WORLD ENERGY COUNCIL
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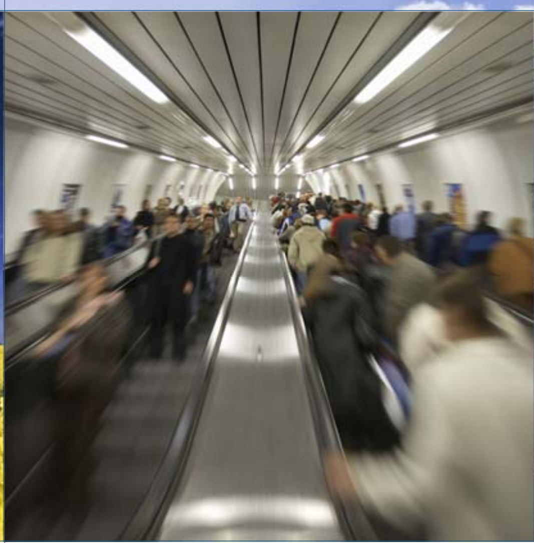
# Transport Technologies and Policy Scenarios to 2050

## Executive Summary

World Energy Council 2007

Promoting the sustainable supply and use of energy for the greatest benefit of all



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# Executive Summary

## Officers of the World Energy Council



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**Executive Summary**
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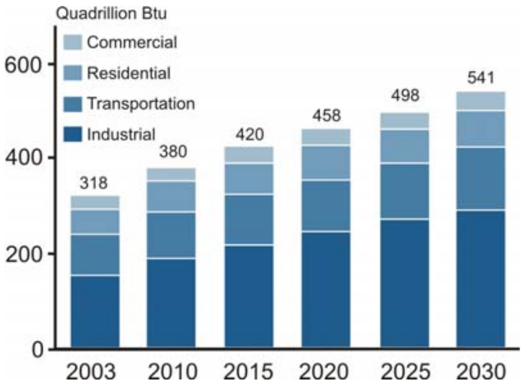
# Introduction

Transport is one of the major global consumers of energy, currently representing between 20% and 25% of aggregate energy consumption and $CO_2$ emissions. Strong growth in energy consumption to 2050 is projected in all sectors, with the transport proportion projected to remain stable up to 2050. Transport therefore has an important role to play in contributing to the primary objective of the World Energy Council: sustainable energy for all. Transport is the only energy sector in which the energy itself is mobile during consumption, rather than being delivered for use at a fixed location. For this reason, energy for transport is dominated by petroleum, which is widely available, relatively inexpensive and from which easily transportable liquid fuels of high energy density such as gasoline and diesel are made.

**Figure 1** World energy consumption by end-use sector to 2030
Source: EIA, International Energy Outlook 2006




The sustainability of petroleum and other fossil fuels within the timeframe of this study: to 2050, has been put into question by scientists, policymakers and other stakeholders. Sustainability is measured in terms of the 3 A's criteria of accessibility, availability and acceptability, with a variation in the relative importance of these factors between the different regions. Sustainability of fuels brings into question the sustainability of the associated vehicle technologies.

In this study, existing and potential fuel and vehicle technologies are assessed both qualitatively (by the 3 A's criteria) and quantitatively (by the contribution to reduced consumption and emissions) to determine a roadmap for technologies which can help meet the objective of sustainable energy. Other non-technical measures are also considered. The major long-term barriers to the introduction of beneficial technologies and the potential measures to overcome them are analysed. The roadmap of technologies and measures is put into a practical context by considering the policies necessary to ensure that the objectives are met in the most efficient and effective way possible.

The following analysis and projections of technologies apply to both developed and developing countries. The penetration of technologies will, in general, occur first in developed countries and at a later time in developing countries, since their less wealthy economies are less able to absorb the technology cost. This delay will be greater for the more advanced and expensive technologies, but the market presence of new technologies in developed countries can be expected to enable early adoption in many developing countries. The analysis of policy options applies equally to all countries and regions, since the economic viability of technologies and measures in a functioning market is an essential condition for effective transport policy, regardless of the stage of economic development.

