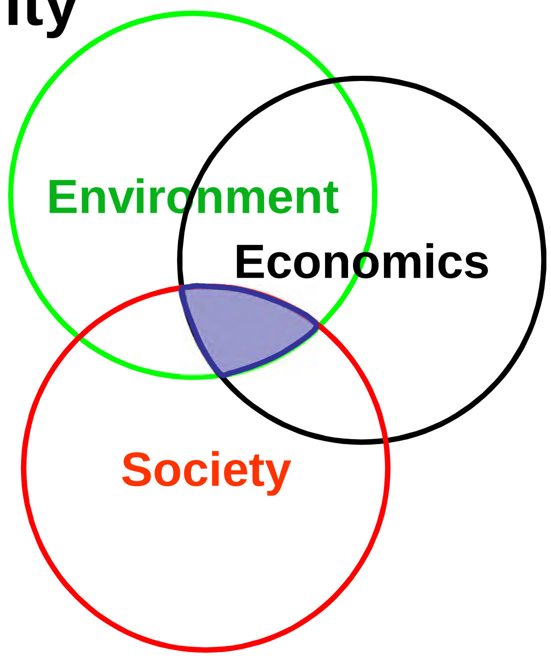
# Energy scenario concerns

1) Social and national security

which is intimately tied to energy security

2) Economic prosperity

3) The environment



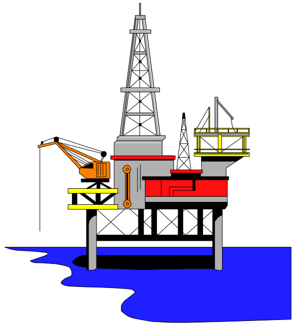

**Sustainable, $CO_2$ neutral energy**

Greenhouse gas emissions in the UK will be cut to almost zero by 2050
– BBC 12 June 2019

# Energy scenario factors

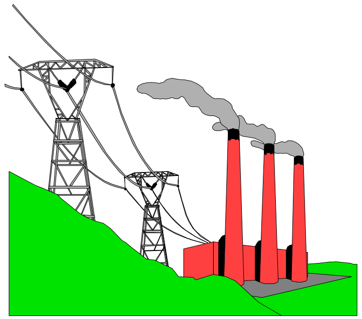
**Demand – population growth, economic development**

**Supplies – availability/price**



**Renewable energy**

**Energy efficiency**



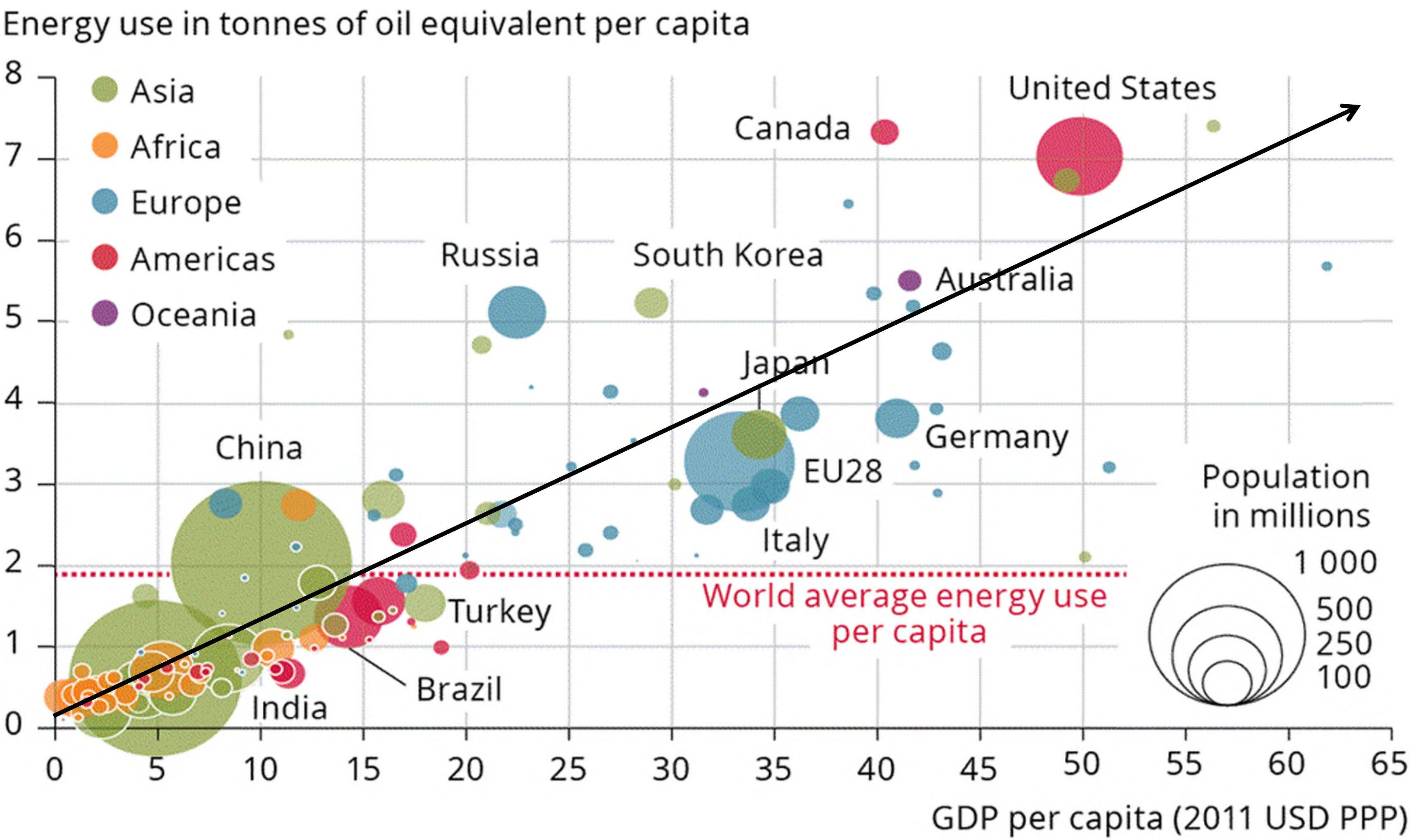
**Public attitudes – Climate change etc**

**Government policies / incentives**

**Carbon emissions**

**Hydrogen economy etc, etc…**

# Demand: Energy Consumption vs GDP

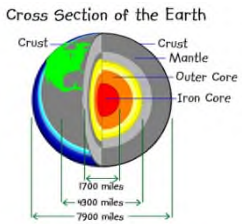



https://www.eea.europa.eu/soer/data-and-maps/figures/correlation-of-per-capita-energy

# Potential of renewable energy

- Nuclear (fission and fusion)

Require a new reactor every other day for the next 50 years



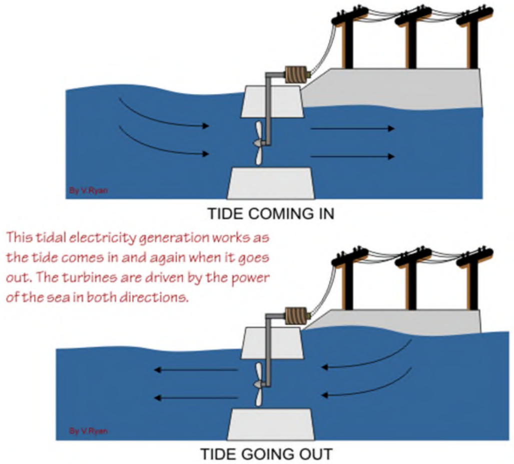

- Hydroelectric

Technically Feasible: 1.6 TW, Economic: 0.9 TW, Installed Capacity: 0.6 TW

- Geothermal

Engineering, practice, Mean flux at surface: 0.057 W/m$^2$

Continental Total Potential: 11.6 TW




- Ocean/Tides

Corrosion and amount of energy is low

- Wind

4% Utilization, 2-3 TW, Storage, integration to grids

- Biomass

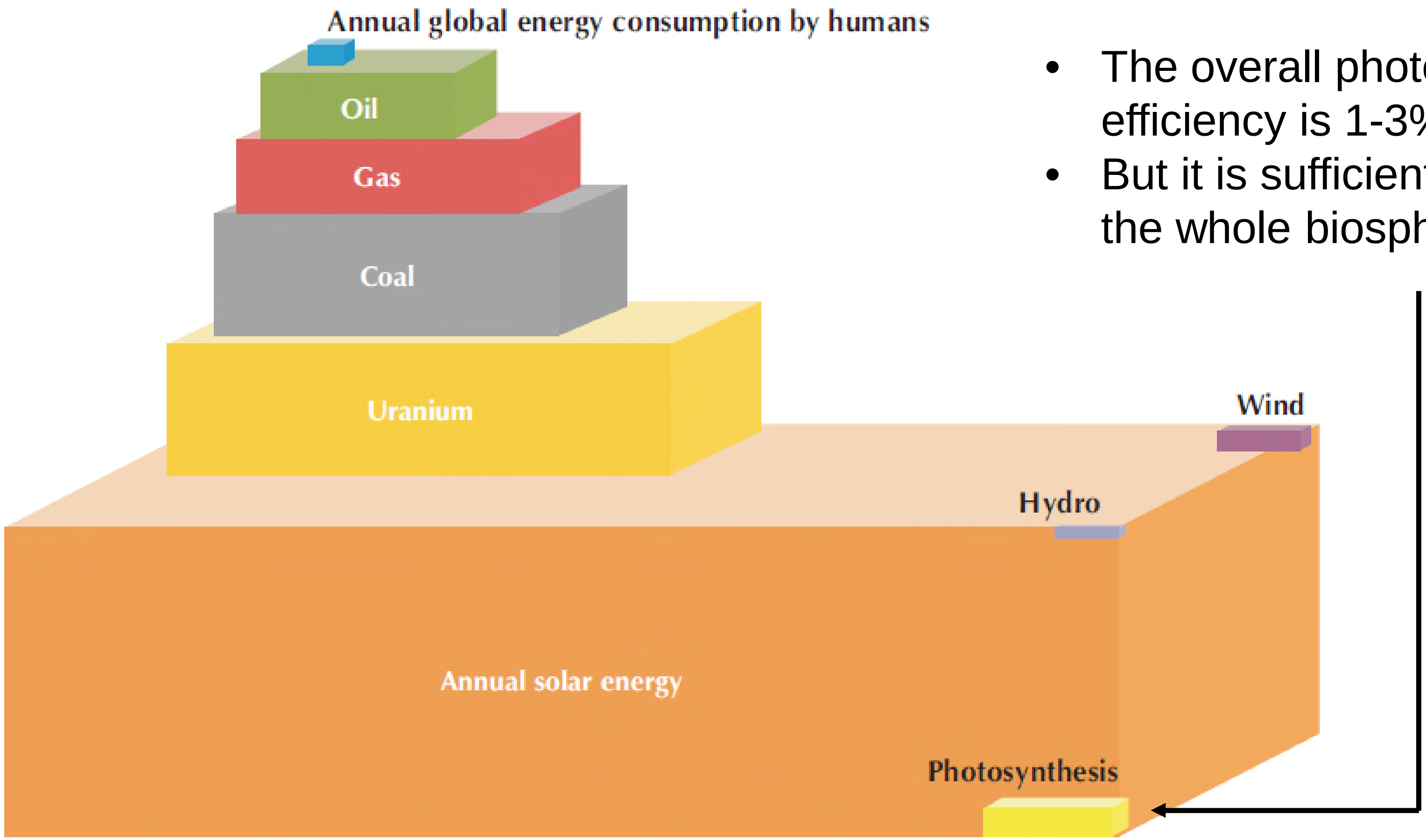
Food security, require 31% of total land area

