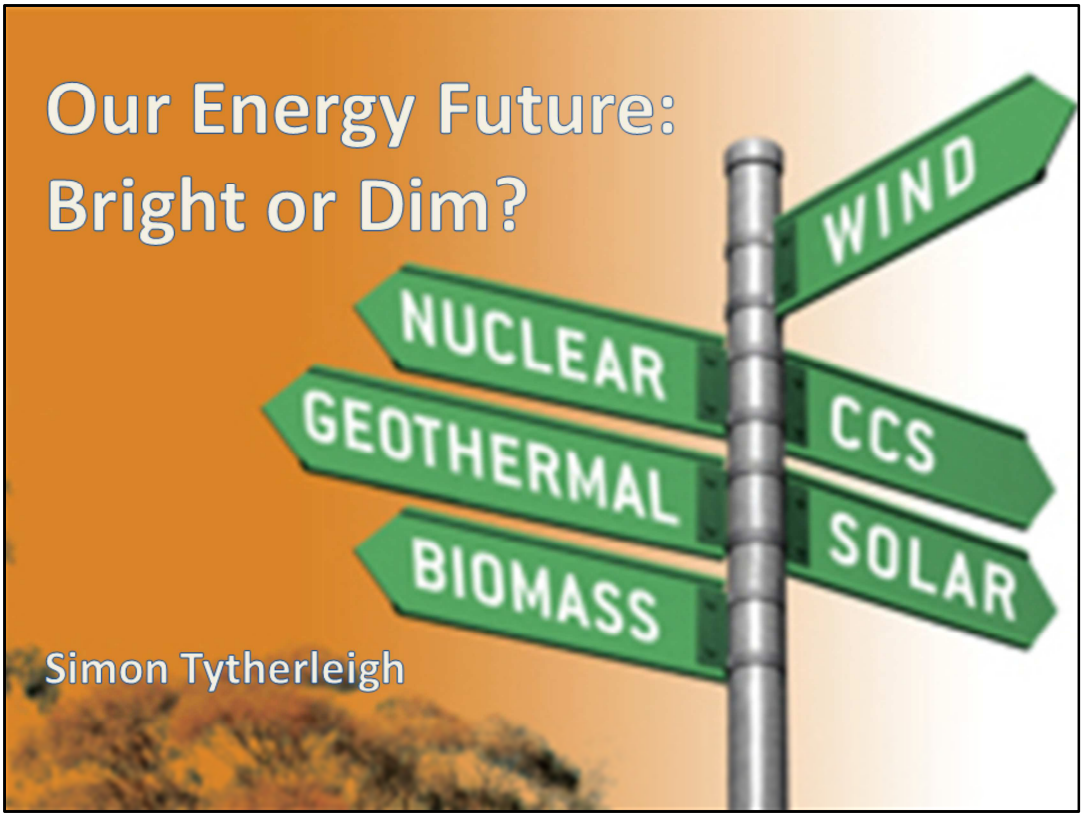
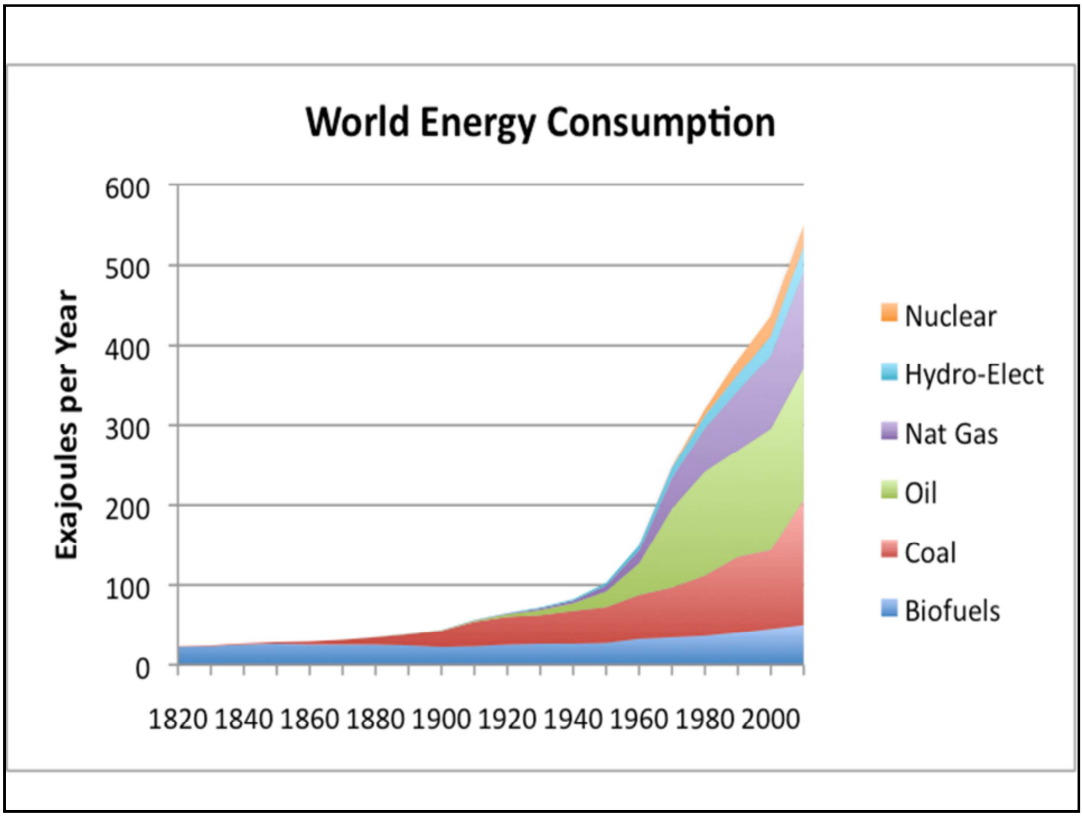
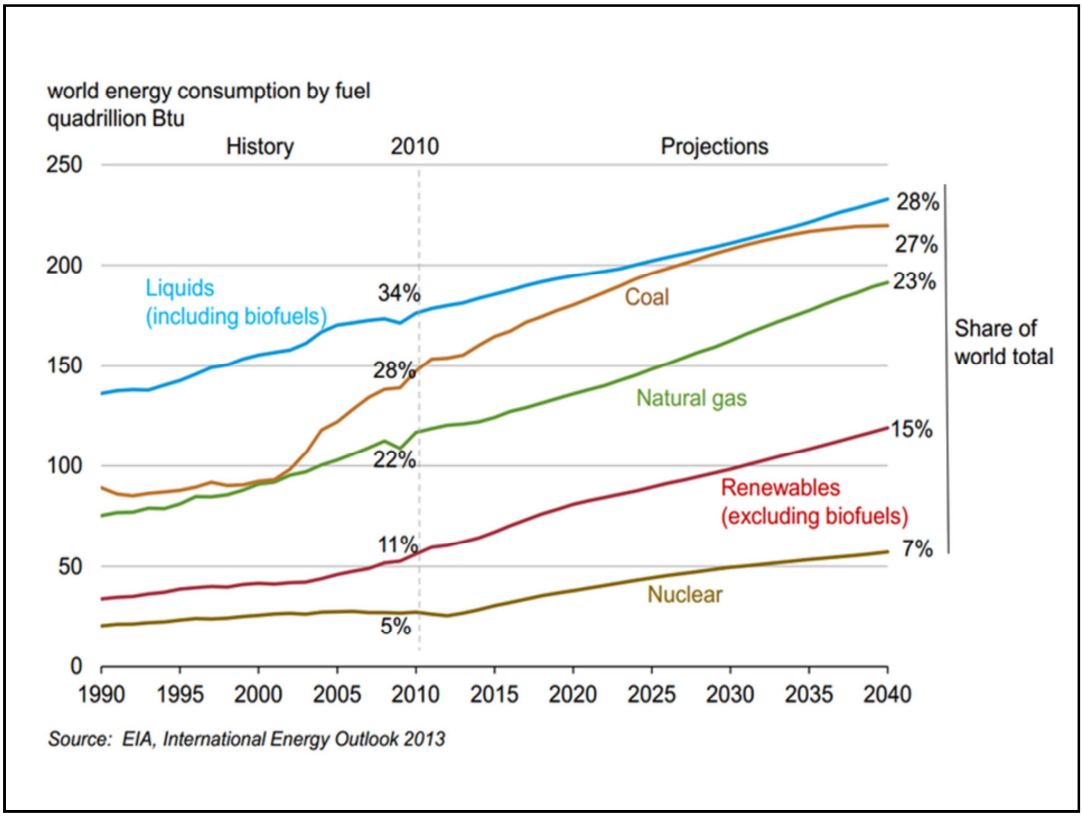


Where are we headed in energy terms? What is the effect of renewables on a system designed for centralised power generation from fossil fuels? And is disruption ahead?