# Technologies for reducing consumption

Passenger vehicle technology is expected to remain dependent on petroleum fuels and internal combustion engines (ICE) for the foreseeable future, since these elements remain the most convenient and affordable for mass personal mobility. Enhancement of ICEs through clean diesels, hybrids and new combustion techniques will ensure increased efficiency, continuing the consistent historical annual improvement in vehicle efficiency. Hybridisation of ICEs is expected to increase in penetration, in particular in congested areas with stop-start driving, where efficiency gains, and therefore reductions in consumption, are highest.

Alternative fuels will also increase steadily in penetration, to support the objectives of improved fuel quality, a more diversified supply base and reduced well-to-wheel $CO_2$ emissions. Second generation biofuels, made from non-food plants and usually through advanced chemical techniques, such as synthetic biomass-to-liquid (BTL) and cellulosic ethanol, are expected to grow significantly by 2035. Synthetic gas-to-liquid (GTL), employing the same basic synthesis technology as BTL, is already expected to grow strongly and reach a significant penetration in the coming decade.

## Fuel and propulsion technologies

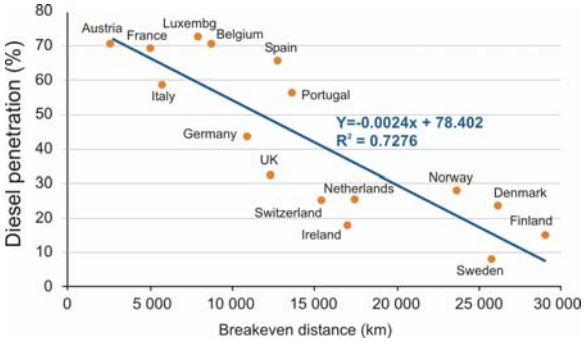
In 2050, gasoline and diesel are likely to remain the dominant fuels, but their composition and quality will continue to develop in order to enable advanced ICEs. Whilst ICEs are therefore also expected to remain dominant, advanced concepts for internal combustion will include processes such as homogeneous charge compression ignition (HCCI), with the objective of combining the advantages of diesel and gasoline. By 2050, the biofuel portion of hydrocarbon fuels will likely be significant. Supported by the extensive research and development activities currently in progress, hydrogen fuel and fuel cell vehicles are expected to gain a market foothold by 2035 and grow towards 2050. On-board electric power utilisation in personal transport will also increase, in particular in OECD and richer developing countries, which have more economic capacity to absorb the cost premium over conventional vehicle concepts. This will initially be manifested as increased hybridisation. A significant presence of pure electric vehicles powered by batteries and/or fuel cells is a potential scenario, assuming that progress on the necessary technologies and their costs is sufficient to enable a commercially viable product.

Commercial vehicles comprise globally over 40% of energy consumption in land transportation. Improvements in efficiency and reductions in consumption will likely remain based on the diesel engine, which is currently dominant in this sector. Innovations in engine performance will be shared with the passenger vehicle diesel sector and include variable valve timing and new combustion techniques such as HCCI. Hybridisation, which has already penetrated in certain applications, can be expected to increase in popularity. In particular, urban buses have found a niche hybrid segment, which will likely expand. Certain short-haul and even long-haul trucks may also be considered for some type of hybridisation, due to the significant amounts of braking energy that can be recuperated. Alternative and biofuels also apply to this sector.

In aviation, engine and materials technologies and flight management measures will potentially be available which can improve aircraft efficiency by over

## High penetration of diesel and hybrid passenger vehicles can contribute a reduction of several percent in global transportation energy demand.

**Figure 2** Diesel penetration vs. breakeven distance in European countries
Source: J.D. Power 2003




30%. Set against the expected 200% growth in air travel by 2050, efficiency improvements can serve to dampen the projected increase in consumption. Aviation fuel presents a particular opportunity for alternative fuels, since aviation fuel (kerosene) can be, and is already, made using the synthetic Fischer-Tropsch process, which can use gas, coal or biomass as a feedstock (GTL, CTL and BTL fuels).

## Energy potential and economic breakeven

The potential for reduction in energy consumption varies by technology. High penetration (50%, in those regions with currently low penetration) of diesel and hybrid passenger vehicles can contribute a reduction of several percent in global transportation energy demand. This reduction is, however, measured in comparison to a growing baseline of consumption. This effect has been demonstrated in, for example, Europe, where increased penetration of diesel vehicles alongside other efficiency improvements have not been matched by reduction in overall consumption, mainly due to the growth in car ownership, use and traffic congestion.

