2nd
an inconvenient truth

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• If in 2100, all of the world’s people live like the people in developed countries do today, but without the introduction of new carbon emission-free energy technologies, atmospheric levels of CO2 will seriously impact global and regional climates, raise sea levels, and do widespread economic and ecological damage.

• Al Gore’s film “an inconvenient truth” was successful in demonstrating the gravity of the threat to climate if we continue to rely on carbon emitting energy technologies.

• But, the film ignores another “inconvenient truth”.

The need for new energy technologies is far greater than is currently assumed or admitted.

As we shall see, the technology challenge is far greater than is widely believed. Equally, it is far greater than is reported by international groups concerned with assessing what it will take to limit climate change and reduce substantially the emission of greenhouse gases (GHGs).
The need for new energy technologies is far greater than is currently assumed or admitted

Dramatically increase energy efficiency

Supply huge amounts of zero CO2 emitting energy

• Required energy efficiency improvements mean pushing energy efficiency as close to its physical limits as economic costs will allow
• Existing carbon-emission energy technologies need to be made scalable and cost competitive
• New, scalable, technologies need to be researched and developed to the point where they are not too costly
• Incentives need to be provided to deploy scalable technologies once they are ready (“on the shelf”)
Required technologies are available, or awaiting “commercialization”

Barriers are “socio-economic” and institutional, not technological

“Drastic technological breakthroughs” are not necessary

- UN Intergovernmental Panel on Climate Change (IPCC) has systematically understated the magnitude of the energy technology challenge.
- Current climate policy does not reflect the challenge we face.
• Current climate policy reflects the view that technologies necessary to climate stabilization are either available, or soon will be so, and that the cost of mitigation would be as little as 1% of GDP.

• **These views** enormously **understate the magnitude of the technology challenge** required to substantially cut global emissions.

• Unfortunately, the work of IPCC WG III has had great impact, influencing the work of many others including the Stern Review report, and distorting climate policy.

• **One reason** for understatement is the **baselines used** by the IPCC to assess the economic and technological challenge.

• The baselines are reference emission scenarios.
• Various scenarios are used to suggest possible future emissions paths in the absence of policies to mitigate emissions. These are called baseline or reference scenarios.

• The stabilization challenge is typically viewed as reducing emissions from a reference scenario pathway to a target level or stabilization pathway.

• But, this approach understates the technology challenge and the likely cost of achieving stabilization by overlooking what is built into the reference scenarios.

• The technology challenge is better measured from a baseline indicating what emissions would be in the future using the same technologies that are used today. This is called a “frozen technology” baseline.

• If technologies were in fact “frozen” (in fact they won’t be because technologies are slowly but continually changing), global emissions would grow at roughly the same rate as the global economy.
• In the figure, the green area or “gap” indicates the amount by which emissions in the reference scenario exceed, at any given time, the targeted or stabilization emission pathway.

• Policies have tended to focus on the green “gap”.

• The blue area or “gap” indicates the amount of carbon emission-free energy and energy efficiency improvement that is built into the reference scenario, and is expected to occur in the absence of policy.

• The green and blue “gaps” combine to indicate the total technology challenge of getting emissions down to the target level.

• It is important to note that the size of the total “gap” depends on the scenario chosen. The B2 scenario is characterized by a modest global average annual rate of economic growth of 2.2% over the 21st century. Most scenarios use higher rates of global economic growth.
• This figure illustrates, for various emissions scenarios employed by the IPCC, and by many practitioners, the amounts by which cumulative emissions of carbon emitted to the atmosphere must be reduced in the 21st century to reach an acceptable target level indicated by the part of each bar coloured in red.

• In the IPCC scenarios, the blue portion represents emissions reductions already built into the emission scenario baselines. These emissions reductions are assumed to spontaneously occur.

• Only the green portion reflects emissions that are to be reduced as a result of climate policies.

Source: Graph is adapted from the original found in Pielke et al, Nature (2008)
• This slide, and the next three, allow us to break down the stabilization challenge into energy technology components.

• Note that the technology challenge is represented by the light blue and green areas. The dark blue reflects a likely decline in energy intensity attributable to reductions in the share of total energy used relatively by energy intensive industries and activities (sectoral shift).