This much we know:

- Energy consumption has increased exponentially over the last century
- The vast majority of the increased consumption has been of fossil fuels
- Although energy demand in developed countries has reduced slightly recently, due to efficiency measures, global demand continues to increase



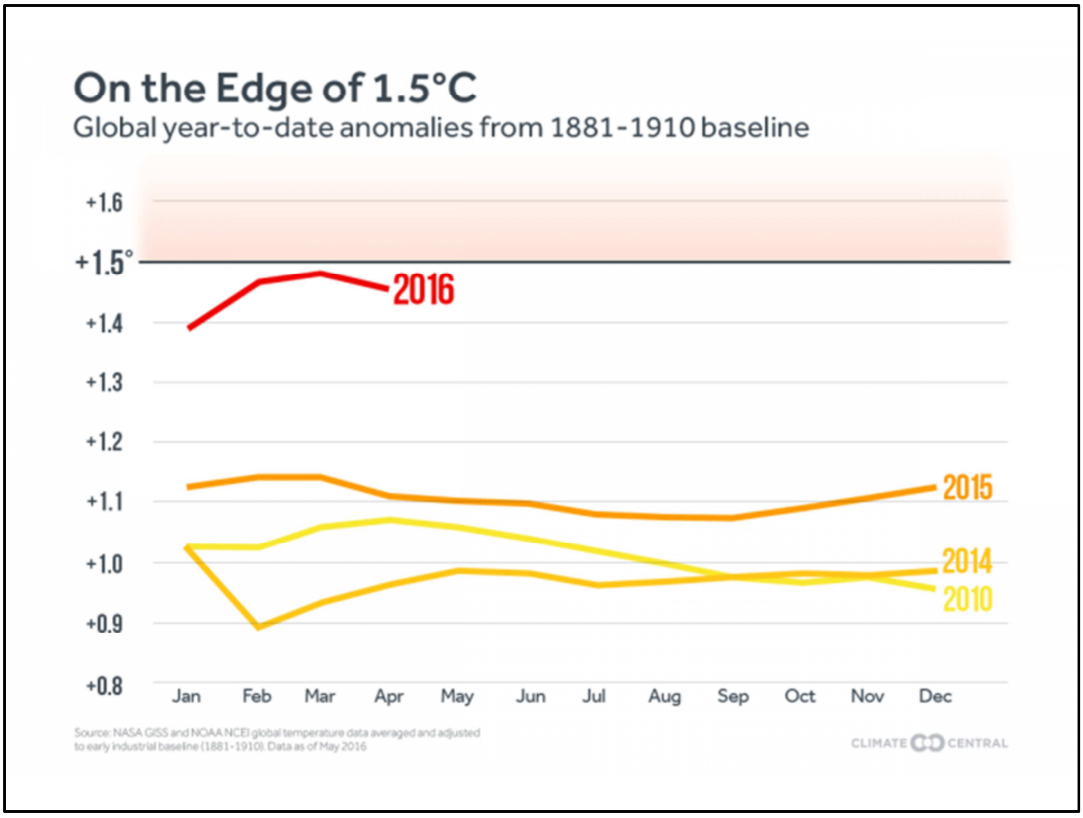
This is the standard graph of recent estimates of future energy consumption, put out by the US Energy Information Agency in 2013.
It suggests fossil fuels will continue to make up about 80% of consumption.
Coal is shown increasing its share before dipping towards 2040
Renewables are shown as increasing linearly to 15% of the mix.
Globally consumption continues to rise.

But we know, from the science, that this business-as-usual scenario will condemn the planet to temperature rises between 4 and 6 degrees C. Therefore it is unrealistic and/or suicidal.
The only way this prediction can play out is if global warming does not happen or sufficient measures are taken to counteract warming or the emission of CO2.

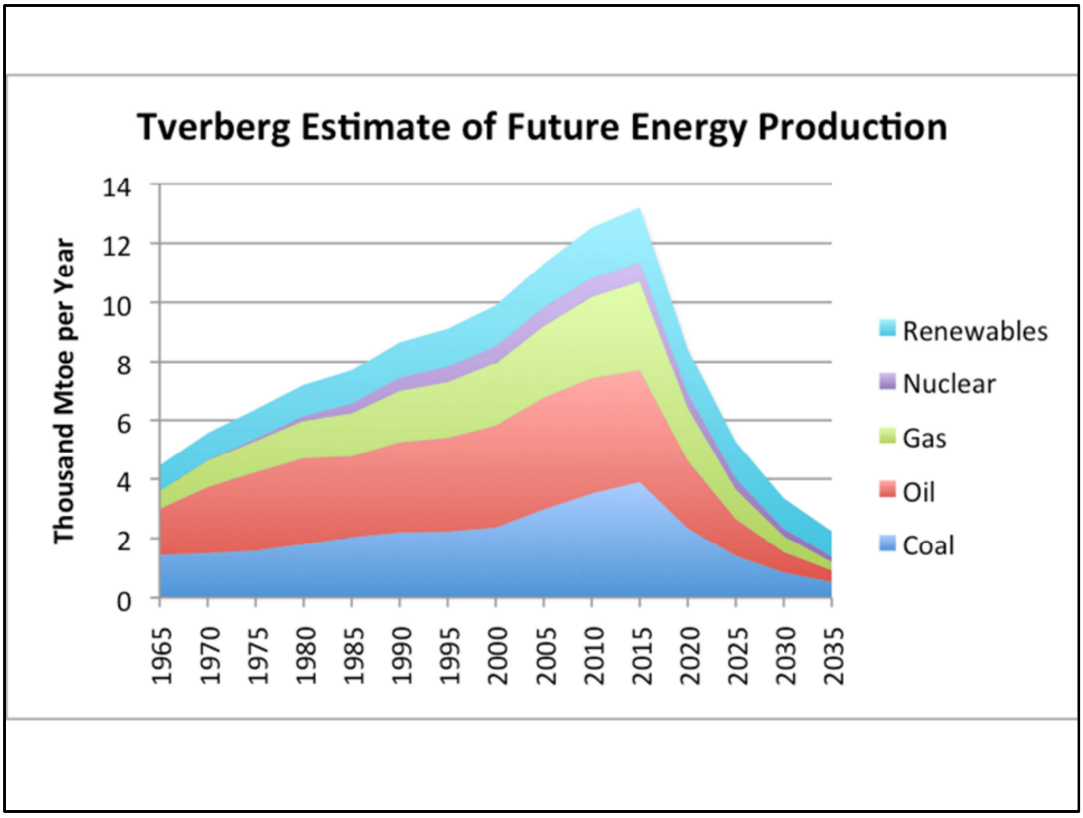
We also know that we have an overall carbon dioxide budget, if the planet is to remain below 2 degrees C of warming. This is one trillion tonnes.

If we continue with emitting at present rates, the last permissible tonne of CO2 will be emitted in 2038. Beyond that date either all CO2 emissions will have to cease or the planet risks uncontrollable warming.

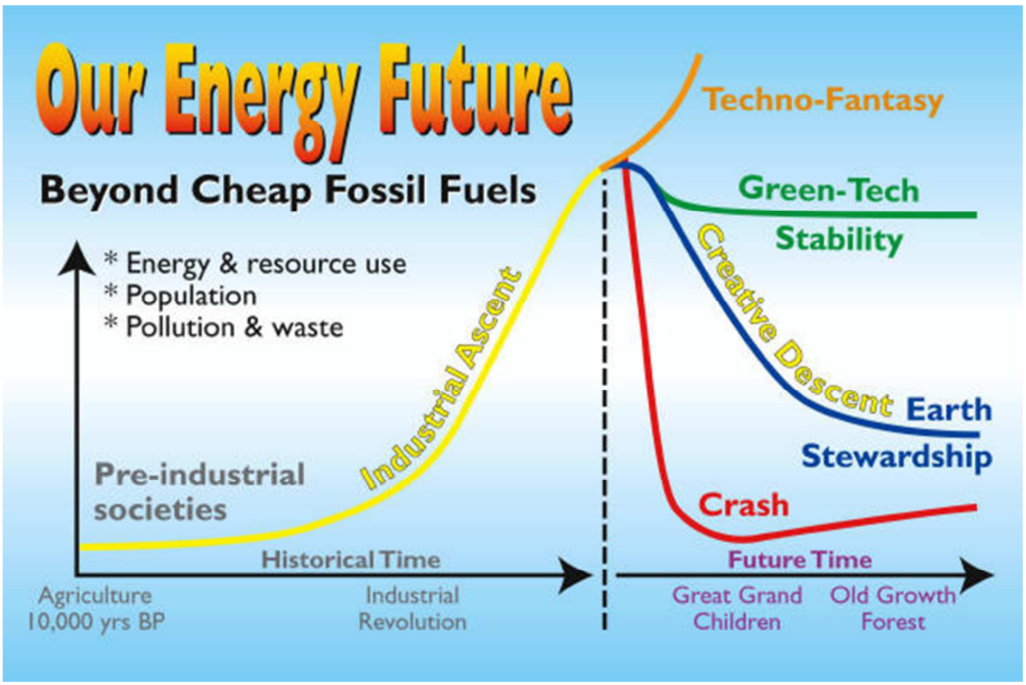
Bear in mind that the Paris Accord gave 1.5 deg C as the limit.



And we also know that we are already seeing a lot of warming. 2016 was the hottest year on record. Australia has experienced severe heatwaves. The Arctic seaice extent is at its lowest ever.



So the conventional response is to limit fossil fuels.
It suggests renewables cannot increase very much, and that energy consumption has to fall by about 80%.
This is just as unrealistic as the graph showing unlimited use of fossil fuels in 2040. No one is going to give up their energy-rich lifestyle without a fight.



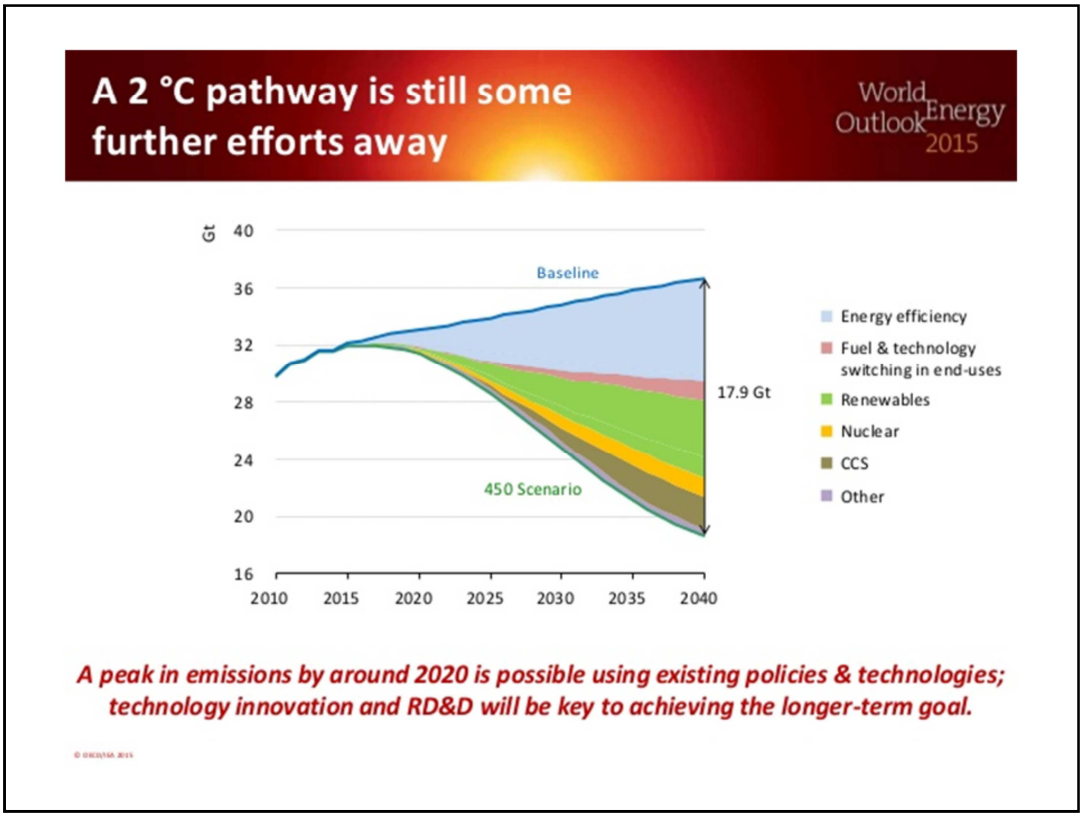
This graphic lays out the options.
The RED line is the business-as-usual route, followed by an emergency stop to CO2 emissions when the world suddenly wakes up to the crisis. Not a clever choice, perhaps best called the Trump Option!

