The WWF *Climate Solutions* Vision for 2050

Paper prepared for WWF's Global Energy Task Force by Karl Mallon[1], Greg Bourne[2] and Richard Mott[3]

EXECUTIVE SUMMARY

This WWF report seeks to answer the question. "Is it technically possible to meet the growing global demand for energy, using clean and sustainable energy sources and technologies that will protect the global climate?" In other words, can a concerted shift to the sustainable energy resources and technologies that are available today meet the more than doubling of global energy demand projected by 2050, while avoiding dangerous climatic change of more than 2 degrees Celsius above pre-industrial levels?

The report's conclusion is that the technologies and sustainable energy resources known or available today *are* sufficient to meet this challenge, and there is still sufficient time to build up and deploy them, but only if the necessary decisions are made in the next five years. Yet it is clear that the economic policies and governmental interventions needed to propel this transition are not now in place, or even in prospect in most cases. This is a matter to which the world needs to give urgent attention.

WWF is acutely aware that many of the steps considered in this report - an end to the dominance of fossil energy, a phase-out of nuclear power, a rapid expansion of biomass energy - carry with them social, environmental, and economic consequences that must be carefully weighed and closely managed. To take a single example, even the limited shift to energy crops today threatens accelerated conversion of wild habitats and further deprivation of the world's poor by driving up food prices. A global energy transition must be managed to reflect the differing priorities and interests of the world community at large.

Halting climate change is a long-term undertaking, but the first steps must be taken by governments currently in power. The future depends on them making critical decisions soon which could lead to a low-emission global energy economy in a timescale consistent with saving the climate, and planning for the social and economic dimensions of that transition to minimize the negative impacts of such urgent change,.

The WWF Global Energy Task Force

In 2006, WWF convened a Global Energy Task Force to develop an integrated vision on energy for 2050. The Task Force explored the potential for successful achievement of the following goal for energy policy: to **meet the projected global growth in demand for energy <u>services</u>**

[1] Director, Transition Institute, Australia

[2] Chief Executive, WWF-Australia

[3] Vice President, WWF-US

while **avoiding the most dangerous impacts of climate change,** but **using energy sources that are socially and environmentally benign[4].**

The time sensitive approach taken here differs from other studies in a number of ways. It draws on authoritative sources for projections of energy demand and climate change trends, uses WWF expertise to estimate the sustainable limits of technologies and resources, and assesses a wide range of published data on the potential rate of development and deployment of these technologies and systems. Finally, it exposes this information to analysis in a model which assesses the feasibility of successful delivery of the goal described above. A scenario showing high success potential is illustrated in this paper.

The task force began by reviewing 25 different sources of sustainable energy, broadly construed: these included renewable energy sources, such as solar and wind power; demand-side options such as efficient buildings and vehicles and reduced travel; and other low- or no-carbon technologies such as 'carbon capture and storage' and nuclear power. The sole constraint was that technologies be "proven", by virtue of being commercially available already.

Each of the energy sources was then sorted and ranked based on its environmental impacts, social acceptability, and economic costs. This ranking exercise yielded three groupings of technologies: those with clear positive benefits beyond the ability to reduce carbon intensity (efficiency technologies dominate this group); those with some negative impacts but which remain on balance positive; and those whose negative impacts clearly outweighed the positive.

The WWF Climate Solutions Model

The technology groups whose benefits were found to outweigh their negative impacts were then run through a newly-designed WWF Climate Solutions Model. This model was designed to determine the *industrial feasibility* of developing and deploying these resources and technologies in a timeframe that can avert dangerous climate change over the period to 2050, and at levels that can accommodate the projected increase in global demand for energy.

It bears emphasis that the WWF Climate Solutions Model is *not* an economic model: no price for carbon was set, nor were the costs of the technologies assigned or modelled. Economic scenarios have been explored by others, including Stern[5], McKinsey[6], noting that costs of dangerous climate change are far in excess of the costs of avoiding it . Likewise, no assumptions have been incorporated about the policies or measures needed to drive a transition to the sustainable energy technologies in the model. Rather, the model seeks to answer only the narrow question whether, given what is known about physical resources, the capacity of the technologies themselves and the rate of industrial transitions, it is feasible to deploy the needed technologies in time to avert dangerous climatic change.

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[4] No energy source is free of impacts. The word 'benign' is used here to describe sources that WWF judges to deliver a positive yield of advantages over disadvantages.

[5] Stern Review Report on the Economics of Climate Change: Cambridge University Press, 2007

[6] Per-Anders Enkvist, Tomas Nauclér, and Jerker Rosander: A Cost Curve for Greenhouse Gas Reduction: in McKinsey Quarterly Report March 2007, http://www.mckinseyquarterly.com/article_abstract.aspx?ar=1911&L2=3&L3=0&srid=246

Findings and Conclusions

On this all-important point, the WWF Climate Solutions Model offers a qualified basis for hope: it indicates that with a high degree of probability (*i.e.* greater than 90%), the known sustainable energy sources and proven technologies could be harnessed between now and 2050 to meet a projected doubling of global demand for energy services while achieving the significant (in the order of 60%-80%) reductions in climate-threatening emissions, enabling a long term stabilization of concentrations at 400ppm (though concentrations in the short term will peak at a higher level before being absorbed by oceans and the biosphere). A solution, in other words, is at least possible.

However, from this threshold determination of technological feasibility, the outlook immediately becomes more complex and ominous. The economic policies and measures, and intergovernmental actions, needed to drive this transition are not yet in place, and may well be years away based on current progress. And with real world constraints on the speed of industrial transition, analysed in our model, it is clear that time is now of the essence. In five years it may be too late to initiate a sustainable transition which could avert a breach of the 2 degree threshold for avoiding dangerous climate change. In that event, dangerously unsustainable options may be forced upon us or we will face more severe interventions which will have significant impacts on the global economy.

The WWF report identifies the following six solutions and three imperatives as key to achieving the goal of meeting global energy demand without damaging the global climate:

1 **Breaking the Link between Energy Services and Primary Energy Production** — Energy efficiency (getting more energy services per unit of energy used) is a priority, especially in developed countries which have a very inefficient capital stock. The model shows that by 2020-2025 energy efficiencies will make it possible to meet increasing demand for energy services within a stable net demand for primary energy production, reducing projected demand by 39% annually, and avoiding emissions of 9.4Gt carbon per year, by 2050.

2 **Stopping Forest Loss** — Stopping and reversing loss and degradation of forests, particularly in the tropics, is a crucial element of any positive climate-energy scenario. The probability of success of the climate solutions proposed here drops progressively from greater than 90% down to 35% in the absence of effective action to curb land use emissions.

3 **Concurrent growth of Low-Emissions Technologies** — The rapid and parallel pursuit of the full range of technologies, such as wind, hydro, solar PV & thermal, and bio-energy is crucial, but within a set of environmental and social constraints to ensure their sustainability. By 2050 these technologies could meet 70% of the remaining demand after efficiencies have been applied, avoiding a further 10.2Gt carbon emissions annually.

4 **Developing Flexible Fuels, Energy Storage and New Infrastructure** — Deep cuts in fossil fuel use cannot be achieved without large volumes of energy from intermittent sources, like wind and solar, being stored and transformed into transportable fuels and into fuels to meet the thermal needs of industry. New fuels that meet these requirements such as hydrogen will require major new infrastructure for their production and distribution.

5 **Displacing High-Carbon Coal with Low-Carbon Gas** — Natural gas as a "bridging fuel" offers an important opportunity to avoid the long-term lock-in of new coal power stations,

providing significant carbon savings in the near-term while other energy sources and technologies are grown from a smaller industrial base.

6 **Carbon Capture and Storage —** The model shows that, in order to stay within the carbon emissions budget, it is essential that fossil-fuel plants are equipped with carbon capture and storage technology as soon as possible – all by 2050. This has major and immediate implications for the planning and location of new plants, since transport of carbon dioxide to distant storage sites would be very costly. Overall, fossil fuels with CCS could account for 26% of supply in 2050, avoiding emissions of 3.8Gt C/yr.