• In the B2 scenario, the magnitude of the technology challenge in 2100 is indicated by the bracket.
• We can break down the blue area (gap) into components. The two main components are (i) energy intensity decline, the reduction in energy per unit of output, and (ii) carbon emission-free energy.

• **Over time, and on a global scale, approximately 80% of energy intensity decline is comprised of energy efficiency improvement.** The rest is attributable to long term _sectoral shifts_ that are likely to move in the direction of less energy intensive activities.

• The improvements in energy efficiency will not be easy to achieve, requiring important advances, and in some cases breakthroughs, in energy technology.

• The energy efficiency improvements built into the B2 scenario are close to estimates of what is physically achievable.

• For the B2 reference scenario, the dark and medium blue areas are approximately 80% of the overall blue (all shades) region. The light blue remainder is carbon free energy built into the B2 scenario.
Hoffert et al (1998) demonstrate a trade-off between the amount of carbon-free power required (ordinate) and the rate of energy intensity decline (abscissa). Because on a global scale energy efficiency constitutes the lion’s share of energy intensity decline (~80%), we have in technology terms a tradeoff between carbon-free power and energy efficiency improvement.

Baksi and Green (Energy Policy, 2007) demonstrate that it would be very difficult to achieve, on a global basis, much more than a 1.0% average annual rate of decline in energy intensity over a period of a century or longer.

Increases in energy efficiency can be thought of as negawatts. Energy efficiency improvement reduces the amount of power (or energy) we need to enjoy our standard of life.

In the Figure, the tradeoff is based on a somewhat higher rate of growth of world GDP and a somewhat higher level of carbon dioxide stabilization than in the IPCC B2 scenario.

• It is useful to translate, if possible, emission reductions into energy or power terms.

• A (large) measure of power is a terawatt (TW) which is equal to a trillion watts generated at a point in time. (A TW=10^{12}w.) A TW is equal to 31.56 exajoules per year (EJ/yr). (An EJ is 10^{18} joules).

• Note that the estimates of TW are in thermal (as opposed to electric) terms, reflecting the amount of primary energy to produce a TW of power or its equivalent in energy terms.

• For the B2 scenario, the TW estimates give a rough idea of the magnitude of the stabilization challenge in power (or energy) terms. The challenge is huge when compared to current consumption of power and the amounts that carbon-free.
Carbon emission-free power required in the future

• **B2 scenario** requires ~26 TW
• In general, at least 25 - 40 TW

Current world power consumption ~16 TW of which only ~2.5 TW is carbon emission-free

1 TW is equivalent to ...

• This is over and above the contribution from energy efficiency improvement. The number of TWs is in “thermal” terms. The difference between TW thermal and TW electric (TWe) is taken up below.

• In general, the number of TW of carbon-free power needed will depend on (i) economic growth, (ii) the achievable reductions in energy intensity, and (iii) the share of electric power in total energy consumption.
• The loose but simple rule of thumb for conversion is that a barrel a day is roughly 50 tonnes of oil a year, but the relationship varies according to density and so according to product.

• Given that one tonne of oil is ~42 Gj and that 1 B/d is equal to 50 tonnes of oil, then there are .137 barrels in a tonne.

• That means there are .137 x 42Gj in a barrel=5.7Gj per barrel

• Since 31.56 EJ/yr = 1 TW  (and an EJ is = 10¹⁸j), we divide 31.56EJ/yr by 5.7Gj/barrel to derive the number of barrels of oil per TW

• There are 5.54 billion barrels per TW.

• Dividing 5.54 billion by 365 days allows us to calculate what a TW means in terms of B/d.

• 1 TW is equivalent to ~15 million barrels of oil per day, 365 days a year.

Source: Image from Reuters news, http://www.daylife.com/photo/071dd1h6Fg3Rp
Chevron’s Petronius oil platform, located 100 miles (161 km) off the coast of New Orleans, in the Gulf of Mexico June 3, 2008.

• The Sleipner field in the North Sea is perhaps the best known site for the sequestration of carbon dioxide from an energy-related operation.

• Each year about 1 million tonnes of CO2 associated with Norway’s natural gas production is stored below the North Sea in a saline aquifer.

