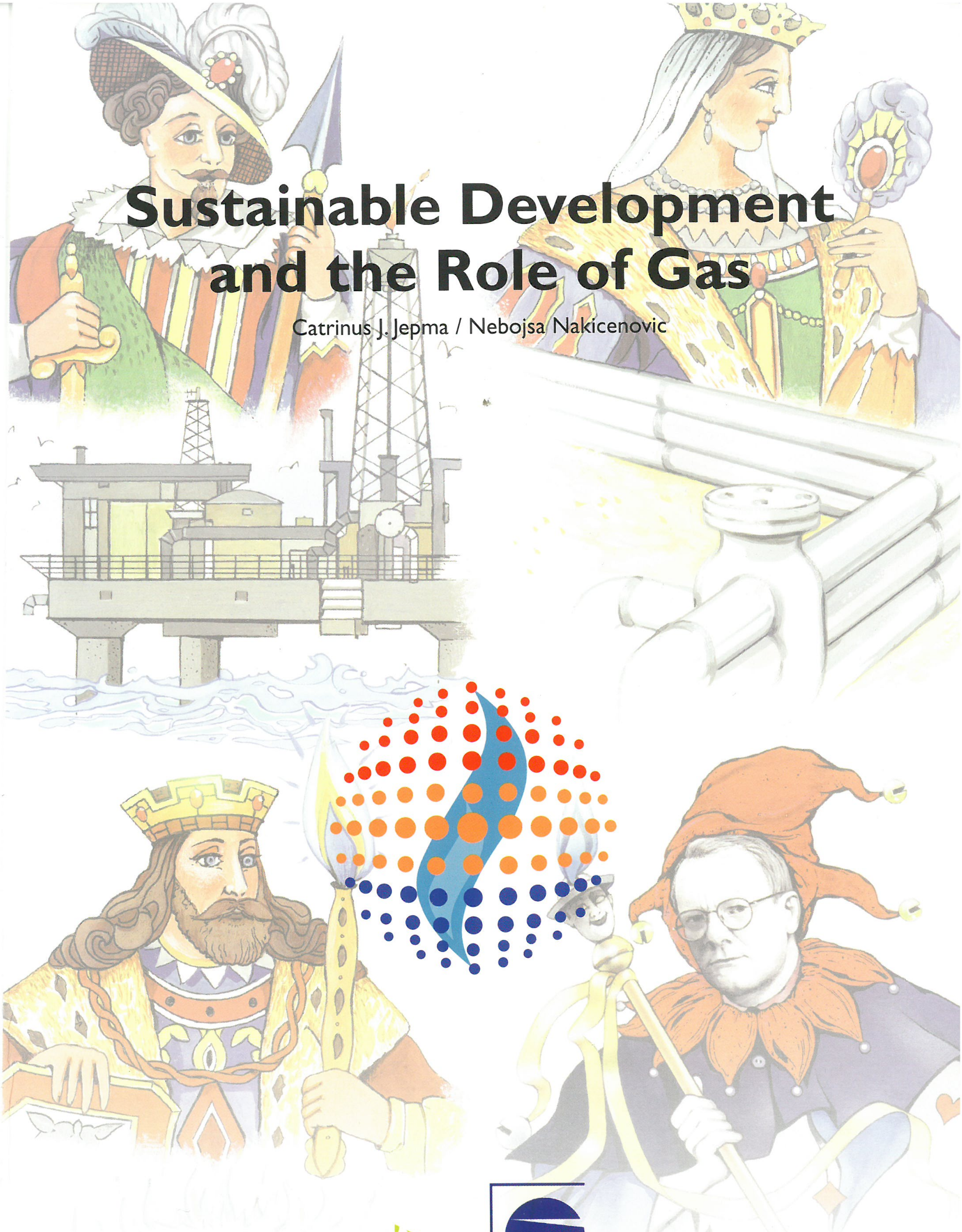
Sustainable Development and the Role of Gas

Catrinus J. Jepma / Nebojsa Nakicenovic



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The International Institute for Applied Systems Analysis (IIASA) is a non-governmental research organization. It conducts inter-disciplinary scientific studies on environmental, economic, technological and social issues in the context of human dimensions of global change.