Additional Imperatives

1 **Urgency**. Delays will make the transition to a low-carbon economy increasingly expensive and difficult, with much greater the risks of failure. The case for early, decisive action is overwhelming.

2 **A global effort**. Every country has a role to play, in response to the scale and the type of challenges arising in its territory[7].

3 **Leadership.** Action is needed by governments of the world to agree **targets**, to collaborate in **effective strategies**, and to influence and co-ordinate the **investment** of the many trillions of dollars which will be spent on energy developments in the coming decades in any event, so that future needs are met safely and sustainably.

Following an introduction, the balance of this report is comprised of sections that provide greater detail on the range of sustainable energy technologies reviewed by the WWF task force; the WWF Climate Solutions Model; and the findings and conclusions that emerge from its analysis.

An Annexe of short Topic Papers dealing with themes, countries and technical details can be accessed at …..

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[7] See topic papers

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1 INTRODUCTION

Averting the unfolding calamity of global climate change, while at the same time ensuring stable and secure supplies of energy services to meet the needs of a growing global population and level of development, especially in the relief of poverty, is the most important challenge our generation is likely to face. Doing so without wreaking new havoc on the environment (*e.g.*, by excessive hydro development or by massive conversion of tropical forests to bio-fuels production) is an additional but so far little considered dimension.

With this in mind, WWF's Global Energy Task Force undertook the analysis and modelling project described in this report. Its aim was to determine whether it is technically feasible, at this late date, to meet projected global energy services needs while avoiding a level of climate change which would threaten catastrophic environmental and social consequences.

The starting point for WWF's analysis was the strong scientific consensus that any human-induced warming greater than two degrees Celsius above pre-industrial levels would have a dangerous and highly damaging impact on both human societies and their economies and the global environment as a whole. The task force then looked at the projected growth in energy service needs, taking into account population trends and development goals, through to the year 2050. It then sought to determine how these needs for energy services might be met while remaining under the 2 degree Celsius ceiling for the average increase in global temperature above pre-industrial levels, and without resort to unacceptably damaging technologies or resources.

The result, described in more precise and technical detail in the sections that follow, represents what we believe to be among the very the first, technically and industrially pragmatic, time-sensitive energy scenarios, containing the threat of climate change while meeting legitimate future development goals.

The good news is that it appears to be still possible to avert the worst consequences of climate change while expanding our energy supplies to meet the needs of both the developed and developing world in the 21st Century. The bad news is that the outcome is extremely sensitive to decisions made in the next five years. In these five years the trajectory must be set for the required technology, systems, infrastructure and resource exploitation, sufficient to ensure that *global greenhouse gas emissions peak and start to decline within 10 years.*

What the study did not examine is the social and economic dislocation which would likely attend the kind of swift energy transition needed to avert dangerous climate change. In this respect, there is no single, easily recommended course for all societies, but it is important that such impacts are anticipated. Global warming of greater than two degrees Celsius will bring with it significant adverse impacts, particularly in the poorest countries. An abrupt global shift of the energy systems which underpin current national economies threatens disruptions of its own.

Nonetheless, the world is fortunate that the technology and resources are available to avert a dangerous disruption of the global climate. With determination, it appears technically and industrially possible to convert this technical potential into reality. However the world is currently on a different and dangerous trajectory. Scientific warnings continue to mount, yet the debate continues and what passes for vision seems to have great difficulty seeing past the next filling station.

The pages that follow contain a blueprint for an alternative vision - one of a world in which human needs and economic development are supported by a robust mix of low emission energy sources and technological efficiencies while nature continues to thrive.

WWF's Climate Solutions Vision is offered in the hope that it will help to inform decisions on energy by demonstrating the technological potential for a cleaner, more secure and truly sustainable energy future. Stripped of its technicalities, the central message here is that if we can find the will, there is indeed a way. But it is up to us to find it; succeed or fail, it is the central challenge by which future generations will judge our own.

2 WWF REVIEW OF SUSTAINABLE ENERGY SOURCES AND TECHNOLOGIES

The groundwork for this report began with an extensive literature review and expert consultation looking at 25 low- or zero-carbon emission technologies and their application (including efficient end-use technologies and systems) from ecological, social, and economic perspectives. The core list of technologies was confined to those that are currently commercially available; thus the review did not consider technologies that may yet be developed, or attempt to take account of the potential for dramatic advancements in the technologies available to prevent climate change.

In this respect, the energy review underpinning this report was deliberately conservative: it limited the suite of solutions considered to those available today. Some technologies, such as "carbon capture and storage" straddle the line of current availability — they are in limited use today, but their potential for truly large-scale application remains uncertain. The review then considered the potential for each technology or application to provide zero- or low-emission energy, compared with a business-as-usual energy scenario in which 14 Gigatonnes of carbon would be emitted per year by 2050[8]. This comparison sets the scale and context for alternative technologies to assume a major role in displacing carbon dioxide.

Using the 14 Gt C/yr as a reference, the Task Force sought and documented a range of expert input on: the environmental (non-climate) impacts and risks associated with each technology; potential obstacles to implementation; the likely social acceptability of the technology; and relative costs. With information on these points compiled in a matrix, three panels of the Task Force independently ranked the technologies on the basis of environmental risk, social acceptability, and cost, each weighted equally. While such a ranking exercise is necessarily subjective to some degree, the results across the three Task Force panels showed a high degree of consistency.

[8] Pacala, S and Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem of the Next 50 Years with Current Technologies. Science 13th August, 2004, Vol. 305.

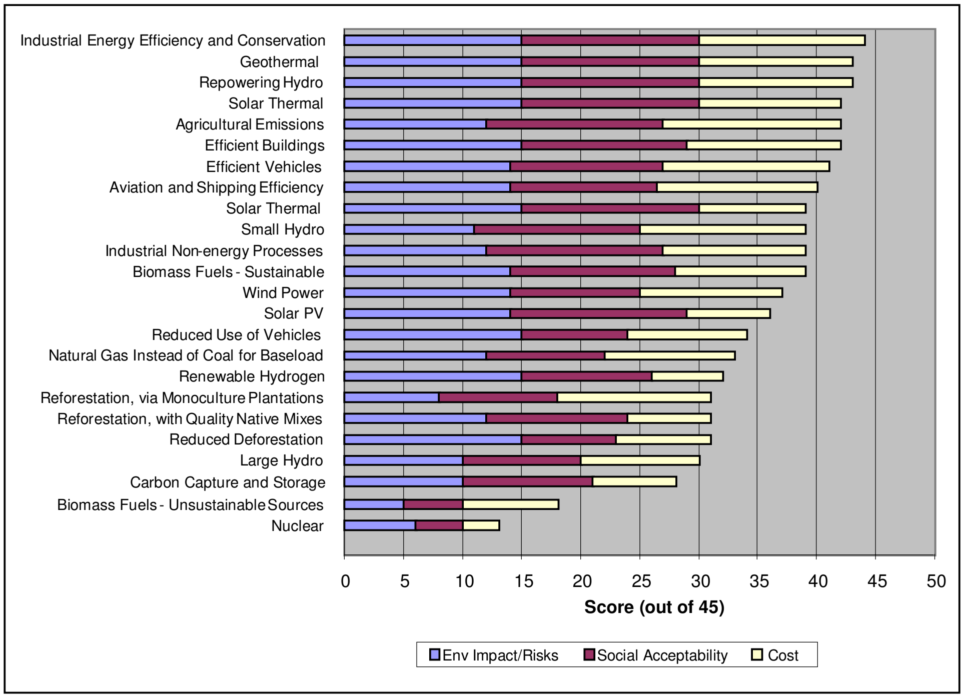

Fig 1 The results of a ranking exercise, scoring a suite of low and zero carbon 'technologies' (including technical demand reduction measures) for their merit against three criteria – environmental impact/risks, social acceptability, and cost.