Estimated economic breakeven points are defined as the point at which the incremental cost of technology is recovered through associated fuel savings, assuming a 3 year payback. Breakeven points for diesel and hybrid technologies in passenger vehicles are generally lower than the foreseeable technology cost, implying that the value of fuel savings does not necessarily justify the upfront cost premium. This indicates the lack of a consistent business case for the consumer, although the variability of consumer expectations and behaviour makes these technologies attractive to a certain portion of consumers under certain conditions. Higher oil prices, consumer acceptance of longer payback periods and complementary benefits of the technologies do and will increase the breakeven point (as in Europe with over 50% diesel penetration).

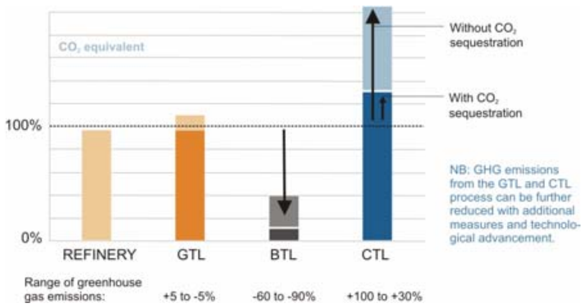
## Potential of biofuels and alternative fuels

Assuming economically, environmentally and socially sustainable production, the highest potential for reduction in petroleum and fossil energy (and therefore greenhouse gases - GHGs) lies in biofuels. In the long term these include advanced second generation biofuels such as BTL and cellulosic ethanol. These biofuels have the potential to reduce fossil and petroleum energy consumption (and GHG emissions) by up to 90%. In particular, BTL has significant potential benefits. Its contribution to reduced petroleum consumption is immediate, it can be used in new and existing vehicles, it is not limited by new infrastructure requirements and it can contribute in all transport sectors which consume liquid fuels (land passenger and freight as well as shipping and aviation).

The production of BTL and cellulosic ethanol is, however, accompanied by a significant increase in primary energy consumption due to the energy consumed in their production process. Other advanced biofuels are under development and may present viable long-term options with lower primary energy consumption. Due to their currently increasing penetration and the investments made in their

BTL and cellulosic ethanol have the potential to reduce fossil and petroleum energy consumption (and GHG emissions) by up to 90%.

**Figure 3** Well-to-wheel $CO_2$ emissions of synthetic fuels in comparison to petroleum diesel




production, conventional first generation biofuels such as ethanol from sugar cane or corn and biodiesel (or hydro-treated vegetable oil, which has similar properties to BTL) from oil-bearing plants can be expected to retain some market share in the long term. Since there is a large number of biofuels in production or under investigation, it is important to ensure the most efficient solutions prevail. For a long-term sustainable penetration, biofuels must be drawn into production according to market forces and viable, consistently applied GHG intensity and sustainability standards, without discrimination, rather than chosen according to government mandates.

Other synthetic fuels such as GTL and CTL increase accessibility and availability by diversifying the fuel supply base and, in particular with GTL, are already available and economically viable. These fuels have the same physical properties as BTL and therefore exhibit the same advantages in distribution and use. On a life cycle basis, GHG emissions from GTL are comparable to those from conventional diesel fuel. GHG emissions from CTL without carbon capture and storage are approximately double those from conventional diesel fuel. The development and production of CTL and GTL also contribute to technological experience and understanding of synthetic fuels in general, which will benefit the development of BTL in the long term.

## Efficiency of mobility systems

A number of measures are projected which can improve the efficiency of mobility systems. These include physical infrastructure measures such as urban planning, enhanced public transport links and operability as well as improved roads to reduce congestion. Behavioural options are also available, which include alternative work scheduling to reduce commuting, encouragement of the use of existing public transport and encouraging more efficient driving styles. Innovative measures also hold potential, such as the implementation and use of intelligent transport systems relying on vehicle-to-vehicle/vehicle-to-infrastructure communications and new transportation concepts such as personal rapid transit.

More efficient transport systems must be both convenient and economically beneficial if they are to contribute significantly to energy objectives whilst supporting mobility. In building the infrastructure of urban areas, of new or renovated transport systems and, in particular, in setting regulations and dealing with costs, policy should seek a balance between the energy objectives and mobility. In particular in developing countries, populations should be enabled to participate in economic growth through increasing their level of mobility, which may include access to private vehicles as well as public transportation.