The ORANGE line of Techno-Fantasy is the geo-engineering route. This involves using untested (and untestable) technologies such as injecting sulphur dioxide into the stratosphere, iron filings in the oceans, mirrors in space. There are several problems with this approach:

- Once started, we are committed to coninue or risk sudden heating
- There will be unforeseen consequences such as the failure of monsoons, alteration of weather patterns etc.
- Who controls it? This becomes a very difficult political issue.

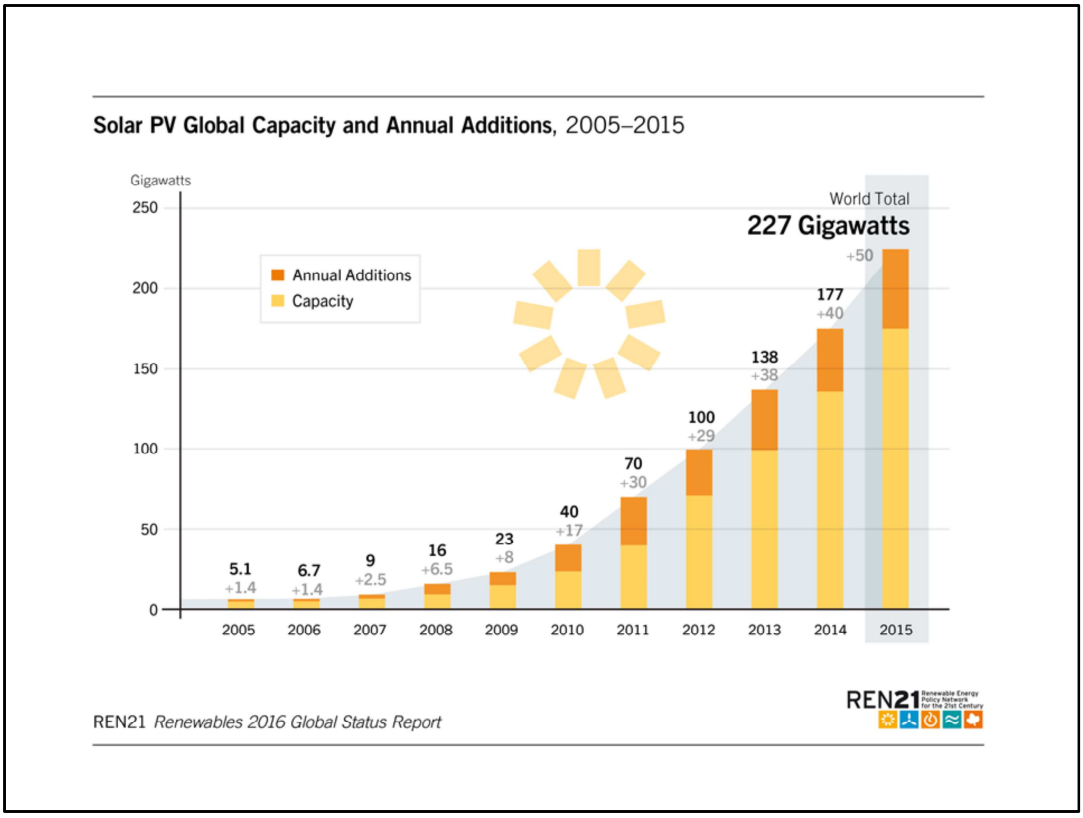
The BLUE line is the commitment to learn how to live on a finite planet, as exemplified by the Transition movement. I think this will have to follow the emergency action needed now. It involves humanity growing out of its adolescent behaviour, adopting a realistic economic system and more equitable distribution of resources as well as changing our attitude to the species we share the planet with. A longer term project.

The GREEN line, green tech, is what I am concerned with here. Is it possible for green technology to change our energy consumption to a degree that enables us to avoid excess warming?

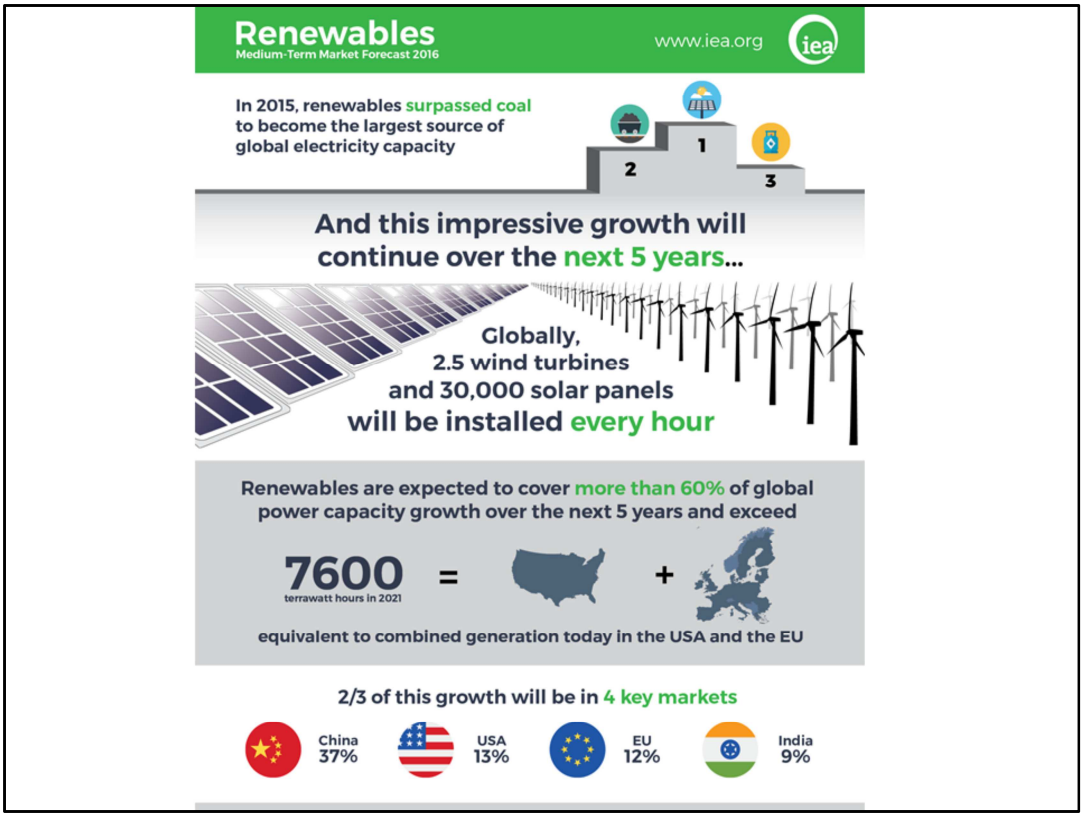


A recent World Energy Outlook from the respected International Energy Agency suggests an ambitious pathway:

- Lots of energy efficiency measures
- Some switching from e.g. coal to gas
- A much bigger increase in renewables than the modest progress suggested by the 2013 graph
- Modest increase in nuclear
- An ambitious target for Carbon Capture and Storage, which has not been demonstrated at scale and will add 25-40% to fossil energy bills.

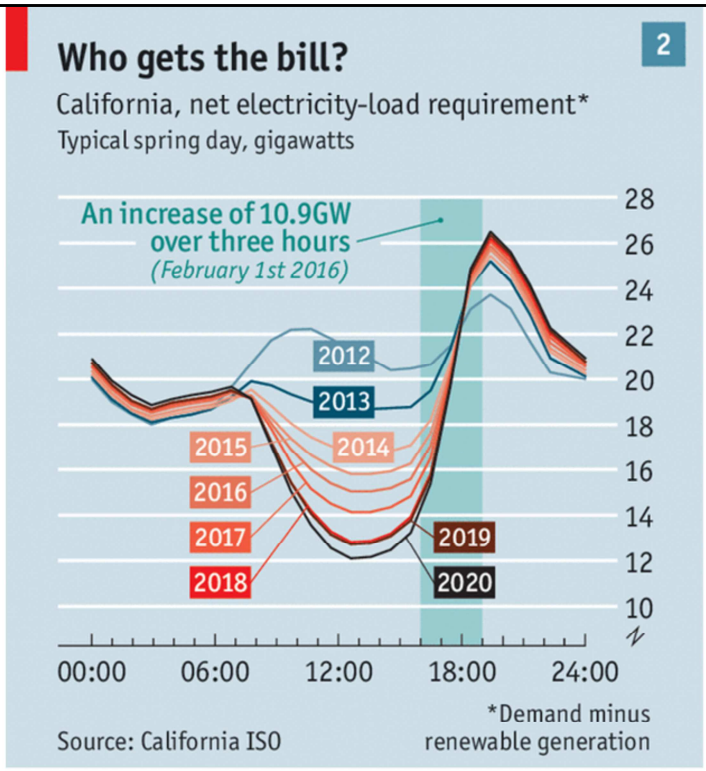


But something remarkable has been happening recently, and the big agencies have not yet taken notice.
Solar PV has been growing exponentially. This graph goes up to 2015. In 2016 an additional 70+ gigawatts of capacity were added.
And the explosive growth shows no sign of slowing. Instead it is accelerating.