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Conclusions and recommendations

Sustainability has become an important issue on the agendas of decision makers and is likely to remain important in the future. Therefore, the natural gas industry has no choice but to take a position on the issue and to formulate a strategy that offers the greatest promises. In other words, what would be the wisest course of action for the natural gas industry?

Opportunities and threats

Most of today's energy scenarios project that natural gas will play the role of transitional fuel on the road towards sustainability. This provides an historic opportunity for the natural gas industry: to meet the growing demand for natural gas in the coming decades, and to live up to the expectation that natural gas is clean, safe and reliable and thus the transition fuel par excellence.

This opportunity is surrounded by a large number of benign conditions:

- The growing demand for low carbon fuels in general and for natural gas in particular.
- The demand for natural gas is likely to grow faster than demand for other fuels, because it is generally considered convenient and reliable.
- The application of natural gas may become broader: e.g., gas-to-power; public and private transport, especially in large cities and metropolitan areas in developing countries and industrialized areas which suffer from massive (local) air pollution; housing and small- and medium-sized enterprises, especially in rapidly developing regions; or regions where reliable energy supply has been lacking so far.
- Natural gas resources are enormous and seem relatively straightforward to recover.
- Security of supply has become a high priority and natural gas is considered to be a reliable source.
- Global liberalization may create additional opportunities for natural gas market expansion and for new, previously unfeasible, roles for natural gas.

A number of aspects may, however, threaten this quite rosy outlook for the natural gas industry:

- Poorly designed regulation may threaten continuity of supply and demand and adversely affect business activity and investment.
- Policy and other decision makers may increasingly feel that an energy future would need to be based entirely on renewables. This could undermine the role of natural gas as a transition fuel.
- Growing debate about resource recovery and transport operations, particularly in unspoiled areas and in areas where indigenous people try to exercise their claims on land, may increasingly complicate exploration and production.
- Production of gas from coal and coal-bed methane has great market potential and may be able to increasingly compete with natural gas.
- Other unconventional fossil resources may yield new fuel gases that are competitive with natural gas, e.g., tar-sand gasification.
- Renewable sources of energy, e.g., wind, solar and biomass, will become more competitive and widespread, possibly at the expense of the role of natural gas.
- Security of supply may be adversely affected by: the relatively small number of mostly politically less stable natural

gas supplying nations: the vulnerabilities of the international transport system; and increasing import dependency of the main destination.

- The scope for RD&D with regard to gas may be constrained by market liberalization and competition.
- The long-term financing of production, transmission and distribution systems may be hampered by a lack of certainty about: the future development of market incentives (e.g., energy prices, CO_2 credit prices, taxation); rules and regulations (post-Kyoto, liberalization, state involvement); and technology development (role of LNG, decentralized energy-systems, new gases and gas applications).

Dilemmas

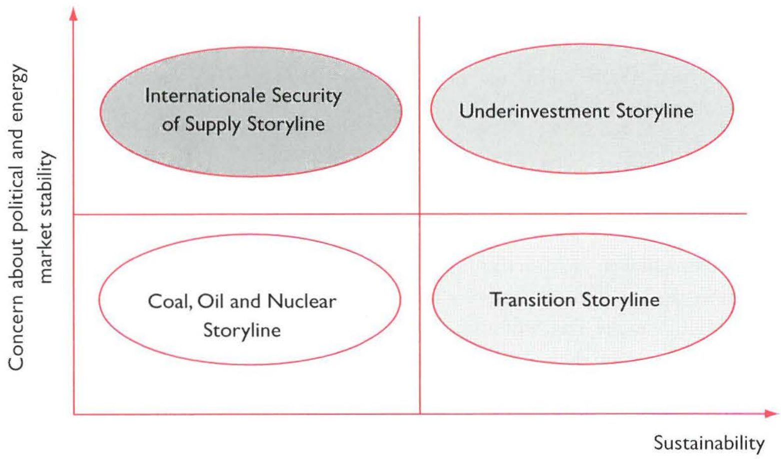
The above mix of opportunities and threats poses a number of dilemmas to the natural gas industry:

- Will gas supply from the existing reserves remain sufficient, and at what cost will natural gas production be feasible in the future?
- Can the natural gas industry find a modus to effectively cooperate with other, potentially competing parts of the energy sector (coal, oil, nuclear) in order to reap market synergies?
- Can the natural gas industry establish mutually beneficial linkages with the suppliers of renewable energy so that the role of natural gas as the transition fuel can be supported?
- Can flexibility of supply (through production, trade and storage) develop in such a manner that demand can be serviced smoothly?
- Will the international gas market in the future be dominated by freely functioning markets, or instead, by state intervention and rules, and will the natural gas industry be prepared for such alternative developments?
- Will the future gas market be dominated by International Oil (Resource) Companies (IRCs) or National Resource Companies (NRCs), and how will IRC-NRC coexistence affect the gas industry?
- How will future technological developments affect natural gas demand and supply structures, the gas industry structure, and technological combinations with other (energy) service suppliers?
- Can the natural gas industry maintain its image of reliability in view of the many fundamental likely changes in the energy markets?

These dilemmas demonstrate that the natural gas industry, despite the promising opportunities it faces, needs to develop an active strategy in order to reap the latent benefits of the coming opportunities.

Elements of a vision: some perspectives

The opportunities, threats and resulting dilemmas give rise to some storylines that can be used to portray the international gas sector for the next three to four decades and which illustrate the main issues that leading stakeholders in the industry may face.



In order to broadly define the four storylines, two overriding drivers of the natural gas industry have been linked: 1. concerns about sustainability issues, including environmental protection and, in particular, the global warming problem, and 2. future political and market stability concerns. The combinations of these key sentiments within the industry have been outlined in the above Figure, and basically allow for four different projections of the shape of the future gas market and the key challenges that the industry may face. If environmental sustainability has a high priority, while there is limited concern about market and political stability, the transition storyline broadly applies. If, however, there is both less concern about sustainability and political and market stability are not considered a substantial issue, the coal, oil and nuclear storyline may be more relevant. In the case of considerable concern about political and market stability, investment may be subdued, even if the sector would be convinced of the need to adjust to stricter environmental rules. In such a case, the underinvestment storyline may become a reality. Finally, if there was no strong concern about sustainability and the environment in particular, but, instead, concerns about energy market and political stability would dominate, one would probably face a world with increasing concern about security of supply, the fourth storyline.

There are no a priori reasons to put any probability figure to the four storylines. They are all equally valuable as a means to show how the key issues to be addressed may vary depending on possible developments. They are, however, not all equally valuable for mankind. If sustainability is accepted as a major concern for present and future generations, then, clearly, the first storyline, in which gas can play an important role as the transition fuel, is the preferred one because it reflects a world in which political and energy market stability can be combined with sustainability.

To start with, for the next few decades the gas industry seems to have a fairly strong card to be among the winners in terms of market share in primary energy carriers. A number of factors contribute to this opportunity: natural gas is the cleanest of all hydrocarbon energy sources because it results in very low emissions of pollutants such as particulate matter, sulphur and nitrogen oxides and emits less than half of the carbon dioxide emitted by burning coal. New technologies for conversion of natural gas into electricity and other energy forms could reduce and virtually eliminate most of the adverse environmental impacts.

These advantages of natural gas as an energy source and energy carrier have six important implications. First, gas takes a relatively favorable position as compared to other fossil fuels in contributing to the ongoing decarbonization of global energy, simply because the carbon emissions per unit of energy are relatively low. Second, based on the same characteristics, gas can be seen as one of the most suitable candidates for being *the* transition fuel *par excellence* in the transition towards more sustainable energy futures. The environmentally friendly image of natural gas is further enhanced by its relatively low emissions of other greenhouse gases. Third, unlike oil, gas seems to face much less serious reserve and resource constraints which may lower its relative price. Fourth, efficiency levels of gas combustion technology are among the highest. In addition, natural gas can be applied in a rather flexible manner. Fifth, compared to most other primary energy sources including renewables, gas is relatively easy to store. Finally, natural gas can be seen as a precursor to hydrogen and therefore as a way to prepare for a long-term development towards alternative energy systems.

Thus, natural gas has a strong card to play. The perspective of gas maintaining its current image as a clean, safe and reliable fuel, and therefore *the* transition fuel *par excellence*, is clearly the one to be preferred. However, the game will not be won automatically. First, other fuels also have some strong cards in hand and this could unexpectedly alter the way in which the game evolves. Second, the gas sector typically also faces some major issues which, if not tackled well, may substantially disturb the game. The most severe issue will probably become the increasing concerns about international security of supply. Third, it should not be taken for granted that the gas industry will automatically take the measures and investment decisions that are needed to substantiate its prospective increasing role.