The precise scoring of these technologies was not considered to be critical; the figure above is shown for completeness and to ensure transparency in the task force deliberations. This exercise informed the selection (depending on significance) and grouping of certain 'technology' options into three categories characterised, as shown in figure 2, by:

- Overwhelmingly positive benefits (efficiency solutions dominate this group);
- Some negative impacts, but outweighed by the positive benefits;
- Serious negative impacts, outweighing any positive benefits.

The last group of technologies, which were identified as representing an unacceptable balance of risk over benefit, includes

- Nuclear power (due to its costs, radiotoxic emissions, safety, and proliferation impacts);
- Unsustainable biomass (*e.g.*, energy crops grown on newly displaced forest land);
- Unsustainable examples of large hydro-electricity (which may flood biodiversity hot spots and fertile lands, force large-scale resettlement of human communities, or seriously disrupt river systems)[9].

[9] Based on the criteria of the World Commission on Dams (2000): http://www.dams.org/

All of the above could cause major disruption to human populations, as well as the environment.

Special mention is made here of the decision to exclude nuclear energy and certain kinds of biomass, as the potentials of both have attracted much attention in the climate change debate:

Industrial Energy Efficiency & Conservation Efficient Buildings Efficient vehicles Reduced use of vehicles Aviation and shipping efficiency Re-powering Hydro	***Benefits >> Disbenefits***
Sustainable Biomass Wind power Solar PV Solar Thermal power Solar Thermal Heat Small Hydro Geothermal (heat and power) Tidal, Wave & Ocean Technologies Hydrogen from Renewables Large Hydro (existing plus sustainable) CCS Natural Gas Displacing Coal	***Benefits > Disbenefits***
Unsustainable Biomass Unsustainable Hydro Nuclear	***Benefits < Disbenefits***

Fig 2 WWF grouping of climate solutions technologies based on environmental, social, and economic criteria.

Interest in nuclear energy has seen a resurgence as the technology increasingly is presented by proponents as a low- or no-carbon energy source. *This study shows that there are more than sufficient benign technologies available, without embarking further on nuclear power with its many associated risks*[10].

Biomass, in some respects, represents the opposite case—a technology with a mixed track record at scale, but one that has nonetheless won early support and raised high expectations, including from many in the environmental community. The task force considered the high risk of large-scale biomass plantations creating unacceptable environmental impacts, especially when grown in areas recently converted from tropical forest. Accordingly it concluded that biomass ought not be considered as a single category, and that separate designations for "sustainable" and "unsustainable" biomass were needed. The task force commissioned specific research to assess the possible range of contribution that could be made from *sustainable* biomass at a global level. Still, a significant shift to biomass as an energy source will surely place new demands on wild habitats, and may adversely impact the world's poor by driving a rise in food prices. Both these potentials sound a clear note of caution, and warrant further attention and ongoing management.

[10] For a fuller assessment, see Topic Paper: 'Nuclear Energy'

Nonetheless, current levels of biomass, nuclear, and large hydro were included in the model, to reflect existing realities such as plants in existence or under construction, along with additional capacity only as far as judged to be sustainable (none for nuclear) according to WWF's own criteria (see topic papers).

WWF recognises that there are currently new nuclear plants being commissioned and that others are being decommissioned. The Scenario assumes that all existing nuclear plants built or under construction will be run to the end of their economic life but will not be replaced. This effectively would result in a phase-out of nuclear power by 2050.

3 THE WWF CLIMATE SOLUTIONS MODEL - INPUTS

This section summarizes the major outcomes of a modelling project undertaken for the WWF Global Energy Task Force.

3.1 Modelling Project Objectives

Our starting point is that the following goals should be regarded by the world community as imperative, since failure would in each case give rise to unacceptable consequences:

- To supply sufficient energy services to meet projected global development needs;
- To avoid dangerous climate change, and other serious negative social or environmental impacts of energy technologies.

The specific objectives of this project have therefore been:

- To assess the availability of energy solutions to meet these goals in the period to 2050;
- To identify the key energy issues which need to be resolved if this potential is to be realised.

3.2 Defining the Challenge

3.2.1 Meeting global energy services needs

The number of people, the level of their consumption, and the nature of what they consume are all-important ingredients in understanding the challenge that is to be met. In all cases we have tried to take a neutral, mid-range projection of these important trends.

Population. The model assumes a growing world population which peaks at 9 billion people in 2050 as forecast by the United Nations Population Project[11].

Consumption. We have assumed an increasing demand for energy services and land production driven by economic development and industrialisation in developing countries facing major challenges in the relief of poverty[12], and increasing levels of wealth in all countries.

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[11] United Nations (2004). World Population Prospects: The 2004 Revisions Population Database. United Nations Populations Division. http://esa.un.org/unpp/

[12] See topic paper 'Poverty and Energy' and Country papers attached

Energy Demand. For a balanced view of projected energy demand we have used the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) scenario A1B storyline which is in the mid-range of energy demand projections.[13] However we have noted that the provision of energy (such as electricity or fuel) is only a means to an important end - the provision of energy services (such as lighting or transportation).

3.2.2 Avoiding dangerous climate change

2 degrees Celsius threshold. We have adopted the position (proposed by environmental scientists, adopted by the European Union[14], and strongly endorsed by WWF) that any human induced warming greater than 2 degrees Celsius above pre-industrial levels will be dangerous for the global environment, human society, and national economies[15].

Stabilisation target. The future levels of global warming are related to future levels of greenhouse gases in the atmosphere. We have adopted a target of 400ppm (parts per million) carbon dioxide equivalent (CO_2e) for greenhouse gases. This is based on Meinhausen's[16] analysis of the impact of greenhouse emissions on the climate system which suggests such a stabilisation provides a high[17] probability of avoiding a 2 degrees Celsius warming. In fact, current atmospheric concentrations of greenhouse gases have already exceeded this point; however the model referenced above indicates a trajectory in which emissions peak at 475ppm but stabilise at 400ppm over the long term, due to the action of the biosphere and oceans re-absorbing a portion of current and future anthropogenic emissions.[18]

Carbon budget. There is an emerging consensus regarding the level of global emissions reductions required – typically 60% below current levels by 2050 – in order to avoid dangerous climate change. However it is the total cumulative emissions that are important in this respect,

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[13] IPCC (2000). Special Report on Emissions Scenarios. The scenario is characterised as follows; "The A1 storyline is a case of rapid and successful economic development, in which regional average income per capita converge - current distinctions between "poor" and "rich" countries eventually dissolve. The primary dynamics are: Strong commitment to market-based solutions. High savings and commitment to education at the household level. High rates of investment and innovation in education, technology, and institutions at the national and international levels. International mobility of people, ideas, and technology. The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion." The A1B sub-scenario uses a "…balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant."

[14] EU Council (2004). Spring European Council 2004 proceedings. "the Council [...] ACKNOWLEDGES that to meet the ultimate objective of the UNFCCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2ºC above levels; [...]" Spring European Council 2004. Document 7631/04 (annex), p20.

[15] For a fuller statement, see topic paper attached: 'The 2°C Imperative'.

[16] Meinhausen, M. (2004). EU's 2°C Target and Implications for Global Emission Reductions. Swiss Federal Institute of Technology presentation.

[17] This refers to the Meinhausen (2004) estimate that a 400ppm CO_2e stabilisation would be consistent with a 74% probability of staying below 2 degrees warming (relative to pre-industrial levels).

[18] Meinhausen, M. (2006) What Does A 2 Degree Target Mean for Greenhouse Gas Concentrations. pp: 265 - 279, chapter 28 in: Avoiding Dangerous Climate Change; Cambridge University Press, 392 pages, 2006. .

so we have adopted the concept of a global 'carbon budget' – the total amount of carbon that can be released from human activity (allowing for natural levels of emission and sequestration) before a particular concentration level is breached.

Land-use emissions. Allowance must also be made for the uncertain contribution of emissions from land uses (of which tropical deforestation will be particularly important, being responsible for a fifth of all greenhouse gas emissions). We have therefore described a 'carbon budget' *range* representing the upper and lower allowances of anthropogenic carbon budget, depending on the success or failure of activities to limit emissions in these land use sectors[19].