- Solar – ultimate energy source!

Nathan Lewis,
Powering the planet.
*MRS BULLETIN* 2007

# Source: Global energy budget

Figure 2.1 **Total energy resources**




*Source: National Petroleum Council, 2007, after Craig, Cunningham and Saigo (republished from IEA, 2008b).*

- The overall photosynthesis efficiency is 1-3%
- But it is sufficient to support the whole biosphere

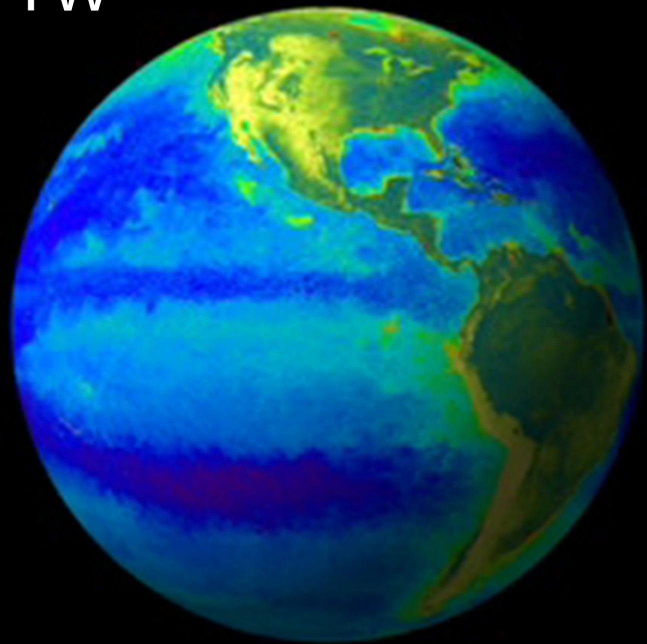
IEA Renewable Energy Technologies: Solar Energy Prospectives 2011

# Solar energy

Taking energy as an example:

one hour of sunlight = Mankind annual consumption ~15 TW

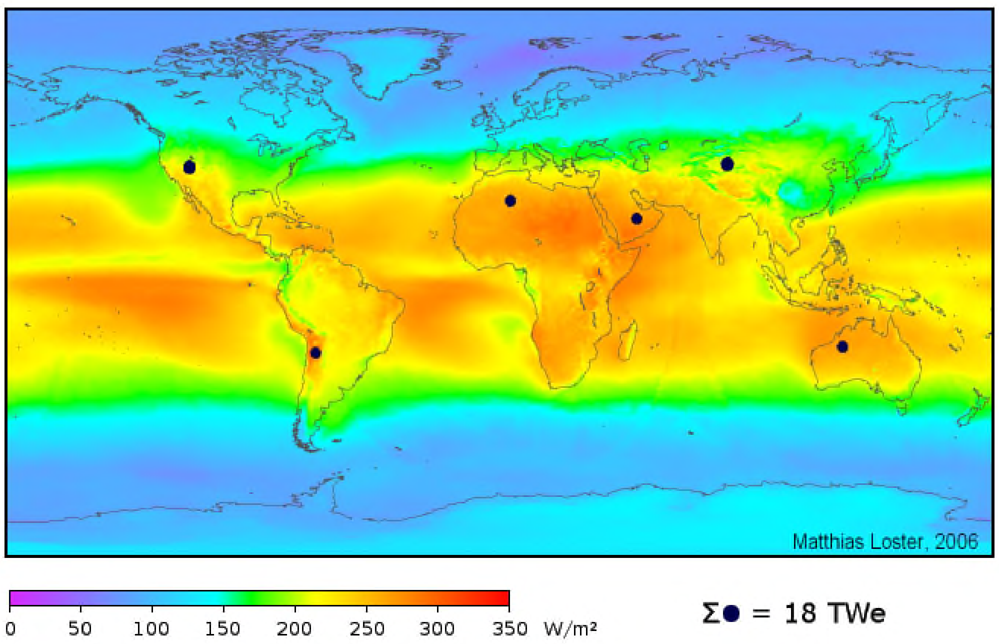
100,000 TW

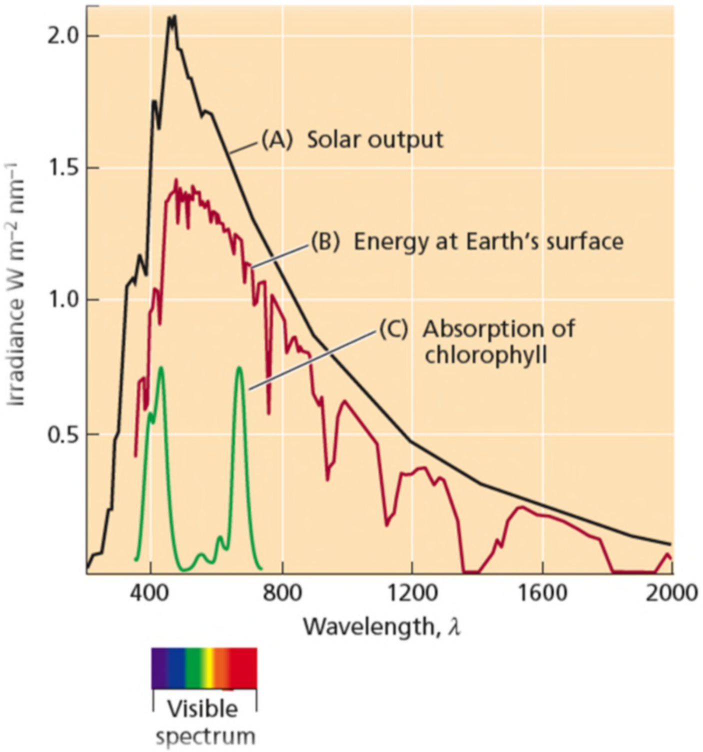


Solar energy is the ultimate and sustainable energy resource

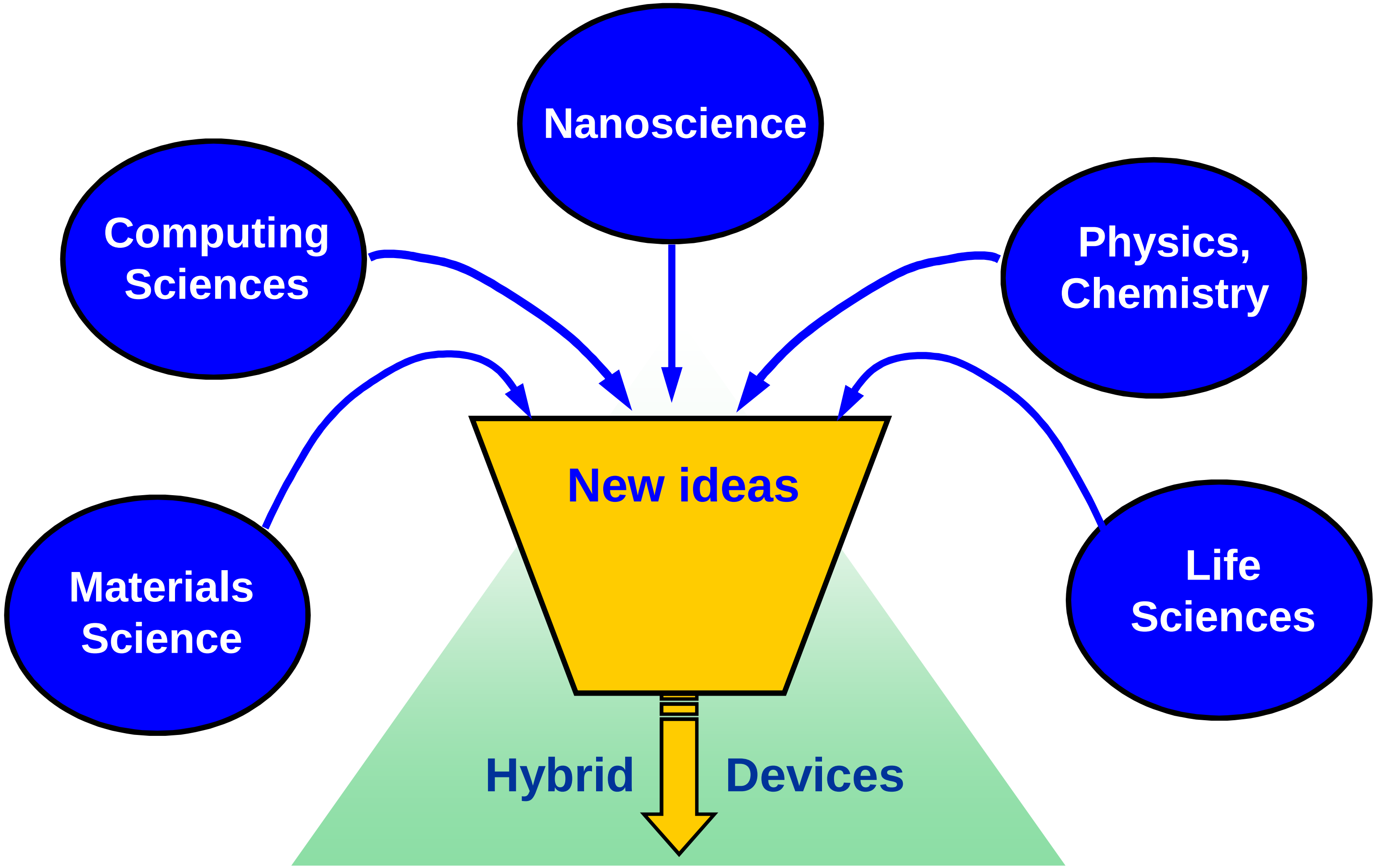
# Solar power facts

- Solar irradiance to earth is 1368 W/m$^2$;
- Solar energy hitting the earth surface is ~ 200 W/m$^2$;
- Solar rays include visible light (40%), infrared (50%) and ultraviolet radiation (10%).



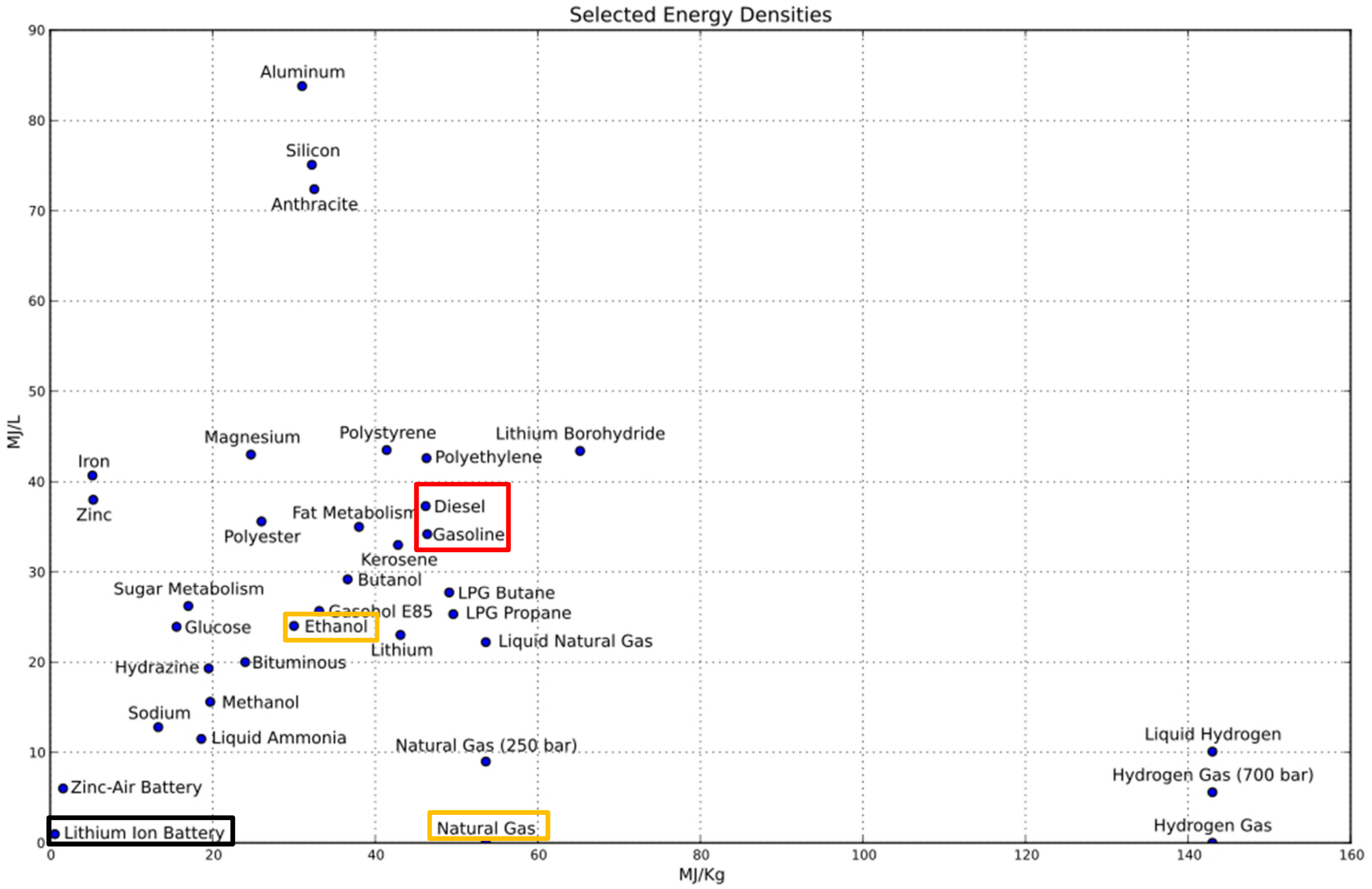
# Integration of many disciplines will be needed




**Chemical Fuel From Solar Energy**

# Energy density

Energy density is the amount of energy stored in a given unit of mass or volume



# Energy transfer efficiency is key

- Oil (30 MJ/L oil) consumption in China is 10.8M barrel/day

The total energy per day = *30MJx(10.8x10⁶barrel/d)x159L/barrel)=5.1x10¹⁰* MJ/d

- Given average solar energy is 200 W/m², 1.5 X Taihu lake (2250 km²) surface is sufficient to China annual oil demand.

$$T = \frac{200W}{m^2} \times 24h \times \frac{3600s}{h} \times 1.5 \times 2250 \times 10^6 m^2 = 5.8 \times 10^{10} MJ/d$$


However, photosynthesis efficiency is 1%, it requires 160 Taihu lake for oil production = 30% of China arable land area. This is not acceptable!

# Renewable Energy

## Could meet energy demand many times over.

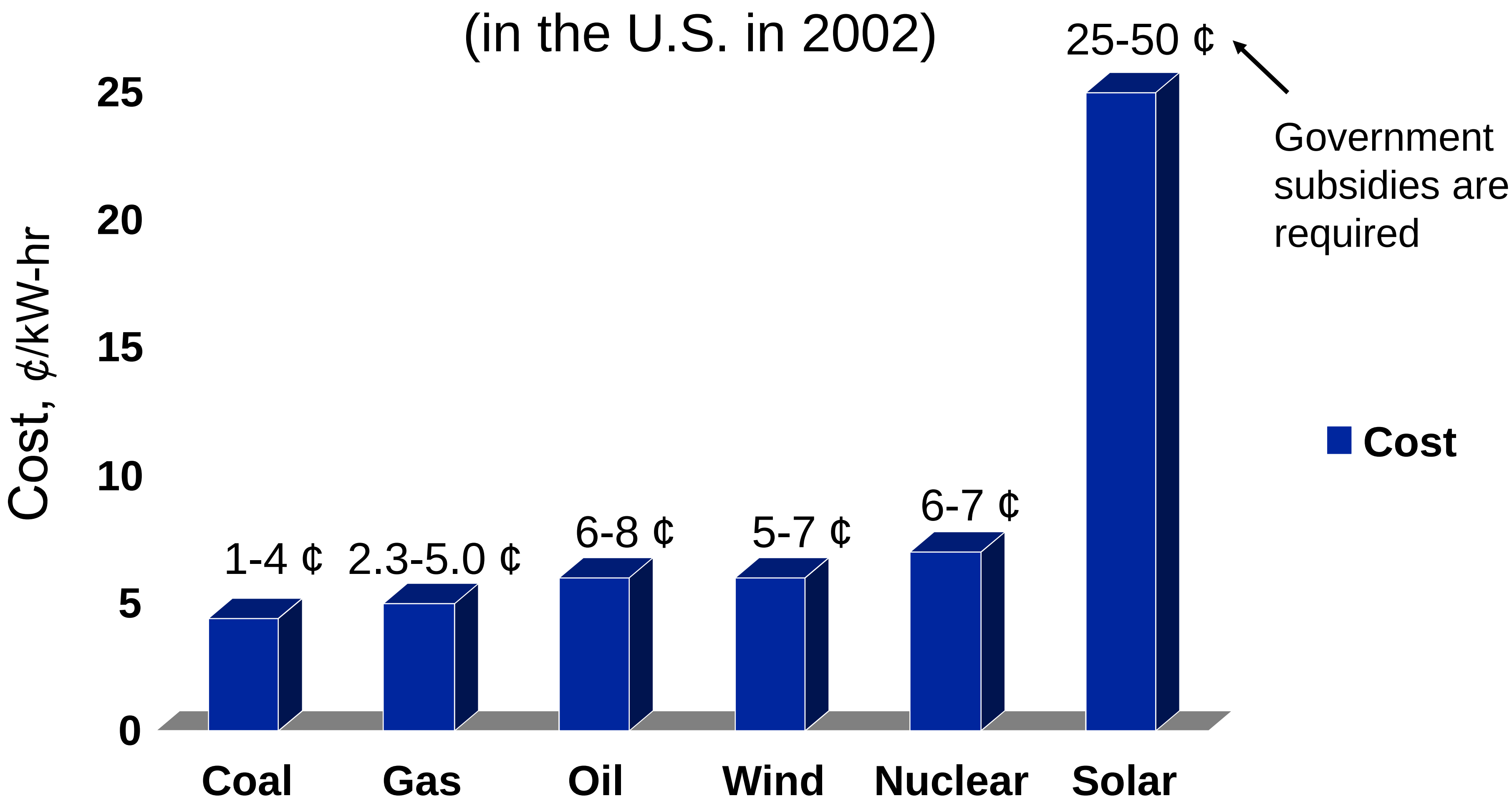
**The sun provides more energy in a day than the world uses in 30 years**