# Technology breakthrough

In order to make substantial improvements in sustainability of energy for transport, in the light of substantial projected economic growth over the next 43 years, breakthroughs in technology will be necessary by 2050.

## Hydrogen and fuel cells

One particular technology that holds significant long-term potential for reduction in fossil energy consumption, as well as $CO_2$ and criteria exhaust emissions, is hydrogen, which offers the long-term promise of emissions-free driving. Hydrogen and fuel cells have the potential to contribute significantly in the passenger vehicle sector if the substantial challenges of fuel cell cost, hydrogen storage, hydrogen production and hydrogen delivery can be overcome.

Current fuel cell vehicle concepts demonstrate that the potential exists for fuel cell vehicles to provide convenient personal transport in the kind of vehicles to which consumers are accustomed. Therefore, the motivation to overcome the obstacles mentioned above is significant and solutions are being developed by manufacturers, engineers and governments. The commercial vehicle sector appears to have less potential in applying hydrogen and fuel cell technology, due in part to the large space necessary for fuel storage, especially on long-haul trucks. However, the eventual maturity of hydrogen technology in the passenger vehicle sector is a foundation on which this sector may also be able to build in the long term, and indeed the use of fuel cells as auxiliary power units in trucks has already been tested.

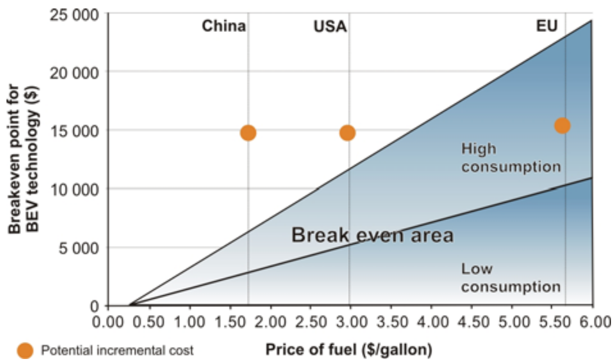
A long-term hydrogen strategy must be based on sustainable hydrogen production and consider the well-to-wheel energy and emissions in relation to conventional forms of propulsion. Local production of hydrogen using renewable energy is already being developed and applied in many regions. However, for hydrogen fuel to comprise a substantial proportion of the transportation market, the energy required to produce it must be derived from the general power grid. Therefore, a hydrogen economy must go hand in hand with widespread sustainable power generation to provide a successful future scenario. Assuming adequate supply, significant technical advances and investments are necessary in the distribution and delivery of hydrogen fuel.

## Battery technologies

Battery electric vehicles (BEVs) have potentially greater energy savings potential than hydrogen fuel cells, due to the higher energy efficiency of batteries. However, battery technology and cost must improve substantially to provide the performance, range and affordability demanded by consumers. In particular, significant increases in energy storage density are required in order to store sufficient energy on board for adequate vehicle range, if BEVs are to penetrate the mainstream. Electric powertrains are initially likely to make advances in small vehicles for city driving (city electric vehicle – CEV), in which range and top performance are of lesser importance and since economic incentives for low emission vehicles in cities are becoming more popular. A number of commercial companies are already offering vehicles to this CEV niche whilst others are offering electric vehicles as a sporty premium product.

## Electric powertrains are initially likely to make advances in small vehicles for city driving.

**Figure 4** Breakeven analysis for battery electric vehicles (July 2006 fuel prices)




Plug-in hybrid electric vehicles (PHEVs) offer most of the benefits of BEVs with the convenience and range of conventional internal combustion engines. These combine a reduced ICE and a high power battery, such that pure electric driving is possible over a range high enough for many daily applications, allowing overnight charging from an electric socket. The presence of two full powertrains in a PHEV means that for this technology to become viable for the mass market, substantial reductions in the cost of the electric powertrain are essential. For both BEVs and PHEVs, enhanced battery durability for these deep discharge applications (as opposed to shallow discharge in current hybrids) is necessary, in order for the battery to last as long as an expected vehicle lifetime of many years.