Carbon budget range. Meinhausen's modelling indicates that to achieve an atmospheric stabilisation target of 400ppm CO_2e requires that emissions be limited to a fossil carbon budget of "about 500Gt C" (Gigatonnes of carbon). We have adopted this as the upper limit of allowable emissions. However, this assumes a significant cut in land-use emissions, in the absence of which Meinhausen points out that the carbon budget "could be lower (400 Gt C)". This has therefore been adopted as the alternative upper limit of allowable emissions.

Carbon band. Clearly, such a budget will be spent (emitted) over the course of many years (the model builds the carbon budget over a period of 200 years). The model assumes the way in which the budget might be spent as an indicative band, as shown in Figure 3, consistent with the upper and lower allowances of the total carbon budget. The smooth curves of this band reflect the inertia in the current energy system which resist sudden change.

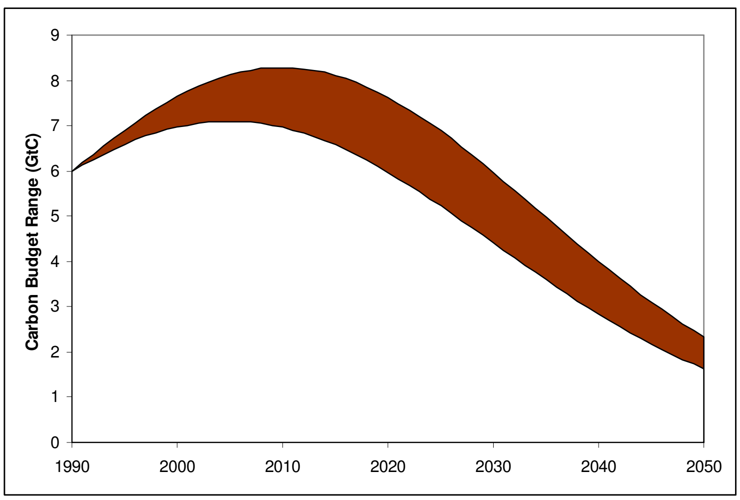

Fig 3 An indicative 'carbon band', showing the difference in the upper limits of annual allowable carbon emissions, from fossil fuels, in Gt C per year, for total carbon budgets of 400Gt C and 500Gt C taken out to 2200 (showing the period to 2050 only). The thickness of the band therefore shows the crucial extra flexibility available in anthropogenic emissions if deforestation is successfully controlled.

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[19] See topic paper attached: 'Deforestation'

Other greenhouse gases. We assume here that reductions of carbon dioxide will see other greenhouse gases reduced in equal proportions provided they are recognised and included in the same regulatory frameworks. So, the model works with carbon dioxide emissions only and does not include other greenhouse gases. However, the carbon dioxide from fossil fuel and deforestation accounts for the majority of all greenhouse gas emissions (62% and 18% respectively[20]). By cutting emissions from these sources, many other GHG emissions will be reduced in addition to carbon dioxide (notably methane and nitrous oxide). A world that seriously undertakes to reduce the carbon intensity of its energy sources to combat climate change is also likely to cut its non-energy carbon dioxide and other greenhouse gases by employing more innovative agricultural and industrial policies.

Persistent Use of Fossil Fuel without Carbon Capture. The use of carbon capture technology will enable low emission use of fossil fuels in major applications (see later). The model also allows for an estimate of ongoing fossil fuel use in a few applications where alternative fuels are not available and/or carbon capture technology has not been successfully applied. These include a proportion of aviation fuel demand not met by bio-fuels, and some aspects of industrial manufacturing and other niche applications or locations[21].

3.3 Key Features of the Model

3.3.1 Commercially available industry forcing

The WWF Climate Solutions Model is primarily a resource, technology, and industry feasibility model. It is not an economic model; price and cost have not been used to limit or guide the uptake of technologies. No assumptions or inferences have been made regarding the policies and measures required to achieve the outcomes. However, to ensure that the modelled scenarios are economically plausible and affordable, only energy sources and climate solutions which are currently competitive - or likely to be in the near term - have been selected. In some cases distributed energy technologies priced at point of use (such as solar photovoltaic panels or combined heat and power) have specific cost advantages which the model recognises. In the case of hydrogen manufactured via renewable energy sources, it is assumed that the added value of storage and creation of flexible, transportable fuels and fuels for high temperature industrial processes will justify the additional costs.

Although commercial viability has been assumed, this may not be achievable by means of single instruments such as a carbon price alone. However the level of commercial and public investment needed to drive industrial production and infrastructure development at the scale required will depend on long term, stable commitments from governments on the pace and depth of greenhouse emission constraints.

Lack of economic plausibility is often used to criticise models that include the use of low emissions, higher cost technologies. However the conclusions of the Stern Review – which was primarily economic – projected that the costs of global warming would severely impact global GDP if left unchecked.

[20] Baumert, K.A., Herzog, T., Pershing, J. (2006): Navigating the numbers - Greenhouse Gas Data and International Climate Policy; World Resource Institute, Washington USA

[21] See topic paper 21 'Persistent non-CCS fossil fuel use' attached

3.3.2 Extending the Pacala-Socolow 'wedges' concept[22]

A considerable amount of modelling has been undertaken in the fields of both climate change and energy. Many models are constructed in ways that let scenarios evolve based on costs such as the price of oil or the cost of carbon. WWF's Climate Solutions Model takes a different approach, focusing on the technology and resource potential of averting dangerous climate change, leaving the political and economic systems to respond to this necessity, rather than the other way round.

A 'wedges' model, developed by Pacala and Socolow[23], is widely viewed as an elegant approach and provides an excellent starting point. It divides the task of emissions *stabilisation* over 50 years into a set of seven 'wedges' (delivered by emissions-avoiding technologies) each of which grows, from a very small contribution today, to a point where it is avoiding the emission of 1Gt C per year by 2050. Its authors point out that many more of these 'wedges' are technically available than are required for the task of stabilising global emissions at today's levels by 2050.

The WWF Climate Solutions Model builds on the Pacala-Socolow 'wedges' model by adapting it to go beyond stabilisation, to achieve by 2050 the significant reductions in global emissions which the current scientific consensus indicates are needed to avert dangerous climate change. The WWF model:

1 Extends the penetration of climate-saving technologies so as to achieve abatement consistent with a more stringent carbon budget.

2 Draws on a diversity of expert opinion on the potential size and scale of solution wedges (from published analysis, internal research, and commissioned research from specialist consultants) as inputs to the model.

3 Employs a probabilistic approach with these inputs (using the 'Monte Carlo' method[24]) so that the results can be considered as probabilities of achieving certain outcomes or risks of failure.

4 Models real world industrial growth behaviour by assuming: that the growth of any technology will follow a typical S-shaped trajectory; that constraints impose a maximum on the rate of sustainable growth; and that the ultimate scale depends on estimated resources and other specific constraints.

5 Seeks to minimise the replacement of any stock or system before the end of its physical or economic life.

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[22] Pacala and Socolow have applied to the word 'wedge' to mean a very specific level of climate abatement defined by a triangle growing from zero in 2005 to 1Gt C per year of avoided emissions in 2050. The WWF model adopts the same principle of growing wedges, but does not require a linear growth nor define a prescribed size in 2050. For differentiation the WWF model refers to 'Climate Solution Wedges'.

[23] Pacala, S and Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem of the Next 50 Years with Current Technologies. Science 13th August, 2004, Vol. 305.

[24] The Monte Carlo method is widely used to predict probable outcomes in situations where two or more inputs have a range of possible values. The model is run over and over again with different input values set randomly within their possible range and in accordance with their individual probability distributions. Consequently the results provide a probability of outcome which reflects the combined probability distributions of the inputs. See references in technical summary.

6 Allows some solutions to play an interim role by being phased-in then phased-out as better solutions become available.
7 Excludes energy technological options deemed by WWF to be inherently unsustainable.
8 Includes a contingency which allows for the possibility that some solutions may encounter significant barriers to development and therefore fail to meet the projections set out in the model.

Considerable analysis and modelling detail supports each of these steps and further explanation is available in a supporting technical document[25].