**More expensive than fossil fuels, but costs falling**

**Fossil & nuclear industries heavily subsidised!**

**Issue of intermittency to be solved (or maybe we should be less used to power on demand?)**

# Production Cost of Electricity



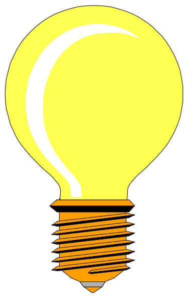

Courtesy Nate Lewis

Nathan Lewis, Powering the planet. *MRS BULLETIN* 2007

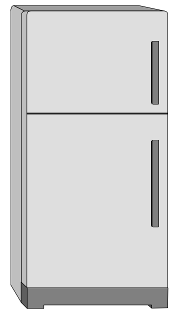
# Energy Efficiency

**Energy used to meet a societal need!**

**Very significant scope to reduce energy use.**



**Domestic applications:**



**Lighting: compact fluorescent (14W = 60W incandescant)**

| Appliances: | Ave new UK | best available |
|---|---|---|
| Fridge/freezer, | 580 | 300 kWh/yr |
| Washing m/c | 1.21 | 0.9 kWh/cycle |
| Boiler efficiency | 75 | 92 % |

**Consumer electronics: cut out standby & clocks.**

# Energy Efficiency

**Buildings:**

**Passive solar; better insulation; smart windows…**

**Combined Heat & Power instead of power alone**

**Power from coal ~35%, gas ~60%; but ~90% with CHP**

**Industry:**

**Pumping: variable speed motors, not throttling.**

**Integration: reduce heating and cooling steps.**

**Cars: over fourfold reduction.**

**Potential between 25 and 50% saving**

# Future lighting systems

- Established technology was incandescent lamps
  - EU prohibited sale of most of these
- Compact Fluorescent Lamps (CFLs) Dimmable versions now available for some time
  - High capital cost and longer life, but much lower running costs
  - Not everyone 'likes' the light
  - Issue with mercury – disposal?

- Future is likely to be LEDs
  - Dimmable versions available
  - Becoming available in higher powers
  - Colour now more acceptable 'warm'

# New frontier Engineering:
# Energy self-sufficient building

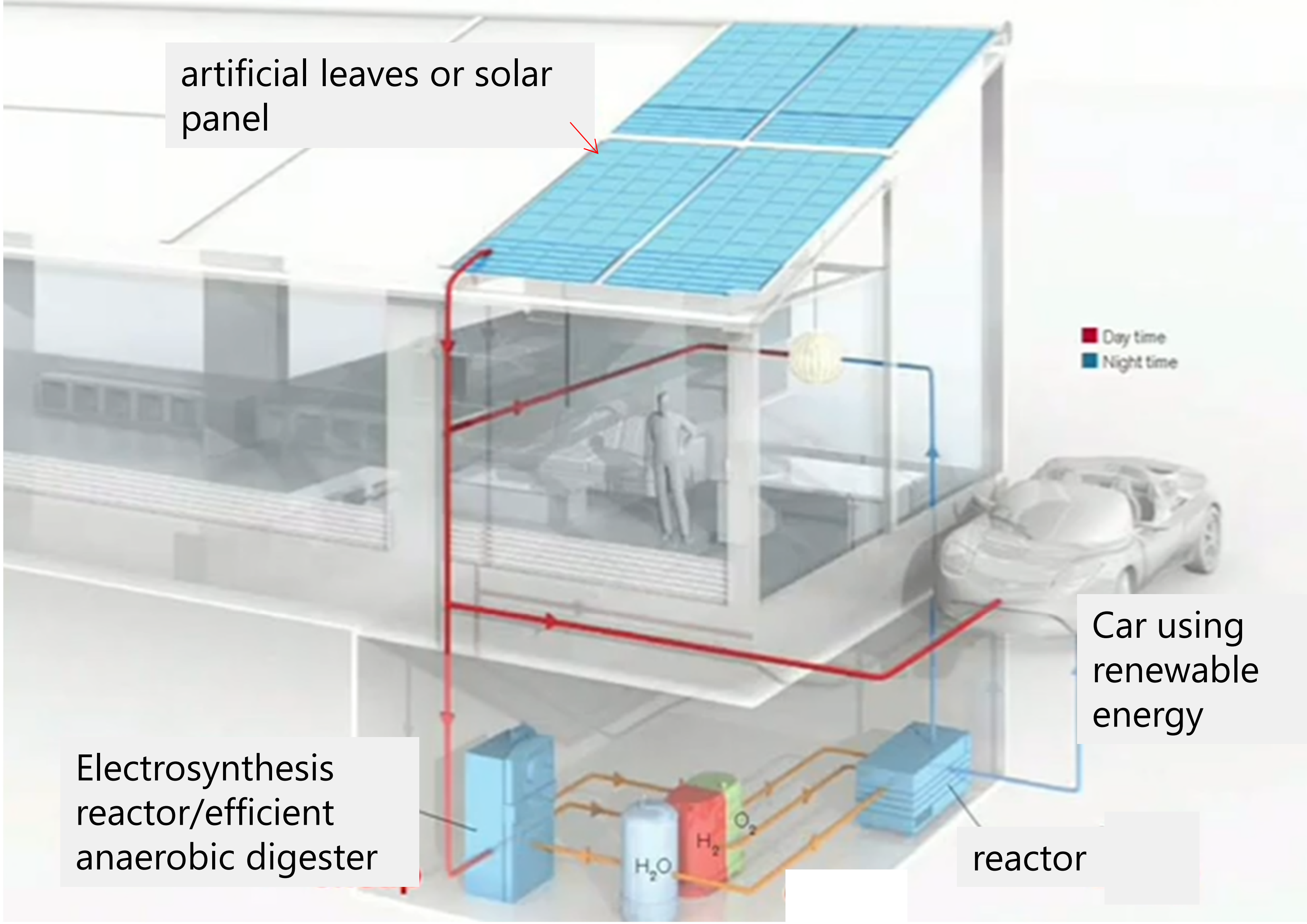
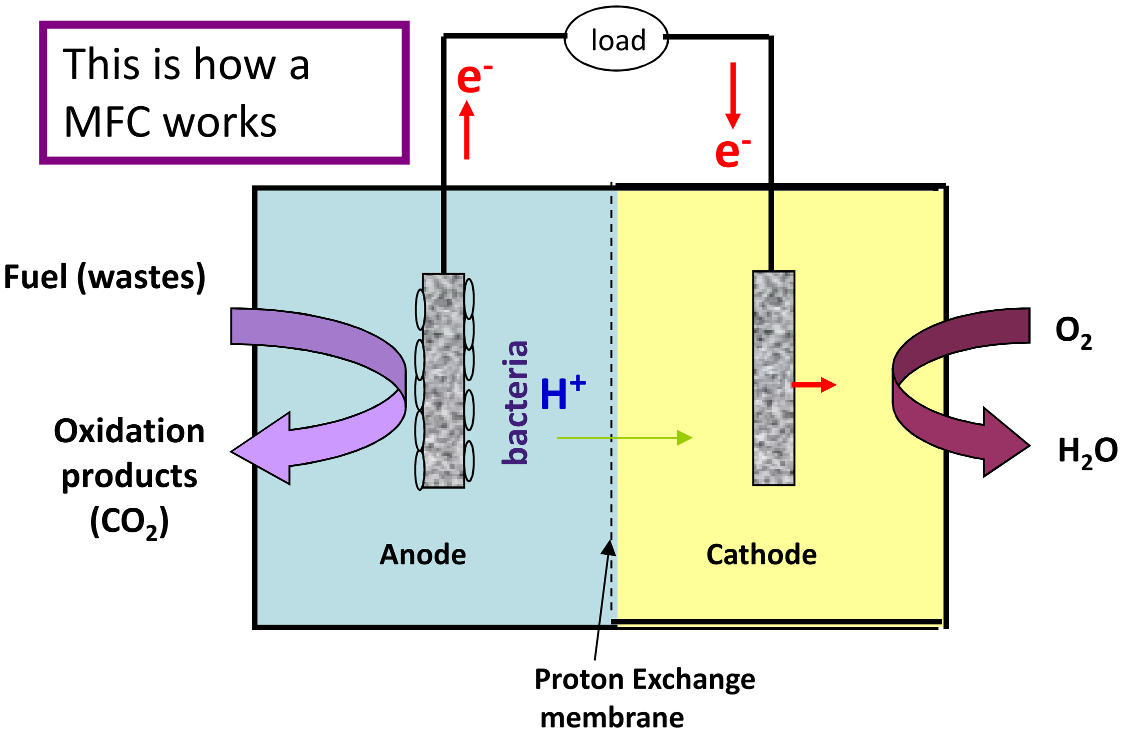



Diagram adapted from Nathan Lewis

# Energy in organic waste can be released as electricity via Microbial Fuel Cell (MFC)?

A MFC device forces bacteria to require energy from organic matter by producing electricity.