## Biofuels and alternative fuels

In order for biofuels to make the maximum contribution to reduction in petroleum consumption and GHG emissions by 2050, significant advances in technology are necessary. Such advances must be balanced with the criteria necessary to ensure sustainable long-term supply, including well-to-wheel $CO_2$ emissions, land and water use, competition with food resources and economic viability. Continued cost reduction in biomass resource management and production processes is a prerequisite for these fuels to be an economically viable prospect at high volumes and thereby contribute to accessibility and availability. Cost reductions can be expected through economies of scale and optimisation of the technologies, as well as identification of innovative new products and production methods. These conclusions particularly apply to advanced second generation biofuels such as BTL and cellulosic ethanol, which rely on expensive technologies to break down the source plant matter and to produce the resulting fuel molecules. Due to their high potential for low well-to-wheel $CO_2$ emissions, advances in these fuels are a long-term priority.

Common to all biofuels, both first and second generation, is the need for breakthroughs in land yield and water management for biofuels crops, to ensure high volume sustainable production. Most studies project maximum global yields equivalent to between 25% and 40% of total fuel demand. To increase past this point, new agricultural techniques would be necessary, perhaps relying on further advances in genetically modified organisms.

The long term environmental acceptability of CTL can be enhanced by the economic viability of carbon capture and storage (CCS). Life cycle GHG emissions of CTL with CCS are approximately 30% higher than conventional diesel (c.f. 100% higher without CCS). Therefore, environmental acceptability of CTL will be difficult even if combined with CCS. CCS technology will need substantial improvements and more investment to realise its potential. If CCS becomes viable, additional potential in its use lies in the generation of electrical energy from fossil fuels (which may be used for electric powered transport) as well as for CTL production. If 100% capture can be achieved, energy generation with CCS would be a zero $CO_2$ technology, which therefore presents a more favourable solution, whether or not electricity penetrates significantly into the transportation sector.

# Rational policy – an integrated market-based approach

Policymakers must first agree on the overall objective, whether it be a reduction in energy consumption or greenhouse gas emissions. From there, technological development must be complemented by rational policy that will encourage and enable the technologies to emerge. The common thread in policymaking is that the market must be allowed to identify and advance the most efficient methods to reach the stated objective. Conversely, selecting specific technologies through direct mandates or beneficial treatment runs the strong risk of selecting inappropriate technologies and therefore not contributing adequately to the objective.

## The integrated approach

In order to meet the defined objective, an integrated approach is the most efficient overall concept, which applies a holistic methodology rather than concentrating only on one element of a solution, for example technologies. The integrated approach incorporates all relevant stakeholders in the chain of energy production and use, to apply effective energy saving measures and technologies. These stakeholders include actors in equipment manufacturing, commercial businesses, consumers and policymakers.

The approach addresses the behaviour of business and private consumers in their vehicle purchasing decisions, vehicle use and behaviour. Fuel suppliers have a role due to the energy content of their fuels. The technology and investment applied by the equipment manufacturers determines the efficiency of their vehicles. Governments and other policymaking bodies have a responsibility for the transportation infrastructure and environment as well as the incentive structure for certain types of public behaviour. It must be ensured that for all stakeholders a productive market is in place which financially rewards behaviour leading to higher efficiency.

## Stakeholders

Vehicle, engine and component technologies do indeed comprise a major element of this approach. Therefore, effective policy can take the form of incentives through the tax system for fuel and vehicle technologies which reduce energy consumption or GHG emissions. Such incentives must be applied in a way that provides a consistent incentive to reduce consumption or GHG emissions (depending on the priority objective). For example, a tax that varies in a proportional fashion with vehicle consumption rating creates such an incentive. The marginal tax level should be sufficient to provide an incentive to purchase a vehicle despite the higher initial cost of its efficiency technologies, but not so high as to distort the market or make purchases unaffordable. Such taxes need not mean a higher overall tax burden, since taxes based on consumption or emissions can be offset by reductions in other taxes, for example by replacing vehicle registration taxes.

In addition, government financial support for bringing new technologies to market is appropriate if objectively assessed and effectively targeted. Such support can be provided as an investment at any point in the technology value chain, from basic research, product development, production facilities, entrepreneurship and product marketing. It should be directed to those products and the point in the value chain which is objectively assessed to provide the greatest incremental leverage in meeting the long-

## Consumers should be educated as to the consequences of their transportation decisions

term energy objective compared to incremental investment. Governments should also invest in infrastructure for both private and public transport to minimise congestion, ensure convenience and mobility, support economic growth and contribute to the energy objectives.