3.3.3 Top-down and bottom-up

The model combines top-down and bottom-up aspects to capture the best of both ends of the debate about how best to approach future emission cuts – the global requirement for energy and abatement opportunities ('top down'), and the wide range of options for meeting these needs sustainably ('bottom up').

The top down aspect of the model is based on the IPCC's A1B scenario for energy and emissions which is consistent with Section 3.3.1 above. However, top down approaches can introduce perversities such as inflated base-lines creating an illusion of greater emissions reduction potential[26]. The bottom-up aspect of the model builds a set of 'climate solutions wedges' to meet the projected energy services demand, sector by sector. This requires some assumptions about the level and type of consumption, what proportion of energy is used on transport, or in homes or in industry and so forth.

It has been assumed that in 2050 consumption patterns throughout the world will be similar to those of citizens with developed standards of living today – for example in the OECD. This information is used to ensure that the climate solution wedges are internally consistent and avoid the 'double counting' of overlapping abatement opportunities.[27] By considering, in each sector, the total energy services needed for that sector and then the role of possible climate solutions, the climate solution wedges maintain to the best extent possible their connection with real world.

To contrast the two different approaches: the climate solution wedges can be built from the 'bottom up' to consider the total energy provided in response to the needs of each sector. Or, in the 'top down' approach used by Pacala and Socolow, each can be seen as a wedge of low- or zero-carbon energy, subtracted from the A1B projection, and displacing conventional fossil fuel supplies which would otherwise have been used to meet energy needs.

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[25] A technical summary of the design of the model can be found in Paper 19 of the Topic Paper Annex to this report

[26] For example, converting an average car to hybrid might save 3 litres per 100km, but if you assume cars in the future are twice as big and would normally use twice as much fuel, then the savings would be 6 litres per 100km. If that were the case, the net consumption rate would have remained unchanged. Whilst it can appear that there are greater emissions avoided, in practice this may not be the case.

[27] For example abatement from transport could be achieved by more efficient vehicles or a switch to biofuels. However these measures are not cumulative - if all cars ran on biofuels, greater vehicle efficiency would have no impact on net emissions.

No preference order of solution wedges is implied and if the combined block of potential solution wedges exceeds the estimated energy demand in a given year, the extent of this excess is effectively a contingency/safety margin against failure of individual wedges, under-estimation of demand, or future requirements for deeper cuts than currently estimated.

4 THE WWF CLIMATE SOLUTIONS MODEL - OUTPUTS

The WWF Climate Solutions Model has been run to look at a variety of scenarios within the boundaries of the chosen modelling methodology, and the scenario presented here considers what is required to ensure that the goals defined by the WWF Global Energy Task Force – energy development needs, climate protection, and avoidance of social and environmental impacts – are met within a safety margin consistent with appropriate risk management.

Importantly, this scenario (see Figures 4 and 5) describes a future in which, due to the long lead times for deploying low emission technology, global fossil fuel carbon emissions continue to rise for the next decade. The scenario shows that, in order to remain within the total carbon budget, decisive action is needed within five years to speed up the growth of *all* clean energy industries. A transition on this scale is needed to avert dangerous warming, and under the model it appears technically and industrially feasible. However, successful delivery will depend on sufficient political will, globally organised, to drive change through a suitable economic and regulatory framework.

4.1 Managing Risk

The scenario has been constructed with the following requirements:

- Meets the anticipated demand in energy services with at least a 10% contingency surplus;
- Achieves the objective of avoiding a 2 degrees Celsius warming by achieving a 400ppm CO_2e stabilisation;
- Is not unduly dependent on any single energy resource or technology type;
- Can be achieved without resort to unsustainable technologies.

4.2 Build-up of Climate Solution Wedges

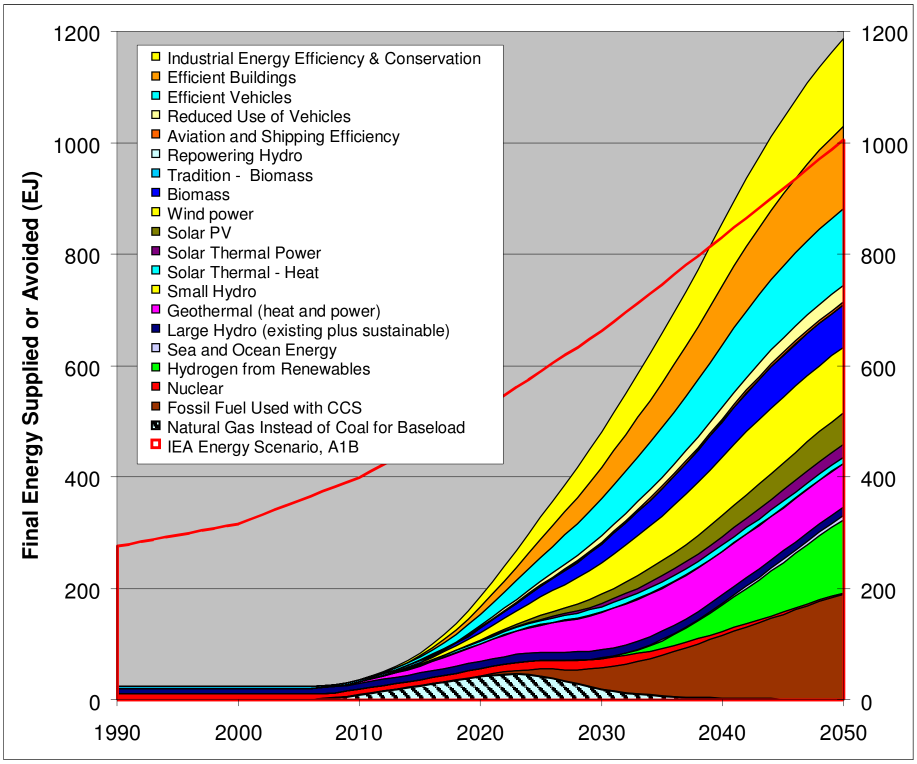

Fig 4 A representative scenario of the Climate Solutions Model depicting technology wedges capable of averting dangerous climate change. Each climate solution wedge grows over time and the sum of all wedges becomes significant as industrial capacity and deployment increase in scale. The top red line refers to the energy demand projection in the SRES A1B scenario. Note that since energy efficiency technologies are shown alongside energy supply from low emission sources the results are expressed in final energy supplied or avoided (rather than primary energy production).

This scenario indicates that a combination of efficiency gains, renewable energy sources and CCS can meet projected energy needs in 2050.

Notes

1 Renewables: Today only traditional biomass and large hydro are providers of globally significant quantities renewable energy, though the international growth of others such as wind and solar continues to be exponential and greater than any other energy technologies.

2 Time Lag: The energy efficiency measures in this simulation have an effect quite early on, making a noticeable impact from 2015 onward. Renewables meaningfully impact a little later and Carbon Capture and Storage (CCS) only starts to penetrate the emissions profile in the period 2020 to 2030. Meanwhile gas (without CCS) is used heavily in the period 2010 to 2040 to displace the use of coal.

3 Energy for Thermal Processes: There will be a critical constraint on the availability of fuels for industrial thermal processes which can be satisfied only with low emission levels by hydrogen, biomass, or fossil fuels with CCS.

4 Residual Emissions: If there are no significant failures in the climate solutions available, the only remaining carbon emissions from fossil fuels after about 2040 are those from a higher efficiency aviation (see below) and shipping sector, a small fraction of non-CCS natural gas and residual emissions from a growing share of CCS-based fossil fuel use. The model does not include non-energy carbon dioxide (process) emissions, nor non-carbon dioxide emissions from other human uses such as agriculture or fluorinated greenhouse gases (F-gases). These are assumed to reduce in rough proportion with carbon dioxide emissions provided that such gases are identified and included in the same regulatory frameworks. However, assuming the contingency is called upon then the phase out of conventional fossil fuel use will be delayed by about ten years to 2040, see Figure 5 below.