As far as the first major issue, security of supply problems, is concerned, it needs to be acknowledged that many regions and countries in the world increasingly become dependent of natural gas import. In addition, supply is likely to be increasingly concentrated in a limited number of countries, which are typically located in regions with vulnerable political systems. Moreover, the international gas transport infrastructure, particularly as far as LNG is concerned, seems to be increasingly susceptible to risks of accidents or even attacks of transport bottlenecks and other supply interruptions. Also, the fact that international pipeline systems will connect a number of different countries adds to infrastructure vulnerability.

The second major issue to the expected stronger role of natural gas relates to the fact that other energy sources such as for instance coal, nuclear energy and renewables will not remain passive. For instance, clean-coal technologies are rapidly evolving, possibly jointly with CO_2 capture and storage. The perception in some regions that nuclear energy is unsafe may shift gradually towards an image of being clean, flexible and efficient. Moreover, a number of renewable technologies may develop towards large-scale commercial application, much more rapidly than anticipated. In other words, other energy sources may well become stronger and reduce the market share of natural gas, especially if at the same time natural gas would increasingly be perceived as a problematic fuel from a geopolitical perspective.

The third major issue that could alter the picture substantially is that investments by the major players in the gas industry in the various stages of the supply chain will stay behind levels that would sustain a larger role for gas in the energy system. The gas industry is typically facing a large number of uncertainties such as: the climate and other environmental policy regimes, the liberalization and regulatory regimes, the link between gas and oil prices, the public versus the private role with regard to investment, or the role of LNG and GTL. In addition, the gas sector structure may face changes that will shift attention and energy away from investment decisions. This substantial uncertainty may, understandably, cause the sector to postpone significant investments, which may weaken the overall chain. Given the long lead times and significant resources typically required for gas infrastructure development, this may undermine the potential role of gas during the next decades.

Relevance

The variety of storylines that present themselves to the gas industry can be considered an open invitation to start a thorough debate about the position that the gas industry may want to take to deal with the sustainability issue. If sustainability is accepted as a major concern for the present and future generations, then the first storyline in which gas can play an important role as the transition fuel, is clearly the preferred one, because it reflects a world in which political and energy market stability can be combined with sustainability. The gas industry could consider trying to further develop its role in the spirit of this storyline by actively trying to enhance the positive image of natural gas. The preferred scenario with respect to the role of natural gas in a world where sustainability increasingly gains attention is the one where natural gas maintains its current image and position as a clean, safe and reliable fuel, and the transition fuel par excellence. In order to achieve the targets of such a strategy, a clear set of actions and policies may need to be implemented. A possible list of such actions follows below (see *possible actions towards sustainability*). It seems obvious, however, that if the gas industry wants to maintain its position as a clean, safe and reliable fuel, and the transition fuel par excellence, there will be no room for complacency. It will require well-coordinated action.

Another lesson that can be drawn from the possible storylines for the gas industry is that there are a number of threats that may undermine the promising future role of the gas industry and which should be taken seriously. Examples are: the threat that security of supply issues may increasingly dominate the policy agenda and undermine the momentum in the gas sector development; the risk that efforts and lobbies, if left uncounted by the gas industry, of competing energy sources may overshadow the huge potential of natural gas as *the* transition fuel *par excellence*; or the risk that, for various reasons, investment in the gas industry remains subdued thereby adversely affecting the role of natural gas in the energy system.

If the gas industry feels that it will benefit from embarking on a sustainability agenda and that serious and coordinated action would be supportive to that end, a number of activities will probably need to be initiated in parallel. To start the discussion about what such an agenda could look like, in order to respond to the challenge of sustainability, and to solve the dilemmas that arise from the likely future mix of gas sector opportunities and threats, the following five possible strategic goals for the natural gas industry can be formulated:

Possible actions towards sustainability

- Develop a clear and well-communicated commonly shared vision of the gas industry future and actively communicate the special features of natural gas as a source of energy. Remain focused on its image as *the* transition fuel *par excellence.*
    - Start a publicity campaign in which natural gas is presented as the transition fuel based on a package of positive characteristics.
    - Actively support the development and implementation of demonstration projects in different places in the world showing modern and green applications of systems based on natural gas.
    - Increase the emphasis in public statements and other communications on the proven track record of natural gas as a clean, safe and reliable fuel.