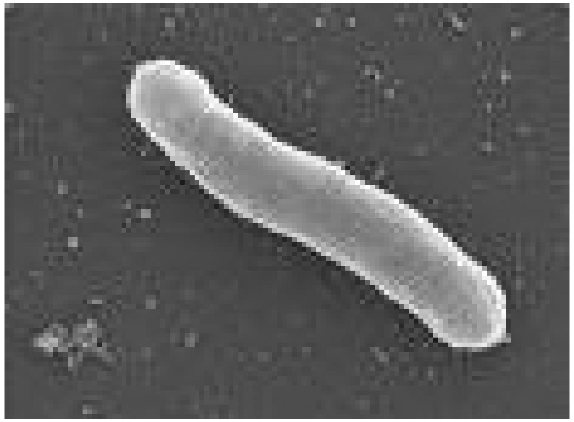
This is how a MFC works



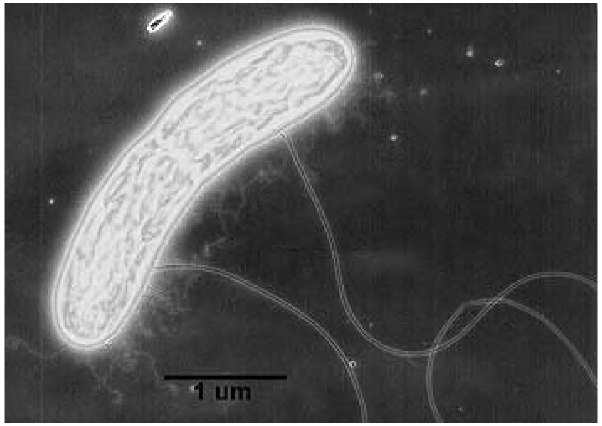

- Bacteria attach to anode and produce $CO_2$ and electrons
- Electrons transport to cathode to produce current
- Electrons and $H^+$ interact with oxygen to produce $H_2O$

Anode: organic waste + $H_2O \rightarrow CO_2 + H^+ + e^-$
Cathode: $O_2 + H^+ + e^- \rightarrow H_2O$
Overall reaction: organic waste $+ O_2 \rightarrow CO_2 + H_2O$

# Mechanisms of Microbial fuel cells



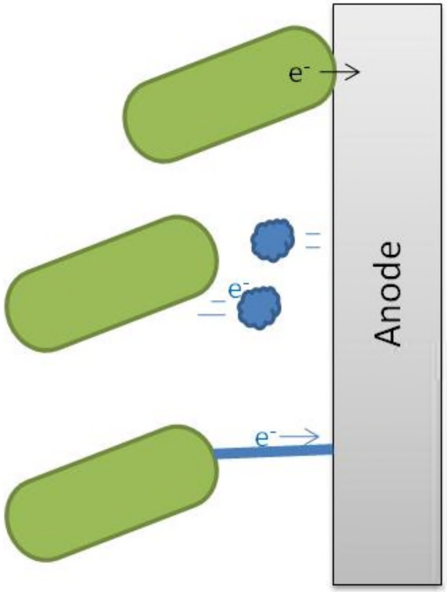
*Shewanella*
(aka Mr. Clean)

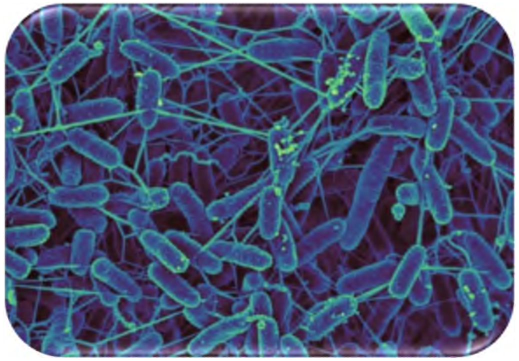



*Geobacter*
(aka The Iron-breather)

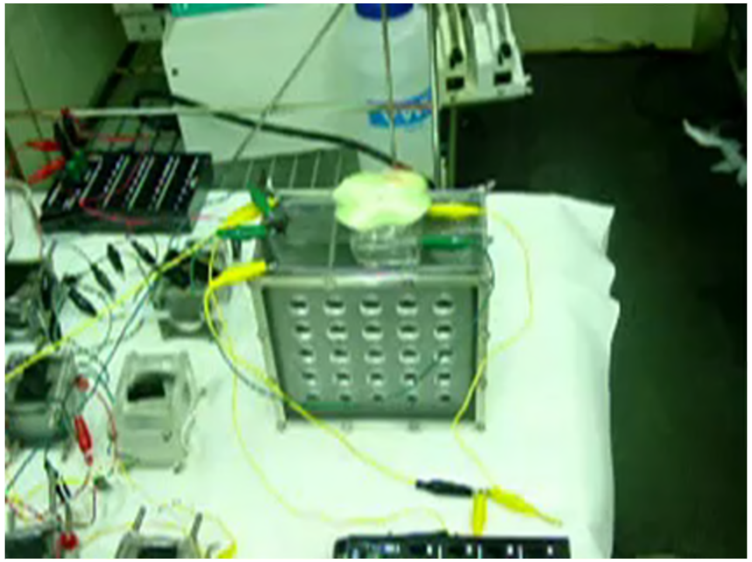
Electron Transfer Mechanisms:

- Direct Transfer
- Electron Shuttling
- Nanowires

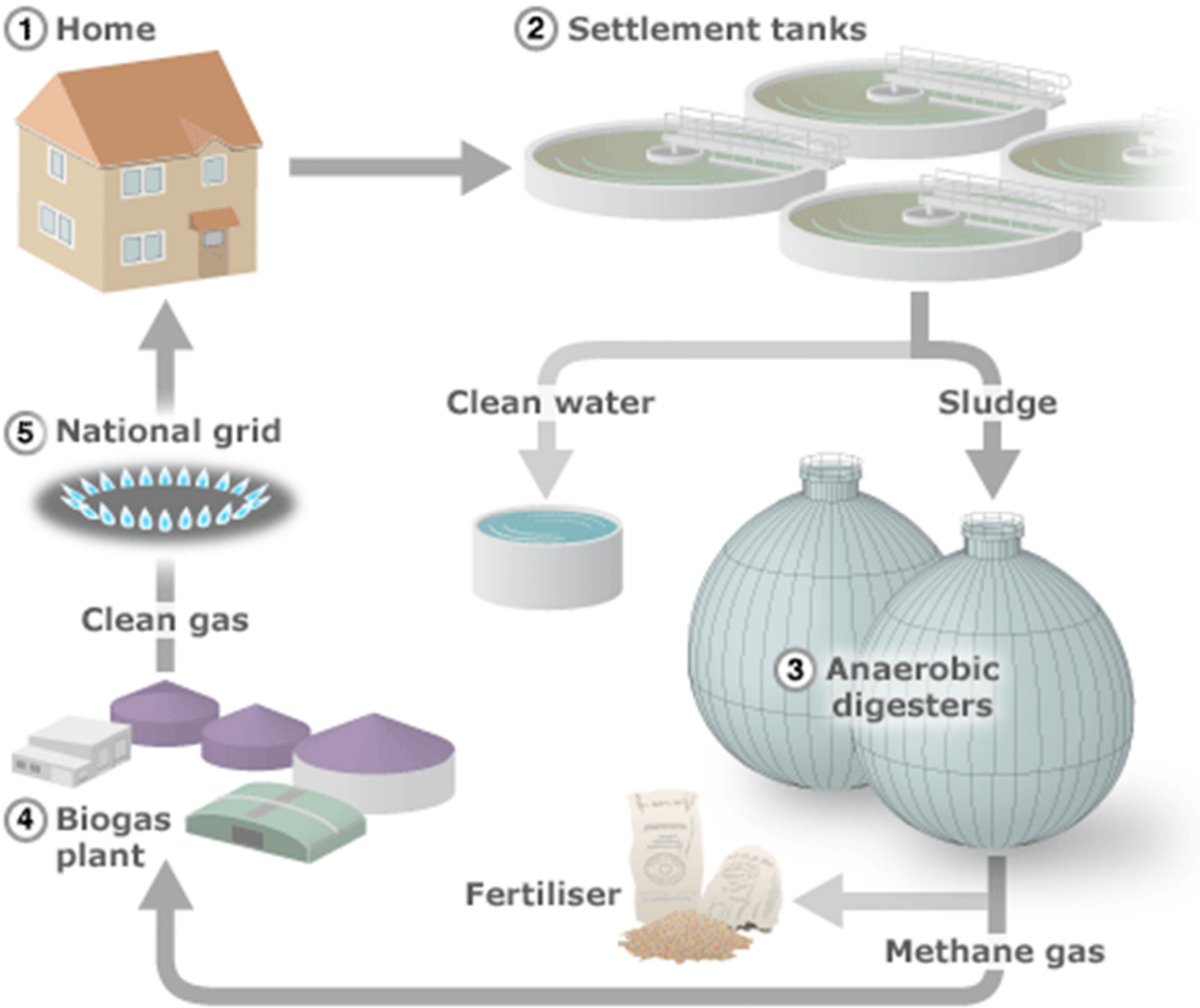


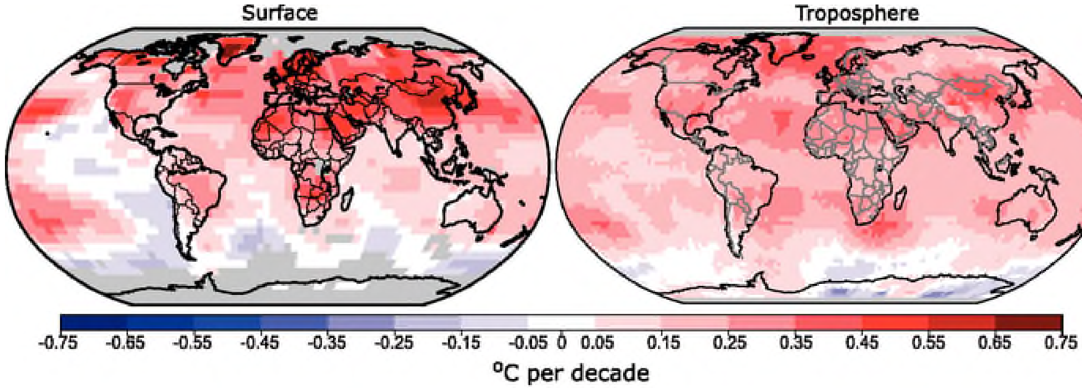
# Wastewater to produce electricity

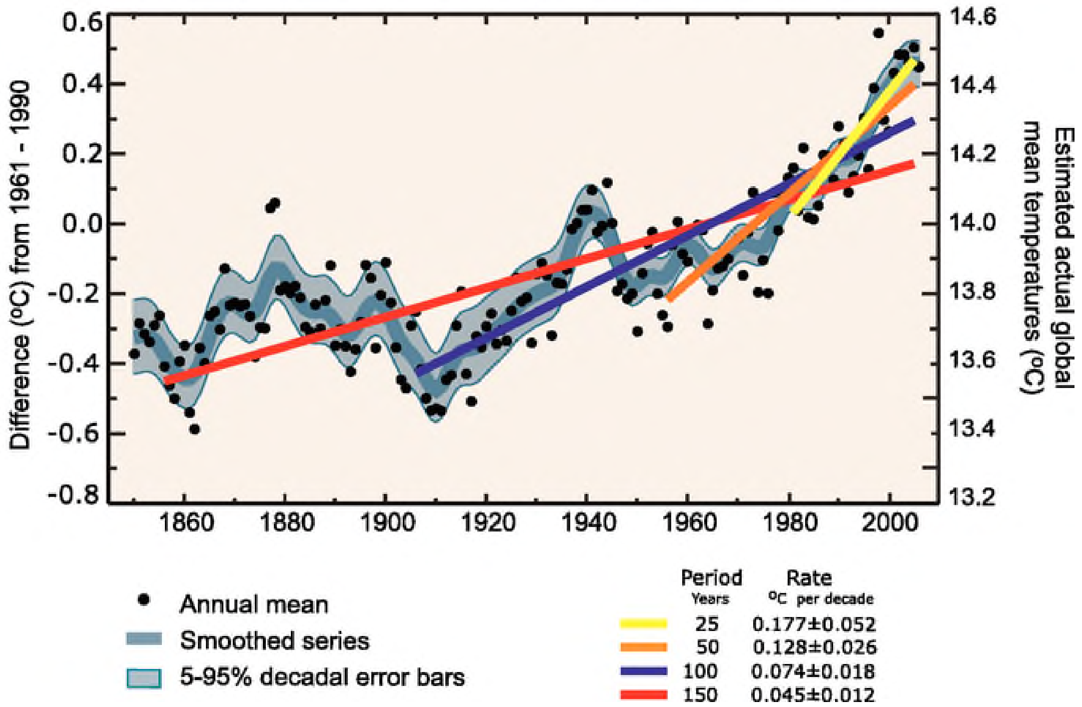


# Methane production from wastewater sludge



# Public attitudes – Climate change

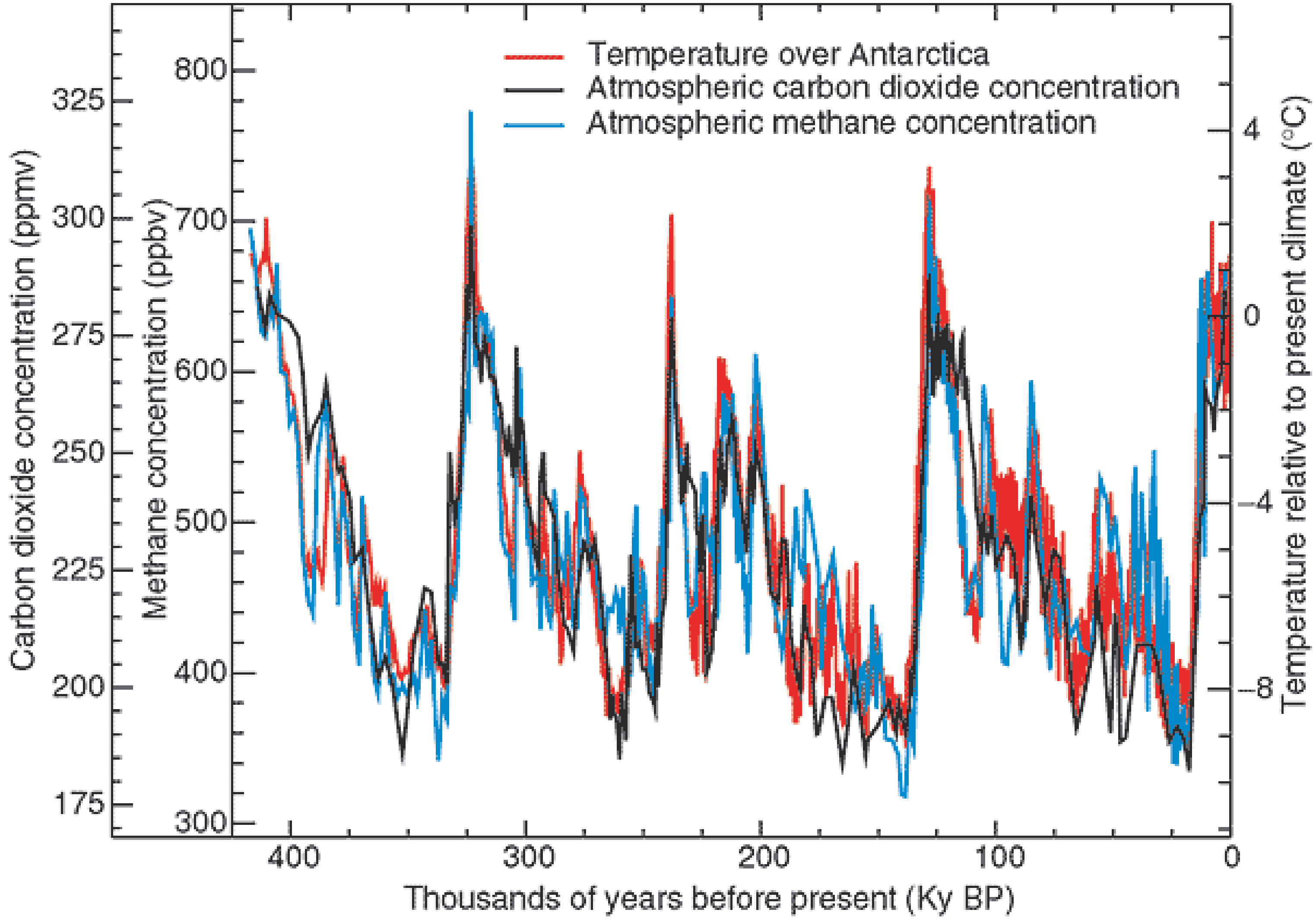



- In the last 100 years, the Earth warmed up by ~1° C
- 100 years is too small by geological time scales!

IPCC Fourth Assessment Report: Climate Change 2007

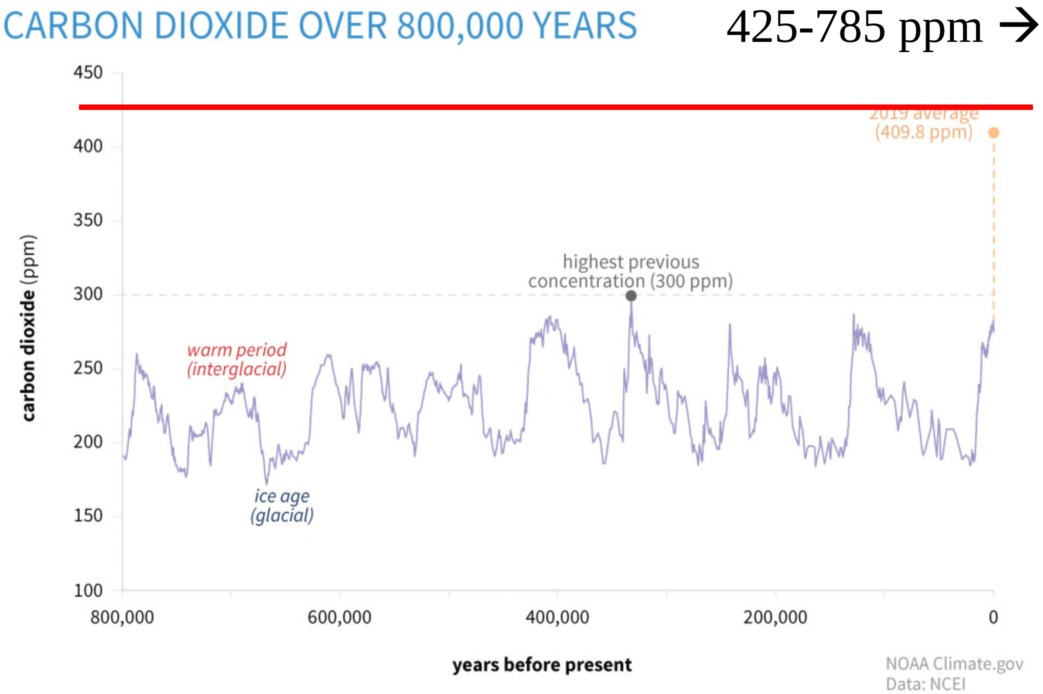
# Temperature over the last 420,000 years