5 Post 2030: Most energy consumption post-2030 is derived from various sources of renewable energies, notably wind, sustainable biomass, geothermal, and various systems for harnessing solar radiation.

6 Hydrogen from Renewables: There are many sources of renewable energy that can supply substantially more energy that the power grids are able to absorb, therefore harnessing this energy requires storage in another form. Hydrogen is an example of one such energy carrier. The importance of hydrogen generated from a non-specified but wide variety of renewable sources (such as large solar thermal installations, wind energy, and similar large resources otherwise constrained by grid limitations) grows rapidly from 2030. This provides more flexibility for the application and time of use for zero and low-carbon energy sources, especially if they are intermittent. It also allows a chemical energy form for thermal and transport applications.

7 Aviation: There is currently very high growth in the levels of aviation and therefore the annual emissions of greenhouse gases from air-travel. In part this trend reflects the lower levels of taxation of aviation fuels and their current exclusion from the Kyoto Protocol. In modeling aviation we have looked at several possible solutions to ensuring that aviation levels can be managed within the carbon budget. The model includes the following provisions:

a) An ongoing increase in the efficiency of aircraft.
b) An increase in the operating efficiency of aircraft by maximising the occupancy levels on all flights.
c) Displacing the use of mineral (fossil fuel) kerosene with direct replacements derived from biofuels.
d) Avoiding aircraft use where possible through use of alternatives such a high bandwidth teleconferencing, high speed trains for short distance travel and other interventions to avoid the need for or uptake of short duration air-travel.

Unlike land based transport, electrical storage of energy or hydrogen are not yet, and may never be applicable to air travel. This means that aviation fuels may need to be a priority for biofuel use or there may be a need to factor in residual use of fossil fuels for aviation. The model includes a provision for continued use of some fossil fuels for persistent applications such as some component of aviation fuels.

4.3 How the Wedges Displace High Emission Energy

Figure 5 shows how the mix of energy wedges performs relative to the energy that is forecast to be required from the A1B reference scenario.

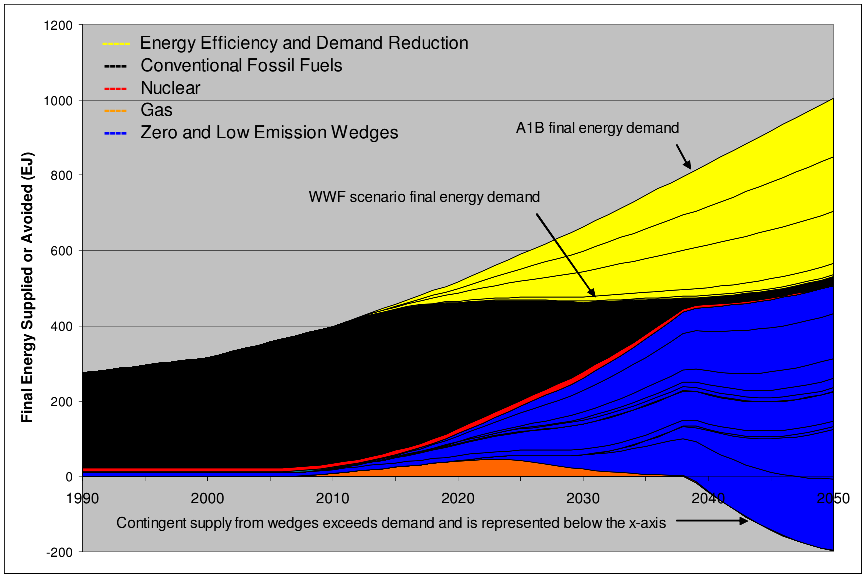

Fig 5 Output of the WWF Climate Solutions Model. Energy efficiency and demand reduction measures (drawing down from the top, in yellow) largely stabilise energy demand by about 2020, allowing a rising demand for the provision of energy services to be met from a more or less level supply of energy (notwithstanding regional variations). Meanwhile zero and low emission energy sources are built up (from the bottom, in blue) until about 2040 when, assuming none fail significantly, fossil fuel use (in black) is reduced to a 'persistent' residual level of 20EJ for applications which are hard to replace. Nuclear energy use (in red) is phased out. It may of course be that some wedges under-perform or fail entirely. The scenario provides spare capacity as a contingency, represented by energy supply shown reaching below the x-axis.

In broad terms the scenario shows an energy world dominated by the demand for more energy services over the full period to 2050.

With the seeds of energy solutions sown in the period to 2012, the effects on the energy mix start to become tangible first with a deliberate expansion of **energy efficiency** (industry, buildings, and in all forms of transport) The overall effect is to cause final energy consumption to plateau from the period from 2020 onwards, whilst final energy services demand actually increases throughout the period.

Despite starting from a smaller base, the growth of **renewable energy** becomes significant in the period to 2020. In addition, an increase in use of gas is postulated to avoid new coal uptake – creating a 'gas bubble' which extends from 2010 to 2040.

As renewable electricity production becomes constrained by about 2040, the growth of **hydrogen** production and distribution allows renewable energy to be both stored and used for end-uses such as transport fuels and domestic and industrial thermal processes.

Most of the remaining phase-out of emissions from conventional fossil fuels is achieved by expansion of **Carbon Capture and Storage** – on both gas and other fossil fuels still used for power and industrial processes.

The scenario is **resilient** to the under-performance of one or more wedges with a 15% contingency; this would even allow for a total failure of fossil fuel CCS.

This scenario shows that it is technologically possible to exceed the projected demand for energy (as moderated by energy efficiency measures) using the mix of wedges which have been developed with the industrial criteria set out for the model and based on published resource and performance data. Of course, this takes a unified global approach. Some regional perspectives are explored in background topic papers[28].

The overall effect of this scenario on emissions is shown in Figure 6 below.

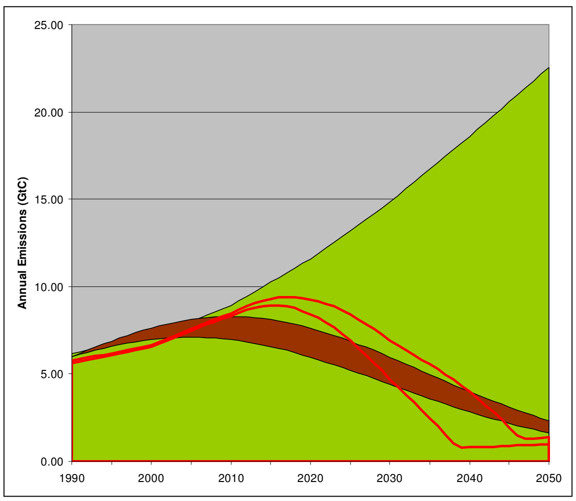

Fig 6 Emissions in the WWF Climate Solutions Model. The diagram shows the range of emissions (red band) in the scenario presented in this paper. The lower red limit of this range shows the technical potential of emissions reduction if all wedges are fully implemented, and the whole 'fossil fuel with CCS' wedge (coloured brown in Fig 4 above) comprises plants burning gas (which has lower carbon intensity). Emissions follow the upper limit line if about 80% of the potential is achieved and the 'fossil fuel with CCS' wedge is made up of (higher carbon intensity) coal plants. Placed against the nominal carbon budget curve (brown, from Fig 3), it is clear that the overall emissions to 2050 of the lower trajectory falls within the total emissions indicated by the upper line of the budget (ie that allowable if deforestation is successfully brought under control). Any failure of efforts to halt deforestation (reducing the budget available for energy emissions to the lower line of the brown band) will reduce the chances of staying within the overall emissions budget, especially if failures or delays in the implementation of solution wedges drive the emissions curve towards the upper limit of the red band. These curves are set against a back drop (green) of the emissions that would occur if the IPCC's A1B energy scenario were supplied with the current fossil fuel mix (ie at about 0.02GtC/EJ). The results of the modelling show that, although the point at

[SR1] Comentário: Designer please show area between red lines as a shaded red band

[28] See Topic Papers annexed

which global emissions start to decline may not occur until 2015-2020, there is potential to drive deep cuts quickly once the industrial momentum behind transition is underway.