Consumers should be educated as to the consequences of their transportation decisions, in particular by sufficient labelling of, and information on, personal vehicles, fuels and public transport options. In addition, consumer education is required on the efficiency of use of energy consuming products. In transportation this specifically refers to driving style in personal and commercial vehicles, in which less aggressive driving, more efficient gear changes, predictive behaviour (when approaching traffic lights or congestion) and switching off when idle can reduce per-vehicle consumption significantly.

The fossil energy and carbon content of fuels is a further element in total energy consumption. As is currently under discussion in the EU, the US Federal Government and at the US state level (California), carbon intensity standards for transportation fuels are being developed. These policies set targets for reducing the fossil and carbon content of fuels and the fuel suppliers will select the most efficient methods for reducing $CO_2$ emissions. This can be expected to promote the use of biofuels with low well-to-wheel $CO_2$ emissions, as well as reduce the energy intensity of producing conventional and alternative fuels. Incentives through the tax system or otherwise can also apply to fuels, as long as these are applied consistently, without discrimination and proportional to the energy or environmental objective that is being sought.

## Standards

Common standards within and between major markets are essential to support technical and market development. In particular, standards relating to conventional and alternative fuels are a key element in energy and climate policy, including the carbon intensity standards described above. Standards relating to conventional, alternative and biofuels are already in place and include quality norms which ensure that the fuels are compatible with the existing vehicle stock and with new vehicles. Applied to biofuels, these regulate their physical and chemical characteristics and the proportion that can be blended with petroleum based fuels. They should remain sufficiently rigorous to ensure increased penetration of biofuels is consistent with vehicle reliability. Ideally, such standards should be aligned between major global markets.

In addition, standards for biofuels should include sustainability criteria relating to land use and social factors, which are developed and applied consistently and without discrimination to all biofuels. These standards thereby support the market in its economic selection of the most efficient solutions whilst contributing to the achievement of the energy objective. Indeed, such standards are being considered in parallel to fuel quality and carbon intensity. Further support for the market through free global trade in biofuels is essential, both to ensure the most energetically effective biofuels have access to the market and to assist in the economic and energy development of lower income countries.

The integrated approach commits all stakeholders to contribute to achieving the energy solution.

## Applying the integrated approach

The integrated approach incorporates all the measures described above and therefore commits all stakeholders to contribute to achieving the energy solution. Each element of the approach can be a stand-alone item. However, the approach achieves the most by ensuring that the task of reducing energy consumption is equitably distributed between the sectors and stakeholders involved. Since the costs of energy reduction are different in each sector, and indeed vary between measures applied within each sector, the most effective overall result is achieved by concentrating on the least-cost measures.

Theoretically, the ideal way to determine the least cost methods and to bring them into being is to ensure a consistent economic incentive for energy reduction across all sectors. Due to the complexity of each sector and the different ways in which price signals are communicated (through vehicles, fuels, ticket prices etc), such a consistent incentive is difficult to identify. It has been suggested by economists and policymakers that carbon taxes or emissions trading schemes can be an effective solution and indeed emissions trading has been introduced in the European Union to cover GHG emissions from certain sectors.

In the absence of such a consistent market signal, any policy decisions which incentivise or regulate actions in the transport sector should be subject to independent and objective assessments. It must be recognised that in the long term, micromanagement of energy policy will create overcomplexity and inefficiency and all policy options must support a long-term strategy to ensure a functioning market, which is then incentivised and enabled to achieve the energy objectives. This ensures that the burden is shared equitably between sectors, that the costs for society are minimised and that the most effective and efficient measures are identified and receive encouragement.

The methods described here support the integrated approach and ensure that the energy objective is targeted in a way that brings the maximum benefit to users of transport and to society as a whole. This promotes in the most effective way the achievement of sustainable energy for all.

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**World Energy Council**
Regency House 1-4 Warwick Street
London W1B 5LT United Kingdom
**T** (+44) 20 7734 5996
**F** (+44) 20 7734 5926
**E** info@worldenergy.org
**www.worldenergy.org**

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