- Stay well informed about new developments, new players, new technologies, and new market opportunities.
    - Develop an information system and expertise network for analysis (e.g., based on a institutionalized network of universities and research centres linked to IGU) that keeps the sector continuously informed about the most relevant technology and market developments in the sector, and put that in the perspective of the developments in the other energy sectors that may directly or indirectly affect the role of natural gas.
    - Systematically monitor and analyze the gas reserves/resources and gas exploration activities and investments worldwide and provide a reliable and up-to-date source of information on such issues.
    - Think actively and creatively about establishing coalitions by integrating natural gas supply with renewables.

- Try to be optimally involved in relevant consultation and decision-making processes in international organizations, national and local governments, the knowledge community, and other energy stakeholders.
    - Be better engaged in the debates on future climate policy regimes and policies and measures based thereupon.
    - Provide guidance to national governments about different ways to diversify their energy security of supply and the contractual and infrastructural possibilities to do so.

    - Put pressure on national governments to pay sufficient attention in their foreign policies to the issue of security of supply of energy, and stress the need for more active diplomacy and international policy coordination for this purpose.
    - Increase engagement and participation in the discussions on the merits and risks of other energy carriers than natural gas, discussions on the international climate policy regimes, or discussions on security of supply and other foreign policy issues.

- Ensure that the sector's own product and processes are exemplary.
    - Stick to the IGU 'Guiding Principles for Sustainable Development' (October, 2003).
    - Develop standardized contracts and protocols for international gas trading and exploration management that match internationally and provide desirable levels of guarantees in terms of security of supply.
    - Establish protocols for the safety and reliability of international gas transport systems and try to activate governments to guarantee security, if necessary, at vulnerable choke points in international gas transport.
    - Improve the international coordination of gas value chain investment decisions through international networks and information exchange on the basis of a clear internationally shared vision on the future role of natural gas.
    - Establish and support international consortia that are able to finance and take responsibility for large-scale gas infrastructure investment projects, along with international agreements on conducive and stable legal and regulatory regimes.

- Support and strengthen the sector's flexibility to be able to cope with a variety of future policy, technology, and market develop ments.
    - Demonstrate the clear and independent role of natural gas in the international energy market by supporting the contractual decoupling of oil and gas prices in order to prevent gas prices to be unduly driven up as oil prices increase due to concern about reserve levels.
    - Develop regulatory systems that are sufficiently conducive to investment in gas infrastructure such that security of supply problems can be prevented, and improve international coordination between national regulators.
    - Develop an information system that can signal market and other trends in an early stage in order to enable proactive coordinated action in the gas industry.

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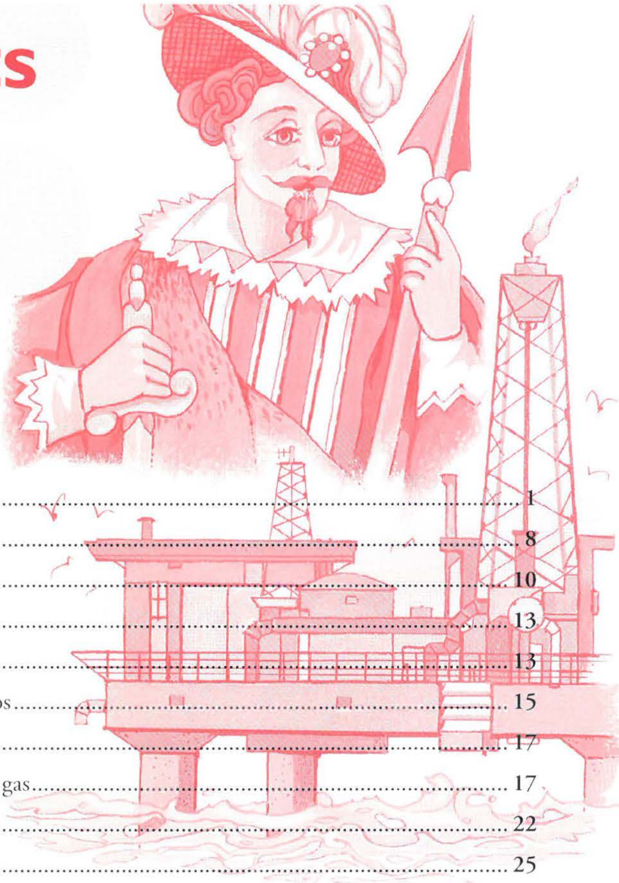