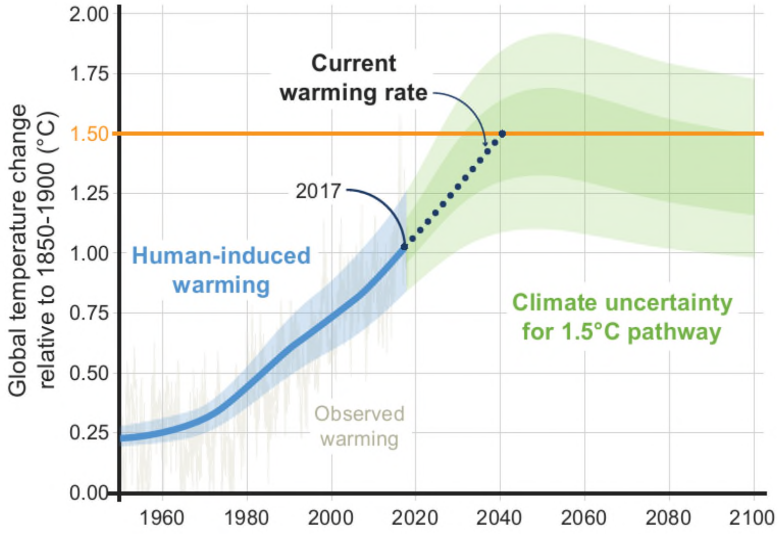



Source: Working Group I of the Intergovernmental Panel on Climate Change

# Global CO2 level

425-785 ppm → 1.5 $^oC$ increase




Global temperature increase above 1.5 C would have extreme weathers and significant damage to human society

https://www.metoffice.gov.uk/research/news/2018/how-much-co2-at-1.5c-and-2c

https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

# IPCC Scenarios

- A1 Rapid economic growth, population peaks then declines
  - A1F – Fossil intensive
  - A1B – Balanced energy supply
  - A1T – Non-fossil energy
- A2 More heterogeneous world
  - Regional development, technological changes fragmented and slow
  - Higher population
- B1 Convergent world
  - Same population peak as A1 but lower thereafter
  - More reliance on information economy, renewable energy generation
- B2 Similar to B1 but more diverse
  - Local solutions to economic, social, and environmental sustainability

In 1992 the IPCC released emission scenarios so-called IS92 scenarios were pathbreaking, which were the first global scenarios to provide estimates for the full suite of greenhouse gases.

http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

https://www.ipcc.ch/report/emissions-scenarios/?idp=0

# IPCC Scenarios

*Table 1a: Overview of main primary driving forces in 1990, 2020, 2050, and 2100. Bold numbers show the value for the illustrative scenario and the numbers between brackets show the value for the range[a] across all 40 SRES scenarios in the six scenario groups that constitute the four families. Units are given in the table. Technological change is not quantified in the table.*

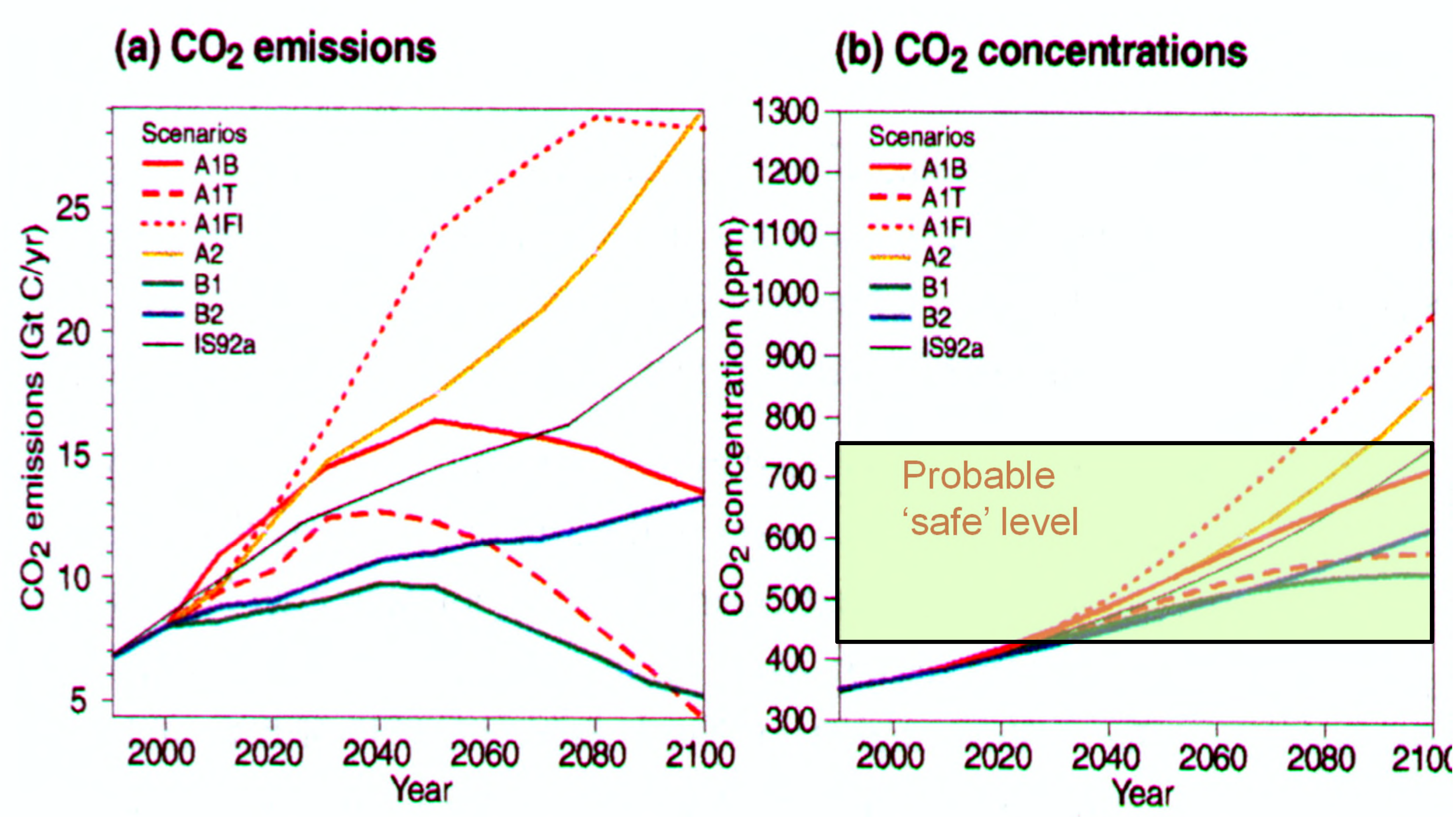
| Family | | A1 | | | A2 | B1 | B2 |
|---|---|---|---|---|---|---|---|
| Scenario group | 1990 | A1FI | A1B | A1T | A2 | B1 | B2 |
| Population (billion) | 5.3 | | | | | | |
| 2020 | | **7.6** (7.4-7.6) | **7.5** (7.2-7.6) | **7.6** (7.4-7.6) | **8.2** (7.5-8.2) | **7.6** (7.4-7.6) | **7.6** (7.6-7.8) |
| 2050 | | **8.7** | **8.7** (8.3-8.7) | **8.7** | **11.3** (9.7-11.3) | **8.7** (8.6-8.7) | **9.3** (9.3-9.8) |
| 2100 | | **7.1** (7.0-7.1) | **7.1** (7.0-7.7) | **7.0** | **15.1** (12.0-15.1) | **7.0** (6.9-7.1) | **10.4** (10.3-10.4) |
| World GDP ($10^{12}$ 1990US$/yr) | 21 | | | | | | |
| 2020 | | **53** (53-57) | **56** (48-61) | **57** (52-57) | **41** (38-45) | **53** (46-57) | **51** (41-51) |
| 2050 | | **164** (163-187) | **181** (120-181) | **187** (177-187) | **82** (59-111) | **136** (110-166) | **110** (76-111) |
| 2100 | | **525** (522-550) | **529** (340-536) | **550** (519-550) | **243** (197-249) | **328** (328-350) | **235** (199-255) |
| Per capita income ratio: developed countries and economies in transition (Annex-I) to developing countries (Non-Annex-I) | 16.1 | | | | | | |
| 2020 | | **7.5** (6.2-7.5) | **6.4** (5.2-9.2) | **6.2** (5.7-6.4) | **9.4** (9.0-12.3) | **8.4** (5.3-10.7) | **7.7** (7.5-12.1) |
| 2050 | | **2.8** | **2.8** (2.4-4.0) | **2.8** (2.4-2.8) | **6.6** (5.2-8.2) | **3.6** (2.7-4.9) | **4.0** (3.7-7.5) |
| 2100 | | **1.5** (1.5-1.6) | **1.6** (1.5-1.7) | **1.6** (1.6-1.7) | **4.2** (2.7-6.3) | **1.8** (1.4-1.9) | **3.0** (2.0-3.6) |

[a] For some driving forces, no range is indicated because all scenario runs have adopted exactly the same assumptions.

- Source: International Panel on Climate Change, 2002

https://www.ipcc.ch/report/emissions-scenarios/?idp=0

# IPCC Scenarios




***Source: IPCC WG3 Jan 2001***

http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

# Low carbon future or zero carbon emission

**Many routes to a low carbon future**

**Will it happen without positive action?**

**Need to start sooner rather than later -**
**Precautionary principle!**

**Governments and consumers have key roles**

**Governments:**

**Stop subsidies to fossil fuels (>$200 billion pa?)**
**Change planning regulations?**
**Encourage / stimulate renewables**
**Educate the public**
**Note: we spend £ billions on defence. Cost effective support for renewables might be regarded as 'insurance'**

# New science and technology are needed

## Science → Technology

**A solution may lie at the interface of biology**
**and**
**the physical sciences at the nano-scale**

- The pursuit of technological goals has led to some of the most innovative science.
- Science done with new technology has the best chance of discovery.

# A smart city

A smart city is a framework, application of Information and Communication Technologies (ICT), to promote *sustainable development* practices to address growing urbanization challenges.