This graphic is also from the IEA.

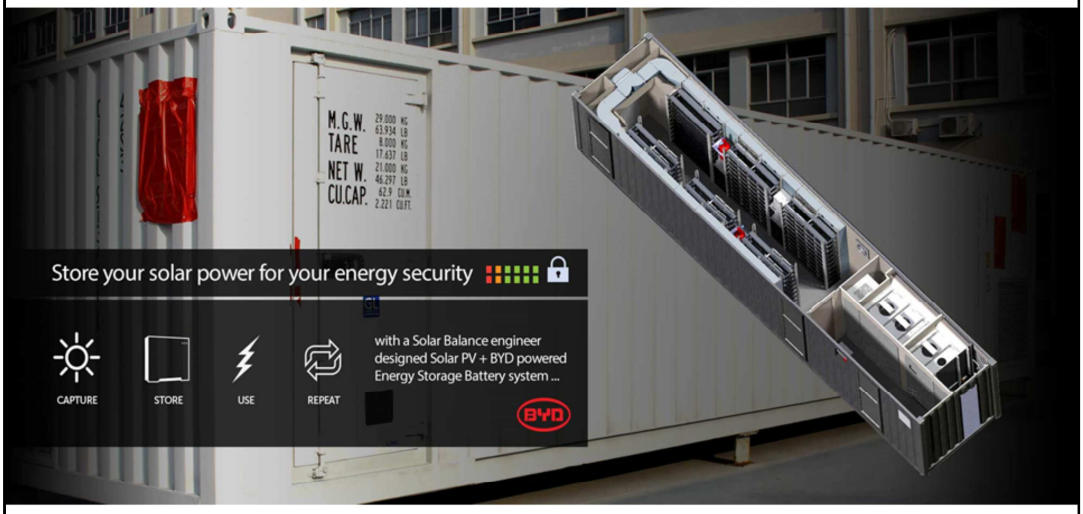
- Coal has been supplanted as the primary source of energy for electricity – also a change from the 2013 prediction.
- In 2016 500,000 solar panels were installed EVERY DAY!
- China is in the lead, both in production and installation. The leaders may be able to bring in clean water and food, but they have discovered that they still have to breathe the same air as the rest of the population.
- The US is installing a lot of Solar PV. In California this is now the cheapest means of generating electricity.
- India has a large programme of installation.
- In Mexico one PV energy provider surprised everyone recently by offering the lowest rate ever seen for supply, undercutting all fossil fuels
- Across the world we are beginning to see Solar PV reaching parity with all other energy sources, and this is highly disruptive



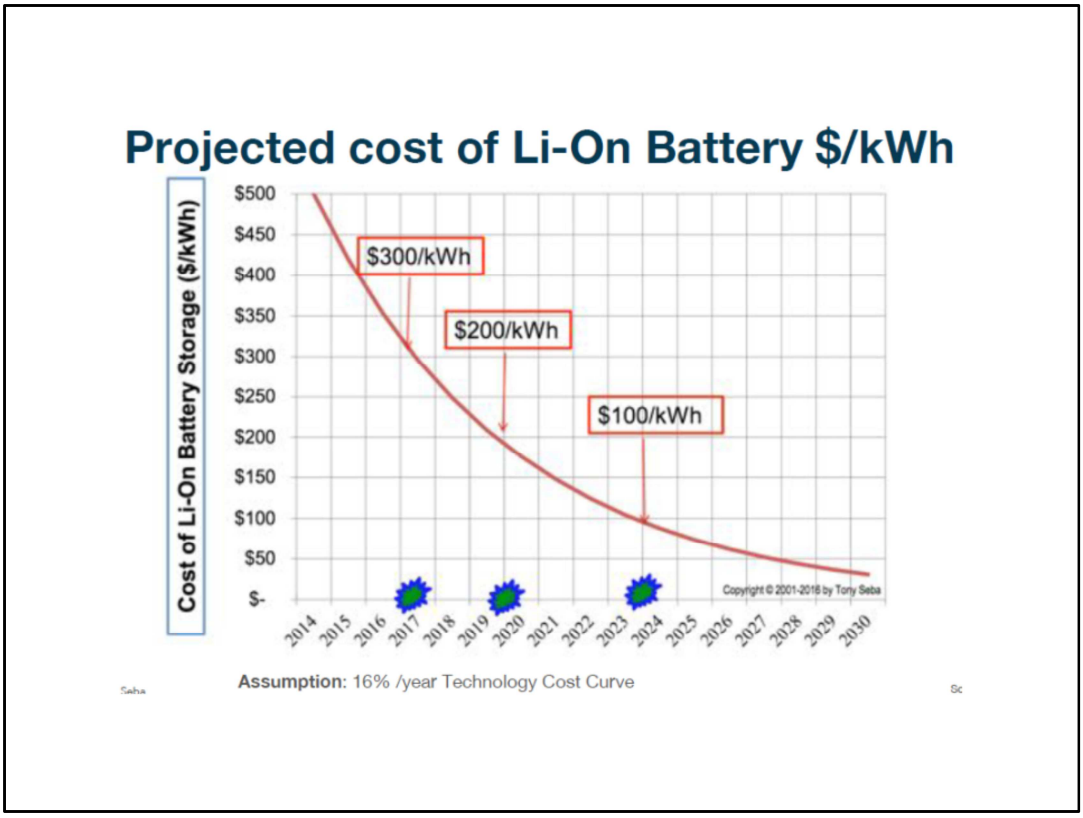
The rapid rise of Solar PV has taken utility companies by surprise too, and it is disrupting their business models.
This graph shows a typical day in California, with steady demand during the night and early morning, dropping away as domestic PV reduces demand, and rising dramatically during early evening to a peak at around 2000.
This characteristic shape is called the 'duck'!
It presents serious challenges. Subsidies for solar generation are making things progressively worse and forcing the utility companies to make capacity payments to back-up conventional generators, effectively paying them just to remain on standby.
The UK government paid £76 million this winter to keep 2 coal-fired power stations on cold standby in case demand exceeded supply – although it has to be said that solar PV does not contribute much in the UK winter, wind is the main contributor.

When solar PV is supplying energy it beats every other competitor, as the marginal cost of energy is near zero. In fact, because the energy has to go somewhere once generated, solar electricity is sometimes sold at less that zero – paying to take the stuff away!

The economist article (Feb 2017) can be found here:
http://www.economist.com/news/briefing/21717365-wind-and-solar-energy-are-disrupting-century-old-model-providing-electricity-what-will



And there's more….
Businesses can be charged a variable tariff for electricity, making them pay much more for energy at peak times.
In order to save money and provide resilience they are increasingly installing back-up generation or electricity storage, often taking the form of a standard shipping container full of lithium-ion batteries. This enables them to charge up when energy is cheap, then switch to battery power when rates go up.
This reduces the steepness of the duck's neck in the early evening, but there is one major drawback – the utility company is not in control any more. Another threat to their business model.

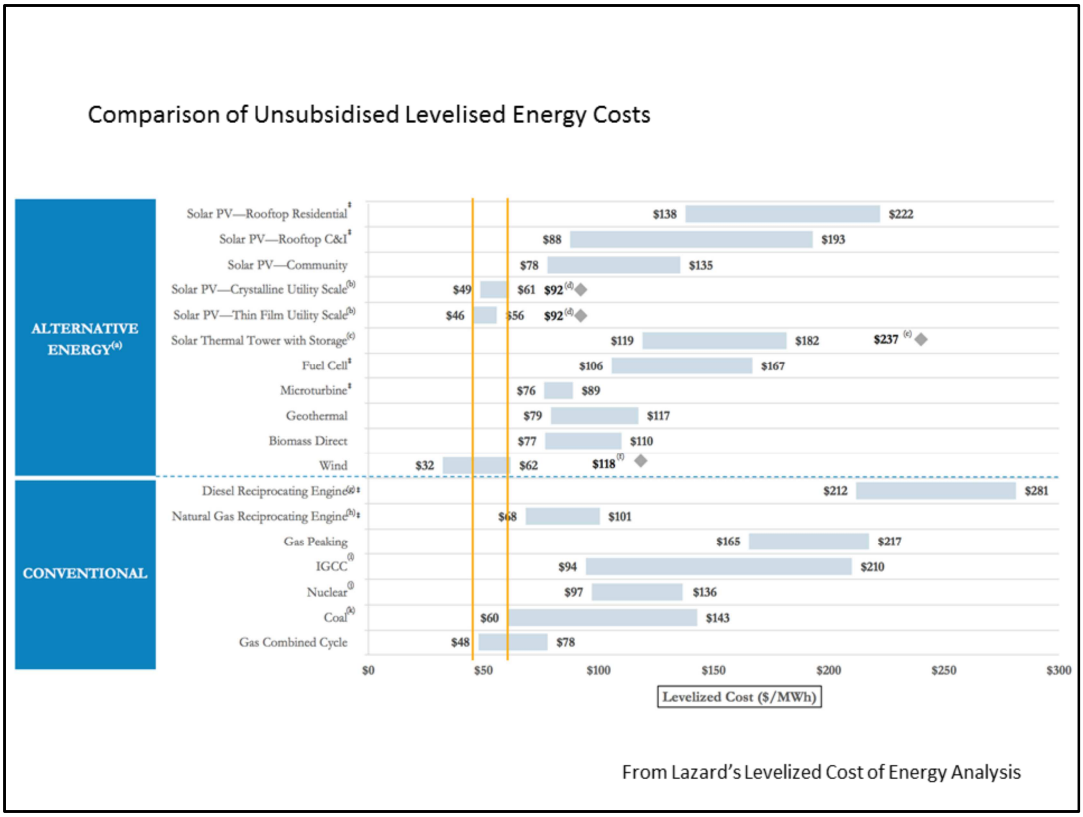


As a result of the demand for battery storage, costs are falling fast, at around 16% a year. Battery storage is clearly the key to maximising the effectiveness of solar PV, and the fact that both these technologies are following a similar cost reduction curve suggests that they have a combined effect.