Abbreviations and acronyms

AAUs	Assigned Amount Units
ACC	Abrupt Climate Change
AFV	Alternative Fuel Vehicles
bbl	barrels (oil equivalent, 1 toe= 7 bbl)
CCGT	Combined-Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCT	Clean Coal Technology
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CFBC	Circulating fluidized bed combustion
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
DCs	Developing Countries
DE	Decentralized Energy
EB	Executive Board
EC	European Community
EIA	Energy Information Administration
EOR	Enhanced Oil Recovery
EORG	European Opinion Research Group
ETSAP	Energy Technology Systems Analysis Programme
EU ETS	European Union Emissions Trading Scheme
FSU	Former Soviet Union
GDP	Gross Domestic Product
GECF	Gas Exporting Countries Forum
GHG	Greenhouse Gases
GtC	Giga tons of carbon
GTL	Gas to liquids
Gtoe	Gigatons (10^9) oil equivalent
IAM	Integrated Assessment Models
IEA	International Energy Agency
IEW	International Energy Workshop
IGCC	Integrated Gasification Combined Cycle
IGU	International Gas Union
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IRC	International Resource Company
KP	Kyoto Protocol

LNG	Liquefied Natural Gas
MEA	Millennium Ecosystems Assessment
Mt	Million tons
Mtoe	Million tons (10^6) oil equivalent
NAP	National Allocation Plan
NRC	National Resource Company
OECD	Organisation for Economic Cooperation and Development
PPMs	Processes and Production Methods
ppmv	parts per million volume
PV	Photo Voltaic
RD&D	Research, Development and Demonstration
RGGI	Regional Greenhouse Gas Initiative
RES	Renewable Energy Sources
RPS	Renewable Portfolio Standards
SRES	Special Report on Emissions Scenarios
Tcf	trillion cubic feet
TPA	third party access
TPES	Total Primary Energy Supply
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WEC	World Energy Council
WEO	World Energy Outlook
WTO	World Trade Organization
ZEPP	Zero Emission Power Plant

Introduction

This report discusses the future role of natural gas and has been prepared under the auspices of the IGU Special Project 'Sustainability' and will be presented at the 23rd World Gas Conference in June 2006 in Amsterdam, the Netherlands. The report's main aim is to reflect the considerable changes that energy markets, and the gas market in particular, are currently facing and will probably face in the foreseeable future. The main trends, which often take place simultaneously, seem to be: liberalization and re-regulation, internationalization, restructuring, and greening. Due to the structural adjustments the gas industry is undergoing, a player in the sector may consequently face: a rapidly changing regulatory framework and reshuffling of market parties and their behavior as a result of liberalization; rapidly changing incentives to introduce other gases, biogases, and other gas applications as a result of environmental policy measures; increasing complexity of planning and investment decision making due to the internationalization of the gas market; and a range of mergers and acquisitions, on the one hand, and unbundling of action, on the other hand.

At the same time, new issues arise which pose new challenges to the gas industry, such as:

- Can natural gas play an important role as transition fuel towards a carbon-free energy system, and how will this work out in the future role of gas on the energy market?
- To what extent will security of energy supply issues dominate public concerns and how may this affect the gas market conditions?
- To what extent may climate change and other environmental and safety concerns affect the trends in fossil fuel and renewable energy use and how will this affect the gas market share?
- Will internationalization and liberalization of the gas market lead to more flexible but less predictable gas flows, and to what extent can flexibility in demand be matched by flexibility of supply?

All uncertainties related to the above aspects make it very hard to draft scenarios or storylines with any degree of predictability and probability. In fact, designing scenarios broadly based on extrapolation of ongoing trends can be risky insofar as the structural changes mentioned and their possible impact are not sufficiently covered. That is why the approach here is to focus on the question:

"What can possibly be the main issues of concern that will dominate the future management challenges of the gas industry, given the likely structural changes and new policy challenges the gas market may face?"