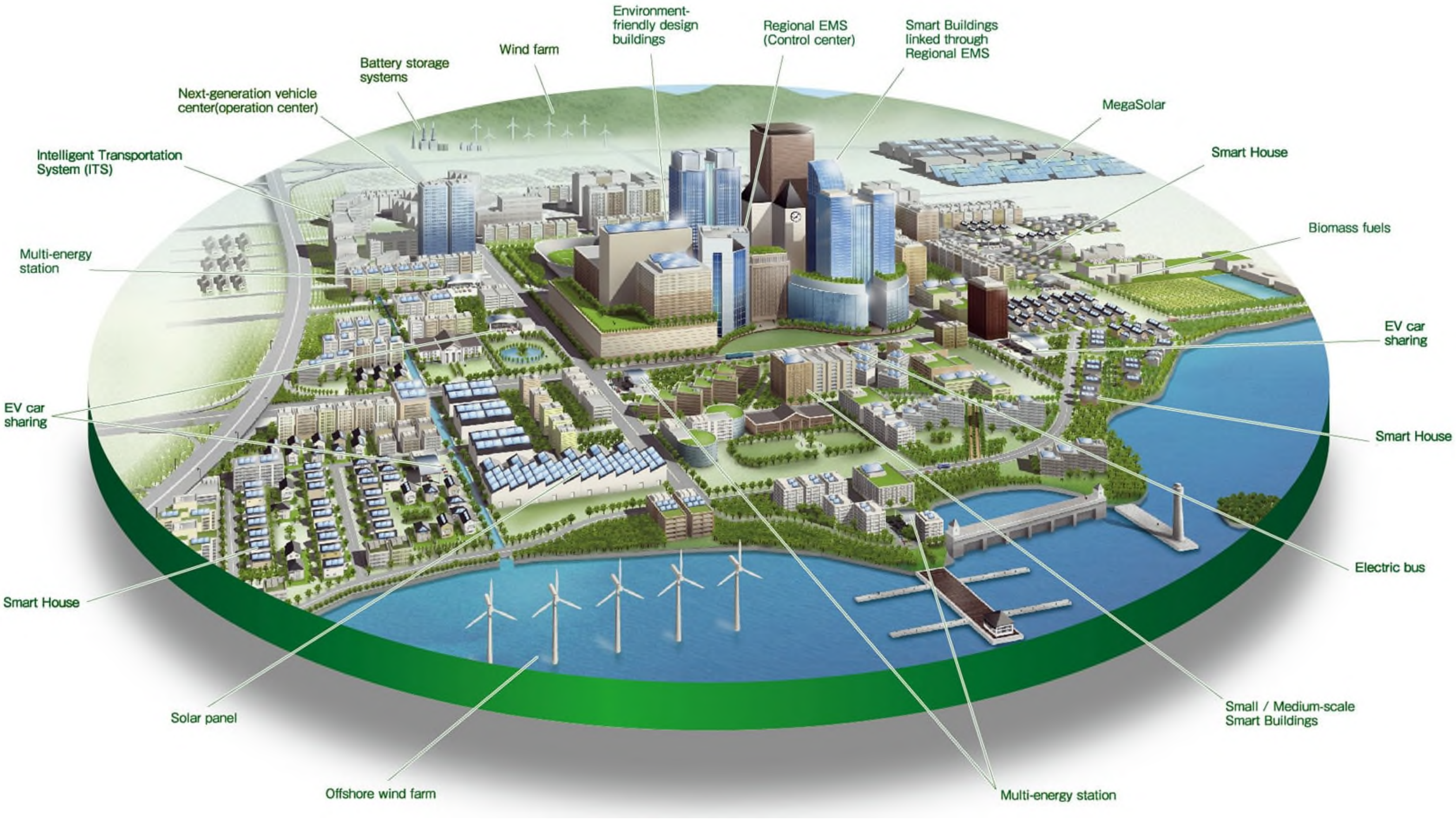
ICT: Intelligent network of connected objects and machines that transmit data using wireless technology and the cloud.

Cloud-based innovative Internet of Things (IoT) applications receive, analyse, and manage data in real-time to help to make better decisions that improve quality of life.

**Citizens** engage with smart city ecosystems in various ways using smartphones and mobile devices. Pairing devices and data with a city's physical infrastructure and services can cut costs and improve sustainability.

**Communities** can improve energy distribution, streamline trash collection, decrease traffic congestion, and even improve air quality with help from the IoT.

# Smart city with energy efficiency




https://www.xenius.in/energy-efficiency-smart-solutions-future-sustained-living/

# Why we need smart city?

- Urbanization is a non-ending phenomenon.
- Today, 54% of people worldwide live in cities, a proportion that’s expected to reach 66% by 2050.
- Combined with the overall population growth, urbanization will add another 2.5 billion people to cities over the next three decades.
- Environmental, social, and economic sustainability is a must to keep pace with this rapid expansion that is taxing our cities’ resources.
- One hundred ninety-three countries have agreed upon the agenda of the Sustainable Development Goals (SDGs), in September 2015 at the United Nations.

https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/inspired/smart-cities

# Oxford Smart City

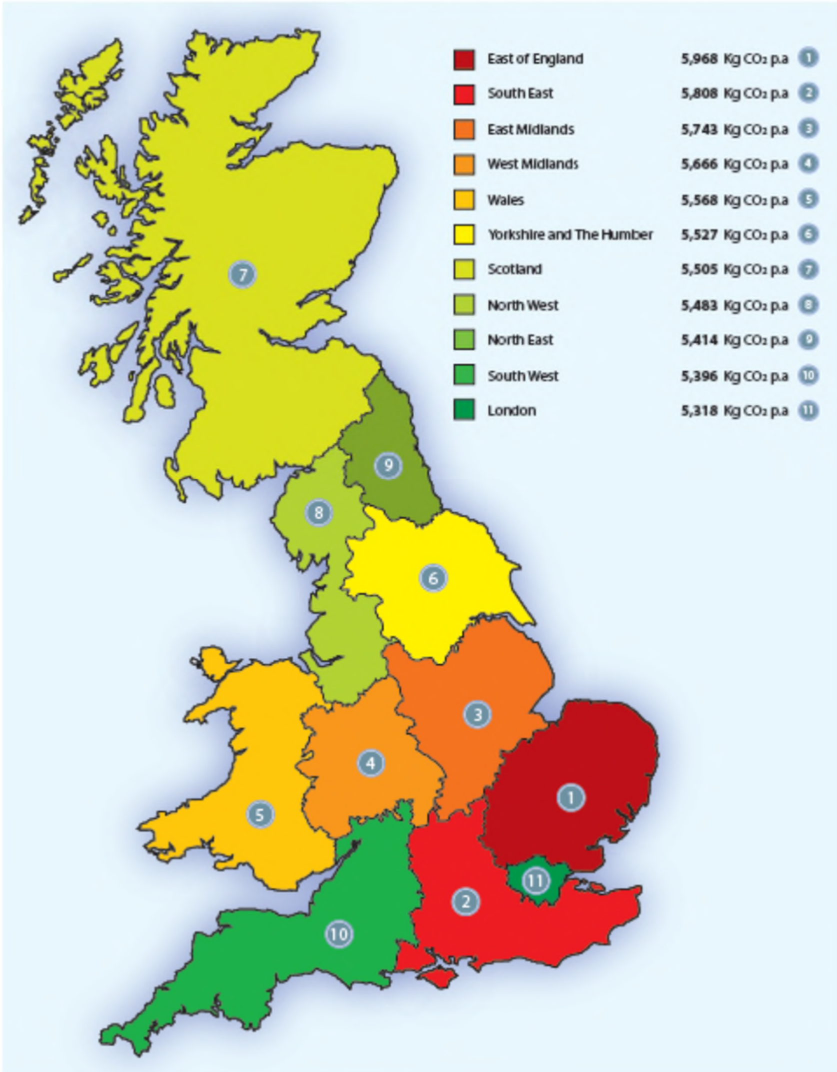
Four essential elements necessary for thriving smart cities:

- Pervasive wireless connectivity
- Open data
- Security you can trust in
- Flexible monetization schemes


Part funded by the European Regional Development Fund, Smart Oxford is the strategic programme.


http://oxfordsmartcity.uk/oxblog/home/

## Average Domestic Carbon Dioxide Emissions Across Britain



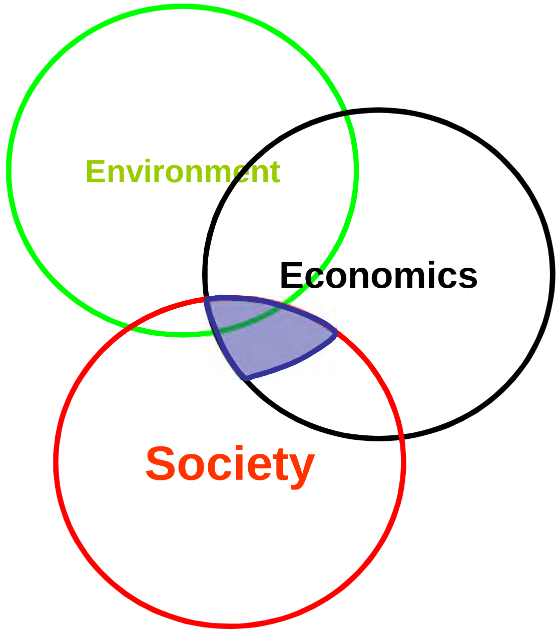

WESTMILL WIND FARM

CO-OPERATIVE LIMITED

**Our share of the Westmill windfarm created new generation capacity equivalent to our net annual electricity use**

# The engineer's tale - summary

- Household energy consumption now 54% of 1999 value and 64% of UK average
- Energy use per $m^2$ 37% of UK average
- $CO_2$ emissions 29% of 1999 value (and 33% of UK average)
- This all came at a cost
  - Certainly not 'economic'
- But it was (and is) good fun (and might be thought sustainable)



# Conclusions

- Sustainable development the key issue for the 21st Century
- Will require a major change of approach
- Affordable energy essential for development
- Scientific evidence clearly suggests manmade emissions of Greenhouses Gases having ‘a discernible influence on global climate’
- Significant scope to reduce energy consumption
- Renewable energy has the potential to meet future demand

# Further reading and acknowledgement

## Further reading:

World Energy Scenario 2016
https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Scenarios-2016_Full-Report.pdf

IPCC emission report
http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

Nathan S. Lewis and Daniel G. Nocera,
Powering the planet: Chemical challenges in solar energy utilization. PNAS October 24, 2006. 103 (43) 15729-15735;
https://doi.org/10.1073/pnas.0603395103

Nathan Lewis, Powering the planet. MRS BULLETIN 2007

## Thanks

- David Nowell, Roger Booth, Richard Darton, Malcolm McCulloch