4.4 Key Characteristics of the WWF Scenario

The WWF model and scenario presented show that within the technological, resource, and industrial constraints built into the model it is possible to achieve a set of transformations in the energy sector needed to avert dangerous climate change. To achieve this in the model:

- All solutions wedges are pursued concurrently; there is inadequate industrial development time to allow for consecutive development;
- Initiation of most solutions occurs between 2007 and 2012, reflecting the fact that some solutions are already underway, though many are not;
- Energy efficiency technologies are deployed as early as possible to create emissions space while other solutions are evolving in scale;
- The rate of development for most of the zero- and low-emission technologies is pushed to the high end of viable industry growth initially (up to 30% per annum), and maintained at about 20% per annum during their roll-out phase;
- The solution has intrinsic resilience to the failure or under performance of one or more climate solutions wedge, this includes the possible failure of CCS.

5 CONCLUSIONS

5.1 Six Key Solutions

If implemented in parallel, the WWF model shows that the following solutions provide a way to achieve the goal of averting dangerous climate change whilst avoiding other serious environmental and social consequences. Topic papers (annexed)[29] include further information on these technologies and WWF's definition of "sustainable" for each.

5.1.1 Decoupling energy services demand from energy production

Investment in energy efficiency, at all levels from generation to actual use, is by far the most immediate, effective and economically beneficial way to reduce emissions, to 'buy time' while other technologies are developed[30], and to decouple rising demand for energy services from actual energy production. The model indicates that by 2020-2025 energy efficiencies will make it possible to meet increasing demand for energy services within a stable net demand for primary energy production. The priority for developed countries is to retrofit their inefficient capital stock with energy efficiency measures, and to enable developing countries to leap-frog by investing in much more efficient technologies and systems from the start.

By 2050 the WWF scenario shows the potential for the equivalent of 200EJ[31] per year avoided by industrial energy efficiency, and a similar amount from building efficiency and from a combination of reduced vehicle use and higher efficiency engines. In total,

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[29] See Topic Papers annexed

[30] See Topic Paper 'Energy Efficiency'

[31] Exajoule (EJ) – a quintillion (10^{18}) joules

efficiencies can reduce the projected demand by 468EJ or 39% annually - equivalent to avoiding emissions of 9.4 Gt C/yr - by 2050[32].

5.1.2 Stopping forest loss and degradation

Stopping and reversing deforestation and degradation of forest land (*e.g*., for charcoal or grazing lands)[33], particularly in tropical countries, emerges as an absolutely crucial element of this scenario[34]. Priority must be placed on reducing emissions rather than on pursuing sequestration. NB: This does not preclude continued sustainable use of forests.

The scenario underscores the need for efforts to curb emissions from land use change and forestry, contributing a total saving of 100 - 150 Gt C towards achieving the overall carbon budget. Without this contribution, the probability of success is radically reduced.

5.1.3 Concurrent growth of low emission energy technologies

The model assessed the potential for a variety of low emission technologies such as wind[35], hydro[36], bioenergy[37], geothermal, solar PV, wave and tidal, and solar thermal. A rapid scaling-up of these technologies is needed, but within a set of environmental and social constraints to ensure their sustainability. In the next fifty years, expansion of sustainable wind, hydro, and bioenergy will be particularly important. Bio-energy for heat and transport, holds vast potential but could go terribly wrong if implemented unsustainably – *e.g.,* by clearing bio-diverse habitats to plant energy crops. Large hydro dams need also to be deployed with restraint.

By 2050 the scenario includes the equivalent range of 110-250EJ per year from sustainable biomass, with a best estimate at 180EJ/yr. Together, this and other low emission technologies can provide 513EJ energy per year by 2050, or about 70% of the supply after efficiencies have been applied, and equivalent to avoiding emissions of 10.2Gt C/yr[31].

5.1.4 Flexible fuels, energy storage and infrastructure

The model shows that the deep cuts in fossil fuel use cannot be achieved without the large volumes of energy from intermittent sources being harnessed through energy storage for better alignment with the timing of demand and for transformation into energy forms needed for transport and high temperature (chemical) heat. Use of fossil fuels with CCS will also create large volumes of hydrogen gas. Therefore, the results imply a requirement for (a) major new infrastructure for the production, storage, transportation and use of hydrogen gas; and (b) development of modular, distributed grid-connected power storage infrastructure.

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[32] Compared with our reference energy demand scenario (IPCC's A1B), supplied at today's average levels of carbon intensity (about 0.02Gt C/EJ),

[33] See Topic Paper 'Deforestation'

[34] see Topic Paper 'The 2℃ Imperative'

[35] See Topic Paper 'Wind Energy'

[36] See Topic Paper 'Hydro-electricity'

[37] See Topic Paper 'Bio-energy'

5.1.5 Replacing high-carbon coal with low-carbon natural gas

In the short term, an increase in use of natural gas[38] as a 'transition fuel' can play a significant part in avoiding locking-in higher emissions from coal, thereby buying more development time for other energy solutions to grow. While this is more applicable in some countries than others, gas should be scaled up in the short-term (where it can avoid coal use) without bringing about harmful biodiversity impacts. The even lower carbon emissions for gas used with carbon capture and storage technology are also taken into account. WWF therefore sees natural gas as a bridging fuel with important applications, provided that energy security issues can be resolved.

The scenario includes a provision of natural gas displacing coal which peaks in supply at about 52EJ in 2023. It is assumed that this can then become sequestered within the CCS wedge as technology comes on line.

5.1.6 Moving on "carbon capture and storage"

The WWF model shows the importance of CCS[39] if fossil fuels are to have an ongoing role within a carbon-constrained energy sector. Clearly, while low and zero emission technologies are being brought to maturity and widely deployed, coal, oil and gas will continue to play a part in the energy supply mix in the medium term, for reasons explored elsewhere in this report and in the topic papers annexed. The model shows that, in order to stay within the carbon emissions budget, it is essential that fossil-fuel plants are equipped with carbon capture and storage technology as soon as possible – all by 2050. This requirement has major and immediate implications for the design, planning and location of new plants, since transport of carbon dioxide to distant storage sites would be very costly.

Overall, fossil fuels with CCS could account for 26% of supply (after efficiency wedges have been implemented) in 2050, avoiding emissions of 3.8Gt C/yr[31].

However, CCS is at best a very important but only partial contributor. The model shows that, since CCS doesn't capture all emissions, the proportion of fossil fuels in the supply mix will have to be reduced to 15-30% by 2050 (the low figure for coal, higher for gas). These points emphasise the urgency of major investment in low- or zero-carbon technologies in order to stay within the carbon budget.

Also, continued exploitation of fossil fuels, even on a declining scale globally, will inevitably involve the opening of new reserves as old sources are worked out. New developments should be exposed to rigorous conditions to protect environmental and social values.

A range of potential capture efficiencies are included in the probabilistic model. The level of CCS which can be used is sensitive to this capture efficiency and the fuel that is used – its contribution is maximised with gas.

5.2 Three Imperatives

The following factors emerge as of particular importance in securing a successful outcome to this challenge:

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[38] See topic paper 'Natural Gas'

[39] See topic paper 'Carbon Capture and Storage'

5.2.1 Urgency

The remedies for climate change have been discussed at length without sufficient decisive action. Meanwhile carbon-intensive technologies are rapidly using up the available carbon budget, reducing options and placing the future in jeopardy. Within five years, measures must be in place to drive the urgent development and deployment of benign energy technologies described in this Vision. Delays make the transition increasingly difficult and costly, and the risks of failure greater.

5.2.2 A global effort

The challenge identified here, of meeting the world's energy needs safely and sustainably, patently requires a global effort in which every country has a role to play. If the worst threats of climate change are to be avoided, all countries must shoulder the challenge identified here, though each has different circumstances, responsibilities, and priorities, as illustrated by the examples of Japan, USA, South Africa, Russia, India, EU, China and Brazil.[40]

5.2.3 Leadership

Action is needed by governments of the world to agree targets, to collaborate in effective strategies, and to influence and co-ordinate the investment of many trillions of dollars (which will be invested in energy in the coming decades in any event), so that future needs are met safely and sustainably, as proposed here.