In areas that have not had a conventional electricity grid, such as large parts of Africa, solar PV plus battery storage now offers a chance to leap-frog technologies and create community-sized systems. Reliable electricity for such regions is likely to spark a revolution in many aspects of people's lives, not least education.

The largest off-grid PV plus storage system in the world has been installed in Rwanda: https://www.pv-magazine.com/2016/06/14/worlds-largest-off-grid-battery-system-headed-to-rwanda_100024973/

The rise in renewables is considered to be unstoppable, according to Bloomberg New Energy Finance:
https://www.bloomberg.com/company/new-energy-outlook/



The unstoppable rise of renewables is due to the fact that they are now reaching parity with all other energy sources – even unsubsidised, as shown in this chart.

One tends to forget that conventional sources are fuels, when solar and wind are essentially technologies, so that once installed they continue to provide energy for a long period of time with minimal ongoing costs. Gas, oil and coal need to be continually found, mined and refined and therefore cannot be subject to the cost reduction curves that solar and wind are experiencing.

(It should be noted that solar PV has one great advantage over wind – no moving parts means little or no maintenance or parts to wear out. This does not mean that wind does not have a place in future energy supply.)

Here's a picture of the new Tesla factory being built in the US. When Elon Musk announced his range of battery storage, the company received nearly $1 billion dollars in advanced orders! As a result the factory will be increased by 45% in size.

Musk has said that battery prices will halve by 2020.

Former Tesla executives have announced plans to build a large battery plant in Scandinavia:
https://www.msn.com/en-us/money/companies/former-tesla-executives-plan-to-build-dollar4-billion-nordic-battery-plant/ar-AAnUKs1

And last year LG Chem of South Korea abandoned plans to build a petrochemical plant in Kazakhstan to concentrate more on batteries for Electric Vehicles:
http://www.chemicals-technology.com/news/newslg-chem-cancels-42bn-petrochemical-project-in-kazakhstan-4794845

As if this was not enough, the acceleration of solar is about to be ratcheted upwards by solar window technology. This is due to come to market this year.

The company behind these windows estimates that the payback time for its products will be less than one year, making it a no-brainer for anyone building an office block. The area that can be covered by solar windows is around 50 times greater than the available roof area for conventional panels.

Better still, the system will be available as a film to retrofit to existing windows.

http://solarwindow.com/technology/

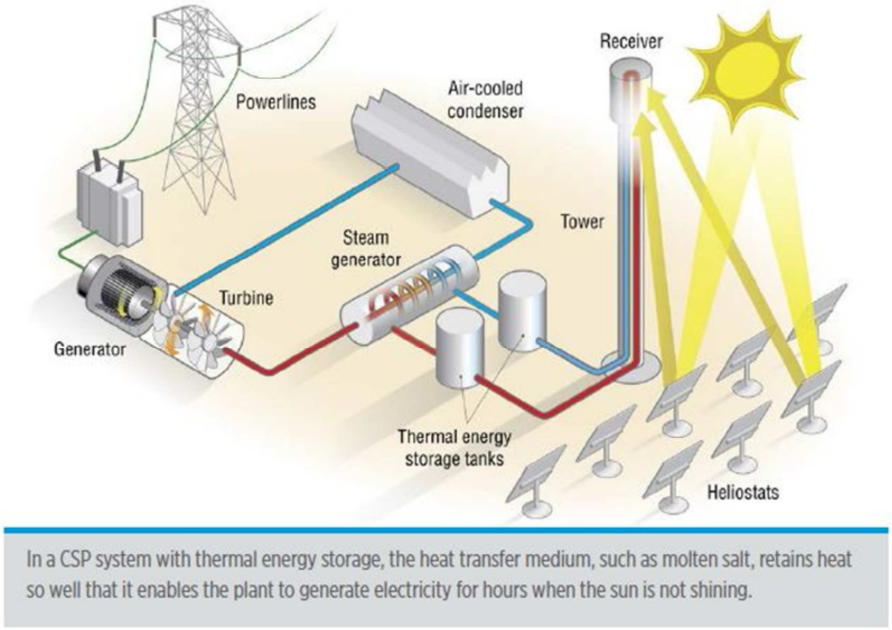
And solar roof tiles in varying styles will become available. Estimates are that they could account for 5% of new roofing business by 2020.

Although they do not generate quite as much as standard PV panels, they can be integrated into existing roofs more neatly.

http://www.solarcentury.com/uk/c21e-tiles-and-slates/

https://www.theguardian.com/environment/2016/oct/29/tesla-boss-elon-musk-unveils-solar-roof-tiles

This is another form of Solar power – Concentrated Solar Power, using mirrors and a collector.



In a CSP system with thermal energy storage, the heat transfer medium, such as molten salt, retains heat so well that it enables the plant to generate electricity for hours when the sun is not shining.

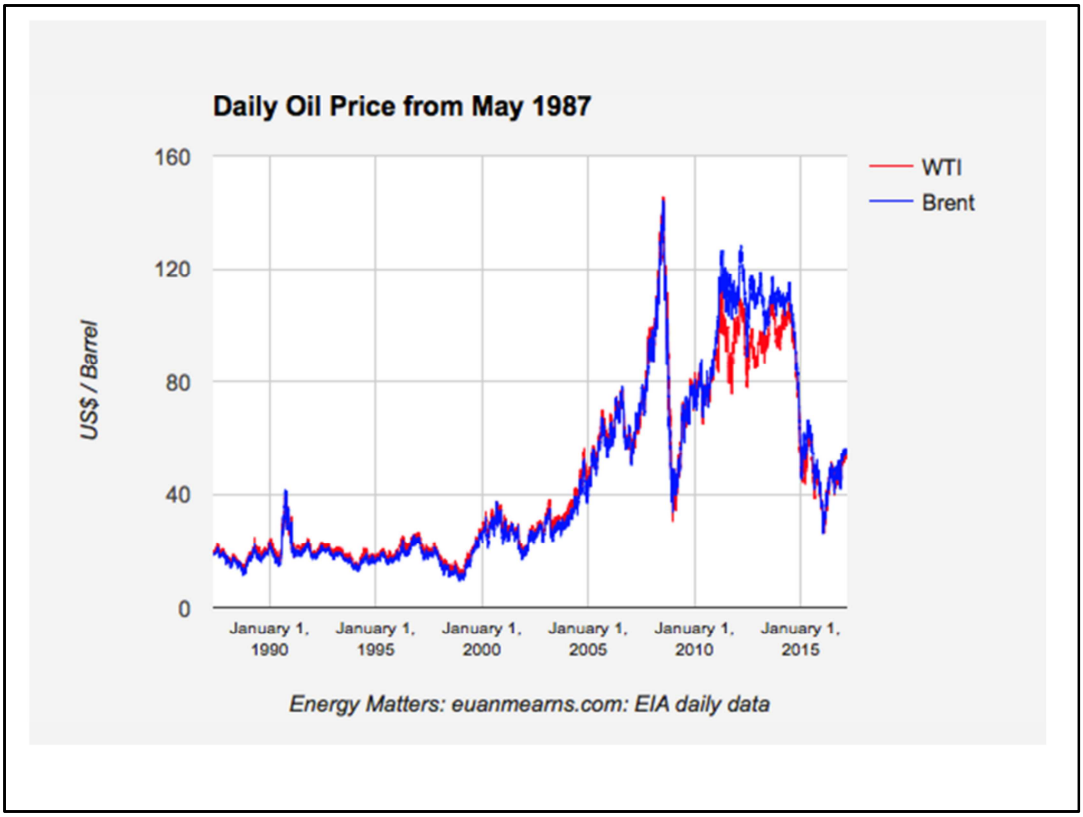
Energy is gathered by the collector and fed to a storage battery, where it can be kept until needed for electricity generation.

An installation in Morocco is set to provide half the country's electricity by 2020: https://www.theguardian.com/environment/2015/oct/26/morocco-poised-to-become-a-solar-superpower-with-launch-of-desert-mega-project

http://www.worldbank.org/en/news/feature/2016/11/08/learning-from-morocco-why-invest-in-concentrated-solar-power

Saudi Arabia has just announced a $50 billion investment in renewables: https://www.bloomberg.com/news/articles/2017-02-20/saudis-kick-off-50-billion-renewable-energy-plan-to-cut-oil-use

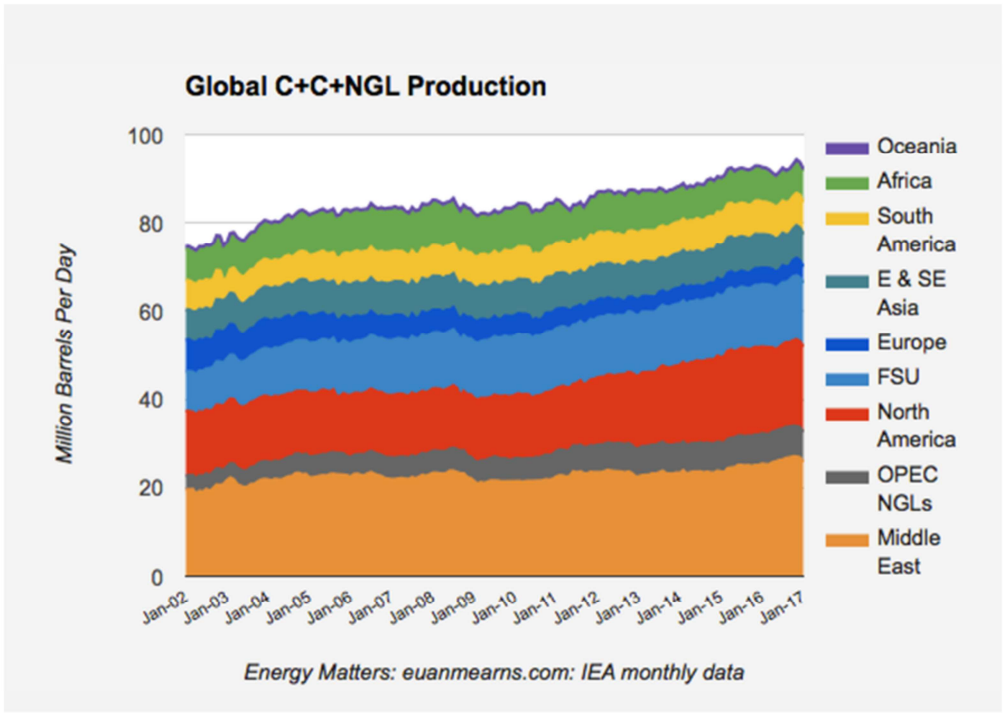
When the biggest producer of fossil fuels in the world is starting to change to renewables, one can be sure that the revolution is really taking place. It may be that the Paris Accord has sparked countries into some serious action, or it may simply be that renewables are cheaper and cleaner in the long run. It no longer requires anyone to be convinced of the need for climate action to want to install renewables – and that is why I am optimistic about them spreading rapidly.