• To give an idea of what this means, an average size coal fired electricity plant (400 MWe) produces about 2.8 million tonnes of CO2 a year (in the absence of utilizing carbon capture technology), or almost three times the amount stored each year in Sliepner.

Source: Image from Statoil Hydro
http://www.npd.no/engelsk/cwi/pbl/field_jpgs/43478_Sleipner_Ost.jpg
Electricity Generation: TWs measured in electric terms

As a rule of thumb

3 TW thermal = 1 TWe.

1 TWe is equivalent to ...

- In what follows, specific technologies may be measured in either TW thermal or, if they are used for generating electricity, usually in TW electric (TWe). The measures for nuclear, hydro, wind, and solar are in TWe terms. The others are in thermal terms.
- For example, for a coal plant the primary energy input is used for analysis (measured in TW thermal), whereas, for hydro the electric output is used for analysis (measured in TWe).
- A standard conversion is that 3 TW of primary energy used to produce electricity through a thermal process is equal to 1 TW electric.
- The difference is associated with conversion efficiency. These vary with the power source (coal, natural gas, hydro, nuclear), but all conversion efficiencies are much less than 100%, implying ratios of thermal to electric substantially higher than 1:1.
Currently the world has 440 nuclear electric plants/reactors. These produce about 400 GW of electricity (or 40% of a TWe).
• New sites may only allow a doubling of capacity.
• Given limited additional sites, a rise in the capacity factor (% of capacity used on average to generate electricity) from 50% to 75% would produce, in electricity generated terms, the equivalent of a tripling of current hydro-electricity generated.
• A rise in the capacity factor could be achieved by some form of time-of-day or real-time pricing.
1500 000, 2.5 MWe wind turbines covering virtually two-thirds of Alberta & massive storage

- 1 500 000, 2.5MWe wind turbines would require approximately 450 000 square kilometers.
- The wind turbines/farms would have to be located in windy areas, with DC grids built to deliver the power over large distances from windy to populated areas.
- For utilities to use most of this power, it would be necessary to have a means of storing excess power when the wind is blowing for use when it is not.
• We are talking here of 600 000 - 1 500 000 km² per TW thermal when biomass is burned to produce electricity and twice these numbers if converted to liquid form for use in transportation.

• **For two reasons, bio-fuels may not reduce emissions much:**
  
  (a) if fossil fuels are the source of the very large amount of energy used in bio-fuel production, from planting, fertilizing, harvesting, and transportation, to the conversion of biomass from solid to liquid form

  (b) if large amounts of carbon are released from the soil as a result of changing land use from pasture to production of energy crops.

Source of Canadian farm land statistic:


Arable and permanent crops in 2003

52 115 000 ha ~ 521 150 sq km
It is important to emphasize that these solar panels must be in sunny areas covering between 40,000 and 75,000 square kilometers.

The sun is a huge energy source. But tapping it in large amounts is neither easy nor inexpensive.

The problems range from its diluteness, intermittency, and complications in efficiently capturing it.

Large scale solar energy, whether in the form of photovoltaics (PV) or thermal, requires substantial amounts of space/land, uses energy intensive materials, suffers from low conversion efficiencies, and requires utility scale storage, if solar energy is to make more than a marginal contribution to electricity supply.

Still, with technological breakthroughs and new energy infrastructure, solar can play an increasingly important role in world energy supply, helping to reduce dependence on fossil fuels, and thereby contributing to global reduction in carbon emissions.

New York 141,299 km² (Wikipedia)
Energy efficiency required in the future

**B2 scenario** builds in \(~43\) TW

Currently \(1\) TW

is equivalent to improving the efficiency with which all current energy is used by \(~6\%\)\*  

- The TW measure used here is in *thermal* terms.  
- Relating TWs to energy efficiency improvement brings us back to the notion of *negawatts*, whereby energy efficiency improvements would make additional carbon emission-free energy (power) unnecessary.  
- \*The 6\% improvement is based on the simple calculation of the percentage reduction in power consumption associated with reducing current global power consumption from 16 to 15 TW. But as energy consumption rises.  
- **Electricity** constitutes almost 40\% of world energy consumption. It takes more than a third of all primary energy (power) to produce it.  
- Note that the amount of carbon-free power that would still be needed after accounting for energy efficiency improvement would be 25-40 TW (thermal), and about 15-25 TW if the electricity portion of the carbon-free power required is calculated in TWe terms.
1 TWe is equivalent to ...