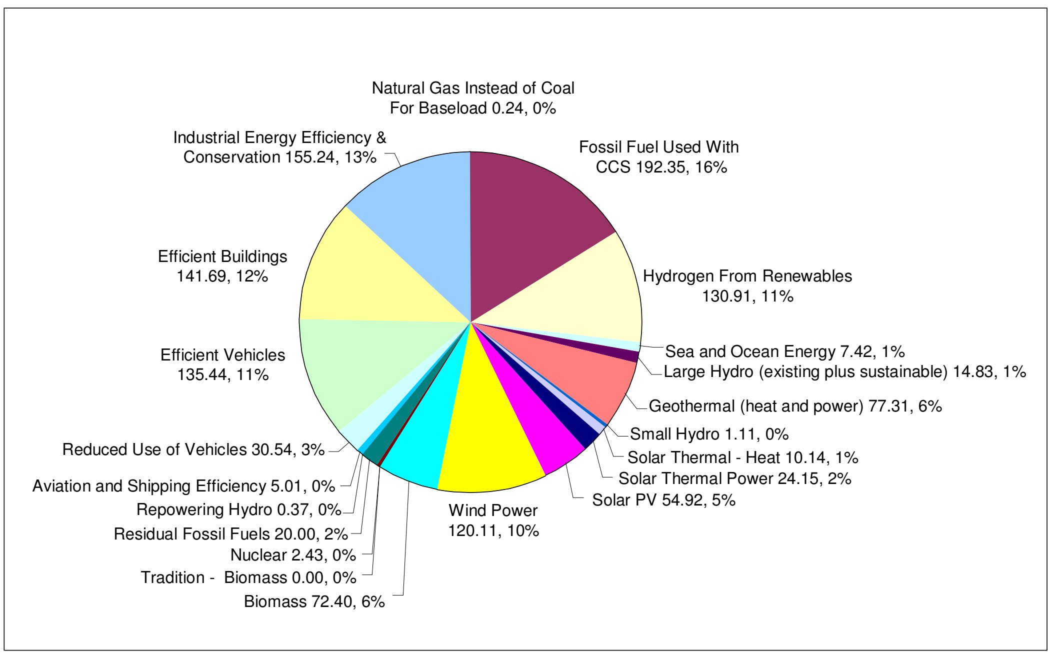

Fig 7 The supply mix. A snapshot of the contribution of each of the 'Climate Solution Wedges' in 2050, first in Exajoules and then as a percentage of energy supplied or avoided, compared with the energy demand projection in the IPCC's SRES A1B scenario. Efficiencies reduce that demand by about 40%; of the remaining

[40] See topic papers

demand, about 70% can be met by low carbon technologies, and about 26% by fossil fuels operating with Carbon Capture and Storage. Nuclear, conventional fossil fuel use without carbon capture, and other small sources make up the last 4%.

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Jim Leape, Director General, WWF International

Members of WWF Global Energy Task Force 2005-7

Robert Napier, CEO, WWF-UK (Task Force Chair)
Greg Bourne, CEO, WWF-Australia
Octavio Castelo Branco, Board member, WWF-Brazil
Dongmei Chen, Head of Climate and Energy, WWF-China
Dr Igor Chestin, CEO WWF-Russia
Jamshyd Godrej, President, WWF-India
Denise Hamu, CEO, WWF-Brazil
Barbera van der Hoek, WWF-Netherlands
Jennifer Morgan, Director, WWF International Climate Change Programme (to Sept 06)
Richard Mott, Vice President, WWF-US
Mike Russill, CEO, WWF-Canada
Dr Stephan Singer, Head, European Climate & Energy Policy, WWF European Policy Office
Paul Steele, COO, WWF-International
Lory Tan, CEO, WWF-Philippines
Thomas Vellacott, Conservation Director, WWF-Switzerland

Principal authors of WWF Climate Solutions Vision

Greg Bourne, CEO, WWF-Australia
Dr Karl Mallon, Director**,** Transition Institute, Australia
Richard Mott, Vice President, WWF-US

Authors of topic papers

Jean-Philippe Denruyter (Bioenergy); Mariangiola Fabbri (Energy Efficiency); Gary Kendall and Paul Gamblin (Gas); Jennifer Morgan (2 Degree Imperative); Richard Mott (Nuclear); Jamie Pittock (Hydroelectricity); Simon Pepper (Energy and Poverty); Duncan Pollard (Deforestation); Dr Stephan Singer (CCS, Wind) Giulio Volpi, Karen Suassuna (Brazil); Dongmei Chen (China); Dr Stephan Singer (Europe); Dr Hari Sharan, Prakash Rao, Shruti Shukla, Sejal Worah (India);Yurika Ayukawa, Yamagishi Naoyuki (Japan); Dr Igor Chestin, Alexei Kokorin (Russia); Dr Harald Winkler (South Africa); Richard Mott (US);

External advisers

Rhuari Bennett, Director, 3KQ, UK; Dr Karl Mallon, Director, Transition Institute, Australia; Dr Felix Matthes, Öko Institute, Berlin; V Raghuraman, Adviser, Confederation of Indian Industry; Philip Riddell, Environmental Adviser, France (Bioenergy Potentials); Liam Salter, former WWF Asia-Pacific Climate and Energy Director; Dr Hari Sharan, Chairman, Dasag, Switzerland (for India); Professor Rob Socolow, Princeton University, USA; Carlos Tanida, Fundacion Vide Silvestre, Argentina; Dr Harald Winkler, Cape Town University, South Africa; Prof Zhou Dadi, Director, Energy Research Institute, China

External peer reviewers
Prof José Goldemberg (Secretario de Estado, Secretaria do Meio Ambiente, Brazil); Prof Jorgen Randers (WWF-Norway); Hugh Sadler (Energy Strategies, Australia); Prof Rob Socolow (Princeton University)

Contributors of material and comments
Jamie Pittock, Paul Toni (WWF-Australia); Markus Niedermair (WWF-Austria); Sam van den Plas (WWF-Belgium); Leonardo Lacerda, Karen Suassuna, André de Meira Penna Neiva Tavares, Giulio Volpi, (WWF-Brazil); Arlin Hackman, Julia Langer (WWF-Canada); Dermot O'Gorman, Liming Qiao (WWF-China); Jean-Philippe Denruyter, Mariangiola Fabbri, Elizabeth Guttenstein, Gary Kendall, Elizabeth Sutcliffe (WWF European Policy Office); Karoliina Auvinen (WWF-Finland); Edouard Toulouse (WWF-France); Regine Guenther, Imke Luebbeke, Christian Teriete (WWF-Germany); Liam Salter (WWF-Hong Kong); Máthé László (WWF-Hungary); Samrat Sengupta (WWF-India); Wendy Elliott, Kathrin Gutmann, Martin Hiller, Isabelle Louis, Duncan Pollard, William Reidhead, Thomas Schultz-Jagow, Gordon Shepherd, Tien-ake Tiyapongpattana, (WWF International); Matteo Leonardi, Mariagrazia Midulla (WWF-Italy); Yurika Ayukawa (WWF-Japan); Melanie Hutton (WWF-New Zealand); I Poxon, Rafael Senga, Jose Ma Lorenzo Tan (WWF-Philippines); Alexey Kokorin (WWF-Russia); Dr Sue Taylor (WWF-South Africa); Mar Asuncion, Heikki Willstedt (WWF-Spain); Denis Pamlin (WWF-Sweden); Patrick Hofsteter (WWF-Switzerland); Dr Ute Collier (WWF-Turkey); Keith Allott, Richard Dixon, Andrea Kaszewski, James Leaton, Richard Wilson (WWF-UK); Jane Earley, Hans Verolme, (WWF-US).

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Manager: Simon Pepper srpepper@tiscali.co.uk
Facilitator: James Martin-Jones james@jamesmartinjones.com
Administrator: Amanda Kennett (WWF-UK)