So where does this leave the fossil fuel industry?
In the short term it does not make much difference, as renewables still make up a small proportion of the world's energy needs (7%).
Saudi Arabia has been trying to bankrupt US frackers by stepping up production, a measure that caused the oil price to fall, but largely failed to yield a quick result. OPEC has agreed to restrict production to reduce the glut, but it seems the frackers are increasing their own production to fill the gap!
https://www.ft.com/content/16b73dc2-d9c6-11e5-98fd-06d75973fe09

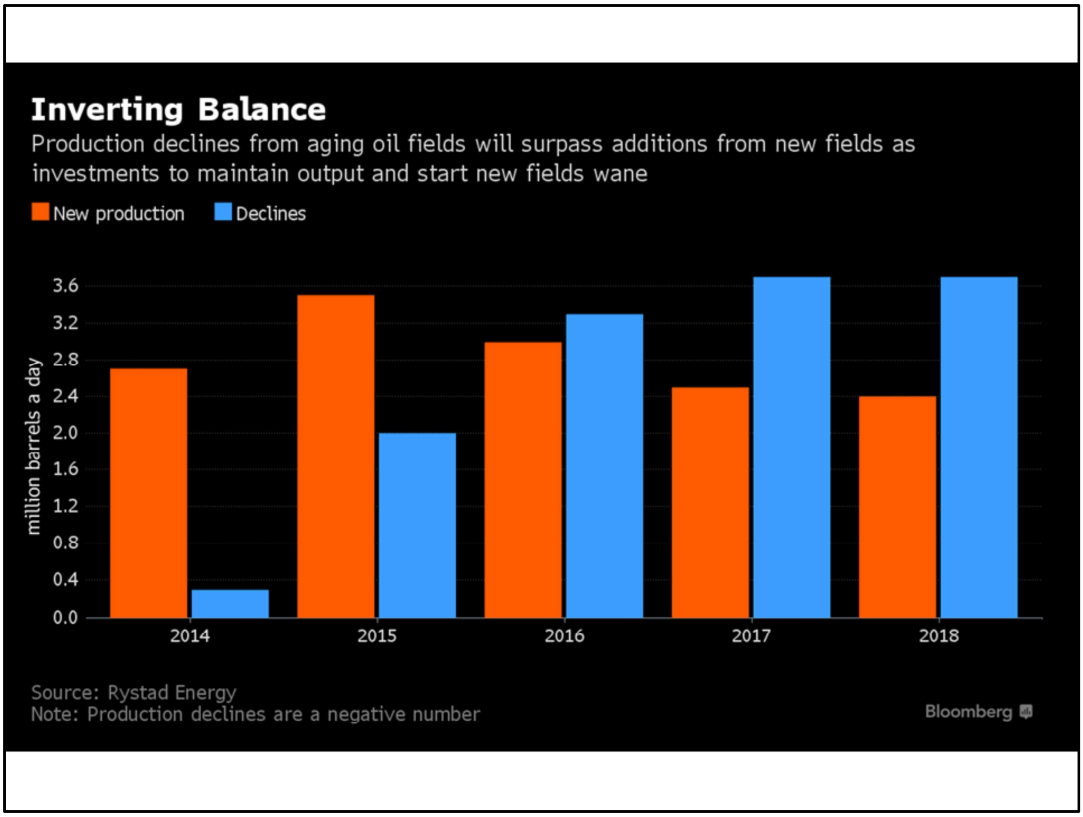
This activity has kept oil prices at around $55 a barrel, a price that just about breaks even. Frackers in the US, according to the FT, would increase activity above $60 a barrel. Production costs for fracking have been falling, making them more competitive on the global market.

But the fossil fuel companies are in a bind. If prices increase (and no one has absolute control over them), fossil fuels become even less competitive against renewables, and so accelerate the switch. If they are low, they have no money for further exploration.



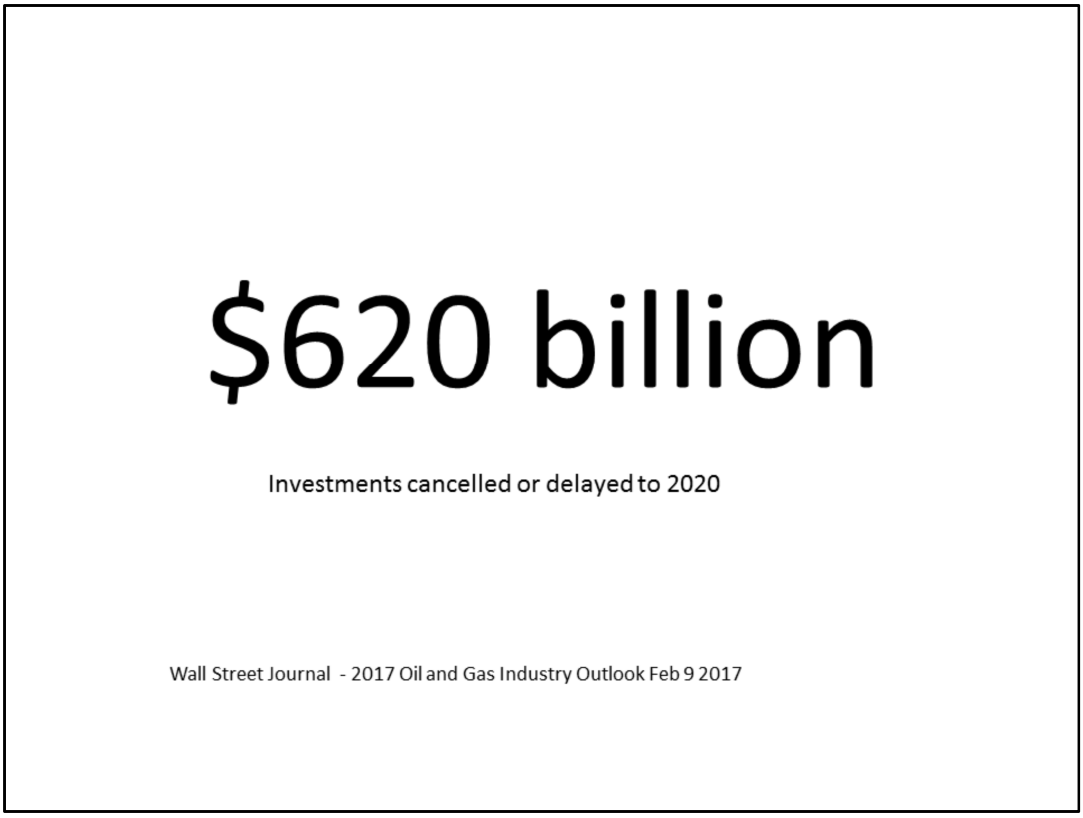
We have seen oil production peak and plateau since 2005, with the only increases coming from unconventional supplies in North America – shale oil and tar sands bitumen. Iran and Libya have recently come onstream again, contributing to an apparent increase in Middle East supplies.
http://euanmearns.com/oil-production-vital-statistics-january-2017/

The situation suggest that Peak Oil really is here, and the industry will now be in long-term decline.

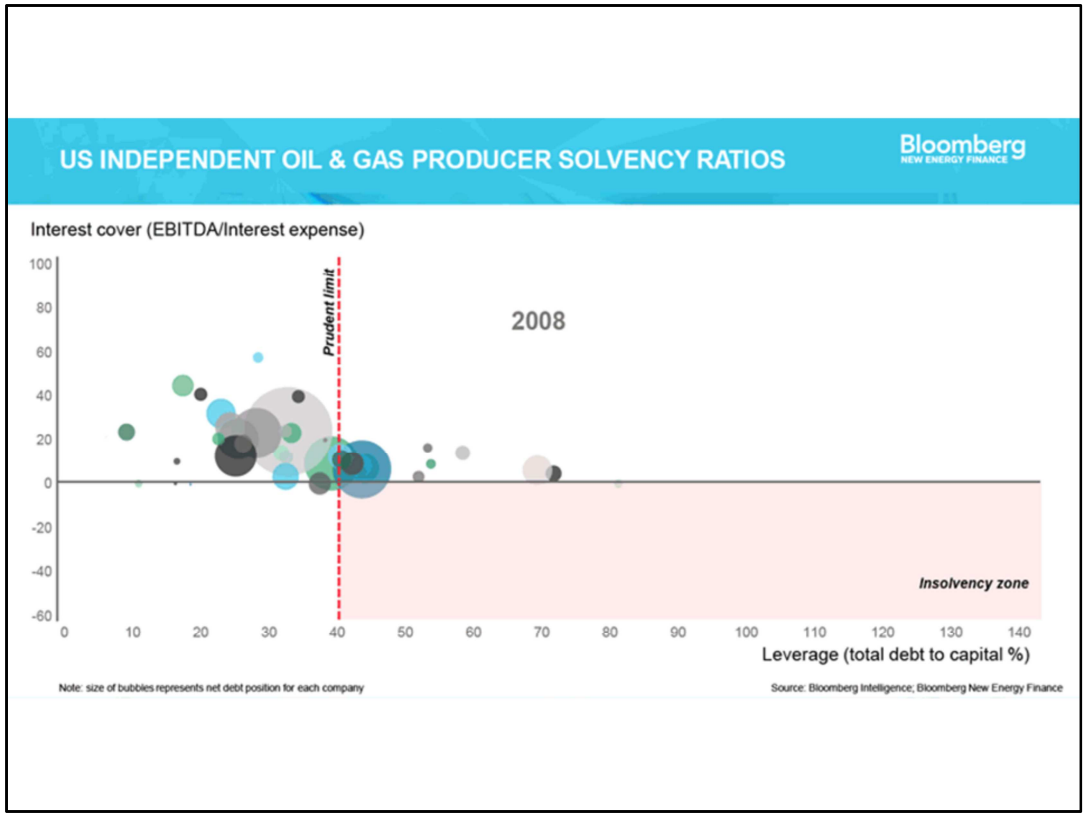


Production declines are increasing, but the low oil prices have led to a drop in industry investment in new finds – these have to be continually discovered in order to replace the declines, or production will decrease.
It can be seen that this is now happening. Some think this will bring about a new energy shock.
http://www.telegraph.co.uk/business/2016/09/13/oil-investment-crashes-to-60-year-low-incubating-next-energy-sho/