50% of all electric power currently generated or consumed*

- There are 8760 hours in a year, so the number of watts in a TW over a whole year is 8760 times 1 trillion. (The number of kwh in a TW over the course of a year is 8760 billion.)
- *Some perspective is important. Global consumption of electricity is about 2 TWe, but since most of it is thermally generated it takes about 6 TW thermal to produce 2 TWe.
- By 2050, world electricity consumption will more than double from its current level of 2 TWe.
doubling US home efficiency is only 20% of a TWe

• If the 122 million residential consumers in the U.S. doubled their energy efficiency (reduced their energy consumption by 50%) that would equal 20% of a TWe (or about 60% of a TW thermal)
• In the US, residences account for 36% of electricity consumption.
an inconvenient truth

The need for new technologies is far greater than is currently assumed or admitted

How can low-carbon technologies be scaled up?

• Many potential technologies exist at a drawing board, pilot plant, or industrial plant level. But for various reasons their scale up to a point where they can make a global contribution is as yet limited, very costly, or non-existent.

• Overcoming the limitation to scale-up is an important starting point for much energy R&D.
enabling technologies

Nuclear waste handling

Smart grids and energy storage

CO2 storage sites

• The scalability of many current technologies is limited by lack of "enabling" technologies.

• One of the most important enabling technologies is utility-scale storage for intermittent wind and solar energy. To allow wind and solar to make more than a niche contribution will require technological breakthroughs in utility scale storage.

• Another "enabling technology" is safe and secure sequestration of captured carbon dioxide emissions made possible by carbon capture and storage (CCS) technologies. CCS technologies could be effectively used by natural gas and coal-fired electricity generating plants; by oil sands operations; and by other large emitters of CO₂ such as steel and cement plants. But to do so, not only requires major improvements in capture technologies; it also must be "enabled" by careful geological surveying and regulatory testing to assure safe and secure (leakage-proof) sequestration.
• Alberta, like much of the US mid-west, China, Poland, and parts of India, relies heavily on coal-fired generating plants for most of its electricity. Unlike most of the rest of Canada, Alberta is not blessed with good sites for generating hydroelectricity.

• Alberta is a prime locale for testing carbon capture technology and the storage of CO₂ in the Pembina sedimentary basin.

• Since Canada would also benefit from efforts Alberta makes in reducing its CO₂ emissions, there is a shared responsibility across Canada for contributing to funding research and development of CCS technologies, the building of pipelines, and especially the safe sequestration of CO₂ in deep geological formations.

• Moreover, what is accomplished in reducing emissions through CCS in Alberta, whether from coal-fired electricity generators or from oil sands operations, could have crucial implications for developing countries, such as China and India, that use huge amounts of coal for power production.

• Thus Alberta’s experience with CCS may have important global implications. It may be the most important demonstration Canada has to offer of a new technology that could substantially reduce global CO₂ emissions over the next several decades.

Source: Image from Google Maps and plant locations estimated from Hydro-Québec (Centre de documentation, études et publications- Les émissions atmosphériques)
Hydrogen, like electricity, is a carrier of energy. It requires other (primary) energies to produce it. Hydrogen can be produced in a carbon neutral manner if (i) non-carbon energies are used, such as solar, wind, or nuclear used to electrolytically split water (of distilled quality) into its elements, hydrogen and oxygen; or (ii) through pre-combustion capture of carbon dioxide as part of a CCS process.

However, produced, the widespread use of hydrogen will require technological breakthroughs in its distribution and storage, and in fuel cell development. (As a gas, hydrogen has a very low ratio of energy to volume; its conversion to liquid requires a temperature of -253°C)

A decade ago, there was speculation on a future “hydrogen economy”, prominently including as a future transportation fuel. Whether such a vision is possible, it is still very far in the future. In the meantime, many technological breakthroughs will be required simply to make hydrogen broadly useful as an energy source. As a result, it seems likely that hydrogen’s first prominent use will be as a part of CCS of emissions from advanced, newly-built coal-fired plants.