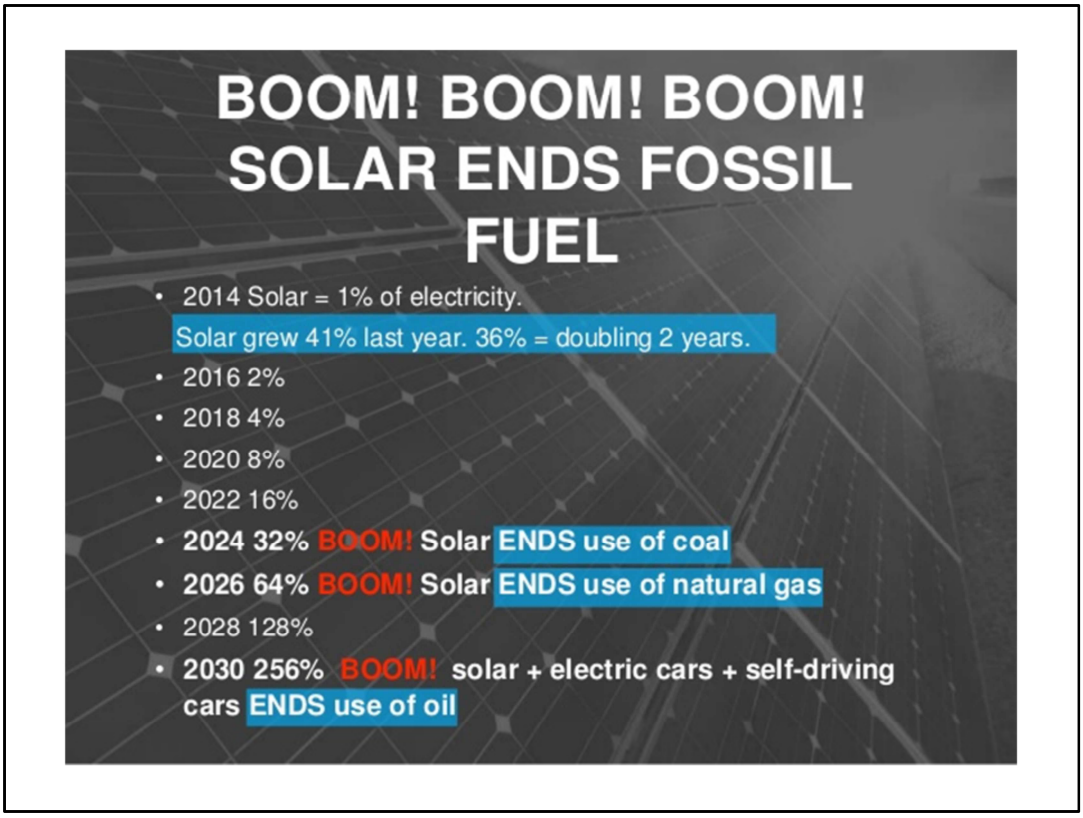
But a doubling of oil prices, such as was seen in 2011 would make it completely uncompetitive with renewables. (Of course oil is useful for other things than providing electricity or power for transport, and will continue to provide these things – plastics, fertiliser etc etc)



This is the amount the industry has not spent on investment into new finds. Does it suggest they are starting to lose?
http://deloitte.wsj.com/cio/2017/02/09/2017-oil-and-gas-industry-outlook/



And Bloomberg New Energy finance has found that some independent producers in the US have been going to the wall as a result of the low prices.
This is a .gif sequence, so needs to run to show the steady march towards insolvency.



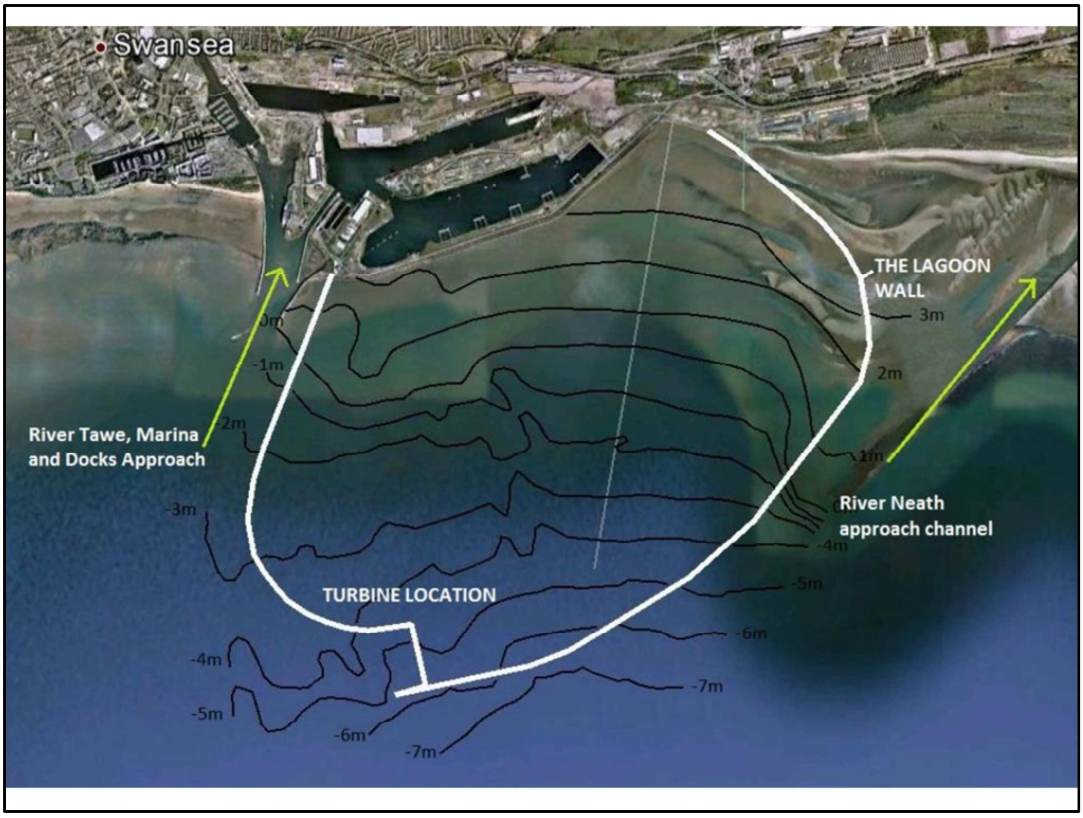
The most optimistic boosters of renewables forecast that if solar can continue to increase at the present rate, i.e. doubling every 2 years, by 2030 it will have knocked out every other source of energy on the planet.

There are some heroic assumptions here: sufficient technical infrastructure to produce and install the panels, enough lithium to make all the batteries, and a continuing cost reduction curve.

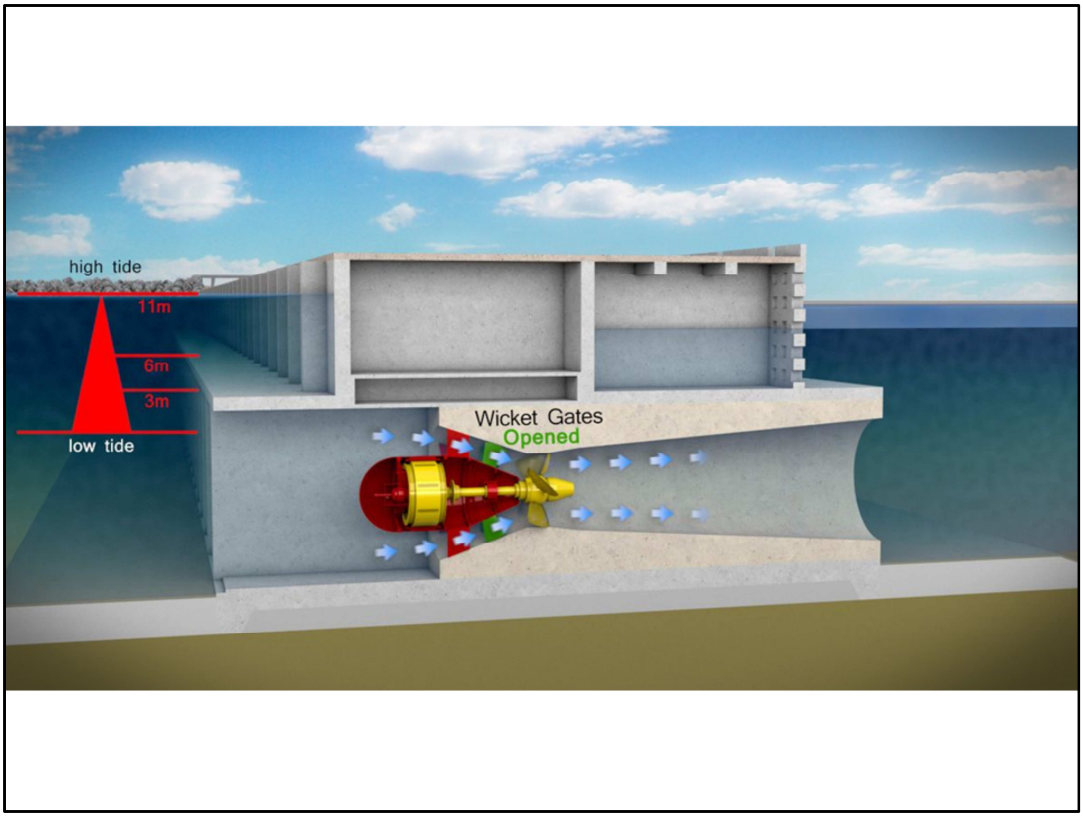
There have been studies suggesting that is is possible. However, many deride this as a pipe dream.
http://euanmearns.com/the-lappeenranta-renewable-energy-model-is-it-realistic/

One of our weaknesses is that we tend to think linearly, and find it difficult to understand exponential growth. It seems to me that when the rise of a technology is only limited by how fast it can be reproduced, and it no longer has price restraints, then significant growth is certainly likely.