Source: Image adapted from original obtained at http://h2www.com
Without the development of new and breakthough technologies, we will not be able to improve energy efficiency sufficiently or produce the carbon emission-free energy that are required to stabilize the climate.

- Retrofits for coal-fired plants
- Reduced cost of coal gasification plants
- Second generation bio-fuels
- Utility level storage for intermittent solar and wind energy.
- Nuclear plants that run on less radioactive fuels
- Deep geothermal
- Nuclear fusion
- Other ?
Reducing global emissions will require technology transfer

- Without scalable, non-carbon emitting technologies that are transferable, global emissions will continue to increase.
- Because a large fraction of future emissions will be coming from the developing world, substantially curbing global emission growth will require transfer to, and adoption, by them of new carbon emission-free technologies.
- While a number of the developing countries are already scientifically advanced, it is likely that some of the low carbon technologies will have to be transferred from the already high income countries.
• As China’s economic development proceeds, so will its demand for energy, especially to produce highly energy intensive products.

• These energy intensive products are particularly important in high-rise building construction and in transportation and utility infrastructure.

• Currently the primary source of power in China is coal. The number of coal plants is steadily increasing to satisfy energy demands. Also, large amounts of coal are directly used in steel production.

• In recent years, China has been building the equivalent of one to two coal-fired electricity generating plants each week.
• The EU, US and Japan currently have much higher emissions per capita than do China and India. In the next 25 years, per capita emissions in the developed countries are not expected to change much.

• In China and India, projected per capita CO$_2$ emissions are expected to at least double in the next thirty years. (The same will be true of many other developing countries.)

• Even after doubling, China and India would have emissions per capita below the comparable statistics for much of the developed world.
• China’s total emission, which were small 35 years ago, surpassed those of the EU in 2000 and the US in 2007.

• These emission projections demonstrate the growing importance of developing countries, especially the very populated ones, such as China and India.

Source: Adapted from graph in Rosen and Houser, Petersen Institute for International Economics, 2007
• As China’s economic growth continues, so will its demand for highly energy intensive products.

• The first three products shown in the graph above (flat glass, cement and steel) are especially important as building materials for high rise buildings; and steel and cement are fundamental to urban and inter-urban infrastructure.

• For very populous countries such as China and India, becoming “middle class” (and more urban) will require huge amounts of the most energy intensive materials and the energy to produce them.

• The development of other populous Asian nations, Vietnam, Burma, Indonesia, India, Bangladesh, seems likely to reflect the “China model”.

• The evidence suggests that economic development in populated developing countries will be especially energy intensive in the next few decades.

• Without transferable carbon emission-free technologies, global emissions will continue to rise even if the developed world is able to curb its own.

**Source:** Adapted from graph in Rosen and Houser, Petersen Institute for International Economics, 2007
2nd inconvenient truth

The need for new technologies is far greater than is currently assumed or admitted

Shift the focus of climate policy

• Commit to long-term R&D programs, financed by a low carbon tax (charge, fee)

• Let the “tax” rise very gradually to induce deployment of scalable, cost effective technologies as they reach “the shelf”

• Climate policy should focus on assuring that technologically capable countries (which includes at least several developing ones) undertake well-financed, long-term programs to research and develop new technologies and to improve and reduce the cost of existing ones.

• Incentives will be needed to deploy improved and new technologies when scalable, cost-effective ones appear “on the shelf”

• A low, gradually rising carbon tax can finance the development of new technologies and induce their deployment when they become ready.

• Agreeing to emission reduction mandates is meaningless without the prior development of a broad set of new scalable technologies and unnecessary if there are appropriate incentives to deploy them.
• If in 2100, all of the world’s people live like the people in developed countries today, without the introduction of new carbon emission-free energy technologies, atmospheric levels of CO2 will seriously impact global and regional climates.

• The UN Intergovernmental Panel on Climate Change (IPCC) has systematically understated the magnitude of the technology challenge required to substantially cut global emissions. One result is that current climate policy does not reflect the challenge we face.

• Without the development of new and breakthrough technologies, available for use throughout the world, we will not be able to improve energy efficiency sufficiently or produce the carbon emission-free energy that are required to stabilize the climate.