It is interesting to see that at 64% penetration the graphic above suggests both coal and gas are superseded. Bloomberg NEF (see report earlier) suggests that renewables will reach this point by 2040.



It's not going to be all solar PV in the UK, that's for sure! We have 5 times less solar energy in winter time than in summer, so our challenge is to store energy for the winter. This is a diagram of the Swansea tidal lagoon, which has been given the go-ahead. It is a prototype for 9 other possible lagoons in the Bristol Channel, which has the second highest tides in the world.
The Cardiff lagoon (proposed) could apparently provide power for every home in Wales: http://www.telegraph.co.uk/news/earth/energy/11445579/Cardiff-tidal-energy-lagoon-could-power-every-home-in-Wales.html



The lagoons operate on a simple basis. As the tide rises, water flows in and turns the turbine. As it falls water flows out and turns it again.

And here is the first of four turbines to be installed in the Sound of Islay, between Jura and Islay. When complete in 2023 this will be the largest tidal power scheme in the world, and by 2022 Scotland should have 640MW of tidal current power coming onstream.

It seems like the beautiful island of Islay in the west of Scotland is a testbed for such projects. That's because it has some ferocious tides.
Here's another turbine which is in development on the west side.

Scotland is also installing tidal generators in the Pentland Firth off the north coast, in a project that will be the largest in Europe. The first one is already generating energy: http://www.bbc.co.uk/news/uk-scotland-highlands-islands-37985293

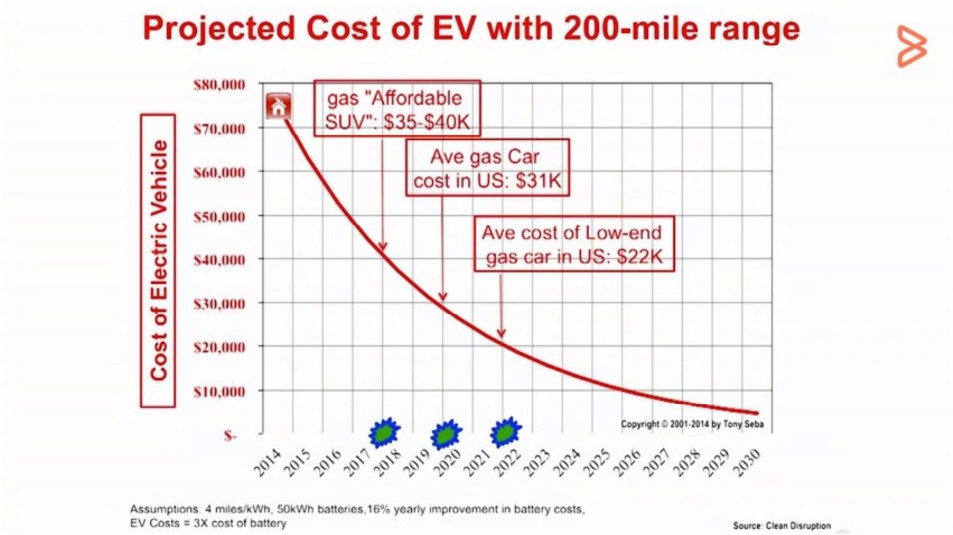
Kite power is another area of development, and Scotland again leads the way in the UK. The principle behind this is to get the kites up into stronger steadier winds, where they can travel at up to 100mph, pulling on the ropes to activate a turbine.

Their particular advantage over land-based wind turbines is that they can be portable and are not so unsightly on skylines.

I have discussed the revolution that is already underway in clean energy production, and there is one other factor that will contribute to its acceleration. It also does not require anyone to care about climate change.
Air pollution in towns and cities has been identified as a major threat to the health of populations. This is mostly caused by internal combustion engines in vehicles, specifically diesels.
The Major of London has announced a Toxicity charge of £10 a day for older diesel vehicles entering central London, although studies show that even new diesel cars can be just as polluting as older models.
It can surely only be a matter of time before ICE vehicles are banned in cities, and this will accelerate the switch to electric vehicles.
The significance of this is that EVs are also portable battery banks.

Electric Vehicles have just 20 moving parts, and their motors are around 90% efficient. ICEs have 2000 moving parts and are around 30-40% efficient.

EVs can also contribute towards smoothing out supply and demand for power by plugging into the grid. So a city car-park becomes a large battery unit, and at home the car can help with domestic consumption at peak times.



Just as solar PV has plummeted in cost, so EVs are set to do the same. And just as solar PV displaces other forms of power generation, so electric vehicles will cause ICE vehicles to become obsolete. This will occur when the cost of electric vehicles approaches that of a conventional car. (Note that the vastly reduced running and fuel costs mean that it will be competitive before reaching absolute parity)
Tim Smit reckons this will be by 2020. Tony Seba reckons it will be by 2022. 5 years away!
(I recommend a video Tony has made about the clean disruption revolution: https://www.youtube.com/watch?v=Kxryv2XrnqM The graphic above comes from his lecture)

And a further revolution is underway. Recall that the IEA projected significant energy efficiency savings as part of the pathway to emissions reduction?

We use our cars between 4 and 10% of the time, a shocking inefficiency. So the idea behind driverless vehicles is that a fleet of these would replace many individually-owned vehicles, operate at above 60% of the time, reducing the need for so many cars to be built. (There are 25 million in the UK alone.)

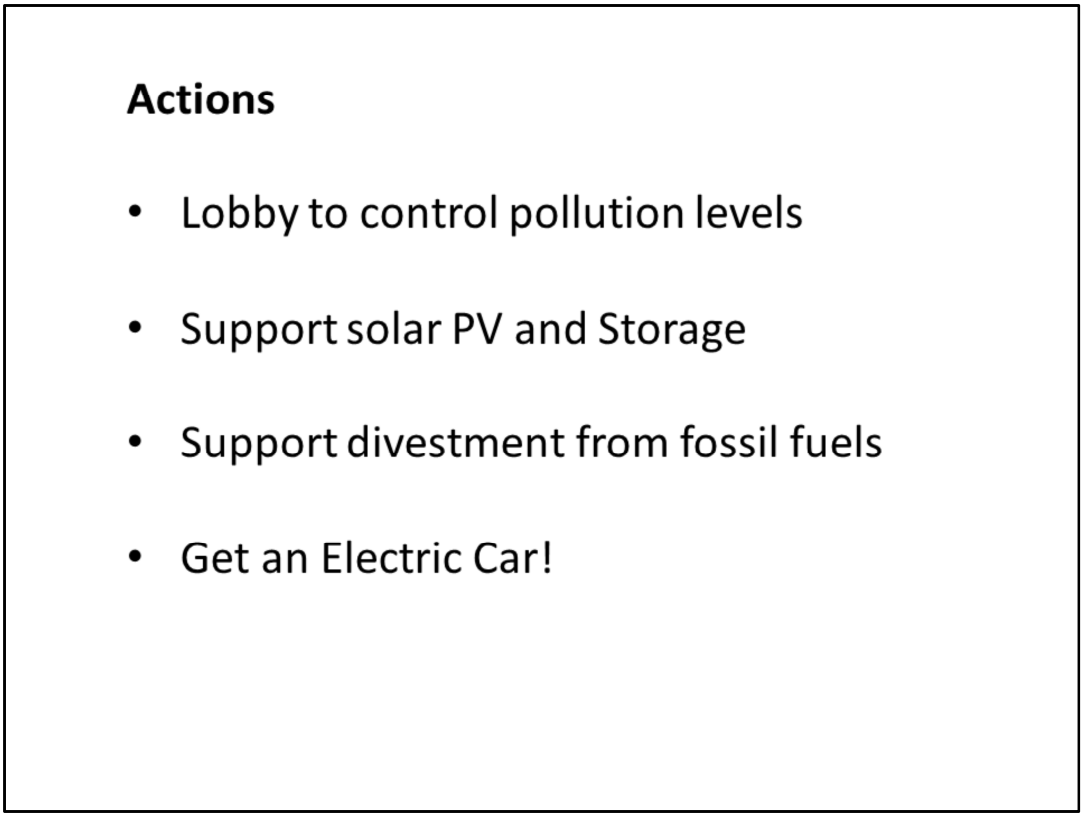
Google and Uber have been carrying out tests on such cars, which depend on a Lidar, the blob on top, to sense the space around the vehicle, GPS and map technology for navigation, and a powerful computer in the boot.

The urgent need to tackle air pollution in cities can only give a boost to this. (Although they probably won't be accommodating muddy dogs in the countryside anytime soon!)

It is clear that major changes are taking place. Whether they will continue at the speed some believe remains to be seen. But it is clear that they are going faster than standard industry analyses have predicted.

The best news is that people are starting to do the right thing, without needing to be concerned about the planet.

And even if the renewable revolution does not go quite as fast as some think, it will disrupt and may end the era of fossil fuels sooner than we anticipated.



We can do some things to help it along.

The global divestment movement, co-ordinated by 350.org
https://350.org/global-divestment-mobilization-peoples-climate-march/
Is getting growing support around the world. This is encouraging pension funds and others to see fossil fuels as an increasingly risky investment, and shifting the debate.

One day we will look back and wonder how we allowed ourselves to continue so long with a filthy, environmentally-damaging fuel when the clean alternatives are available. Roll on the revolution!

Simon Tytherleigh
March 2017