In order to answer that question, four non-traditional storylines will be described and the plausibility of their underlying assumptions illustrated. Each storyline description has been drafted as if presented by its explicit defender. That hypothetical 'advocate' of the storyline tries to argue, as convincingly as possible, why the 13 storyline assumptions[1] are indeed plausible. This approach serves as a challenge for the reader: it would be inconsistent if the reader were persuaded by all arguments; instead, the reader has to decide which combination of arguments is most convincing, and which arguments are the best or the worst.

The storylines emphasize particular issues of concern that may increasingly dominate projections of the future world and its energy markets, namely:

- The role of gas as a ***transition fuel*** in a rapidly greening world;
- The ***security of supply*** in a world with increasing constraints to gas supply or the supply infrastructure;
- The ***market share of gas***, where other energy sources, both traditional (including nuclear energy) and renewable ones, are increasingly successful in enlarging their share in overall energy supply; and
- The ***investment*** issue in an international gas market where change is so dominant that it may paralyze investment activity.

In the first storyline the sector grabs its opportunities and plays the game fairly well. In the three other storylines the different threats become reality: an overriding concern about international security of supply issues, a serious come-back of competing energy sources and a story in which insufficient investment levels pose the major threat. In order to provide a clearer picture of these four storylines, for each of them the most essential underlying assumptions are worked out in somewhat greater detail: jointly they provide the picture of a future gas world and the associated dominating issues.

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[1] Note that this number corresponds with the number of playing cards per symbol; for more inspiration, please play with the cards provided with this report at the occasion of the IGU World Gas Conference in Amsterdam, the Netherlands.

In the following Table (see next page) the main characteristics of the four storylines have been summarized.

Transition Storyline

The first storyline depicts a future with a strong attention to climate policy action and a large number of sustainability aspects, as well as with much attention to energy efficiency improvements. Lifestyles are adjusted worldwide to a greener and more sustainable economic system. After a series of disasters, which are attributed to global climate change, particularly in developing countries, the environmental issue is considered one of the key priorities for global action. Therefore, a wide range of policies and measures, including market-based incentives for GHG mitigation, are readily accepted almost everywhere. In this world, natural gas is considered the transition fuel par excellence, which leads to great optimism in the sector, significant investments in all segments of the gas chain, and an increasing market share of natural gas in primary energy supply.

International Security of Supply Storyline

In the second storyline, international security of supply becomes the overriding concern. Fossil fuels, notably oil and gas, remain the backbone of energy supply in a market, which faces significant increase in demand. Realizing that oil reserves deplete rapidly, at least against acceptable production cost conditions, many countries try to secure their energy supply on the international gas market. With Europe, NAFTA, Japan, China and India all increasingly competing for the available gas (and oil) resources, the world increasingly faces geopolitical tensions. Suppliers of natural gas on the international market may use their increasing market power to further boost prices by restricting their supply. The security of supply issue becomes a dominant factor on the foreign policy agenda of most countries. Increasingly, supplies are being secured via bilateral contracts, and the world cannot avoid an increasing hostility between the various blocs on the issue of access to energy in general and to natural gas in particular.

Coal, Oil and Nuclear Storyline

In this storyline various (especially Asian) countries increasingly use their large coal reserves to fuel their economic growth strategies. In addition, various countries considerably expand their nuclear power capacity (and some renewables) to be sure that energy shortages can be tackled. Extensive investments are made in the exploitation of Canadian tar sands, especially for oil deliveries to the USA. Europe and Japan have a relatively strong focus on renewables and face no serious problems in meeting their energy demand by traditional imports of mainly oil, especially because oil reserves turn out to be larger than anticipated. In short, the energy strategies of the various countries are assumed to be increasingly targeted on self-reliance, i.e. to make sure that energy will be produced as much as possible through domestic primary energy resources or those of close allies.

In this storyline there is quite some optimism that the combination of clean coal technologies, the nuclear option and renewables can solve the problem via technological breakthroughs. Thus, coal will make a considerable comeback, also because of new clean coal technologies, and the nuclear option gains considerable support as well. Accordingly, natural gas will no longer be considered *the* transition fuel. Moreover, there may be concerns, especially regarding internationally traded LNG, that gas could be an unsafe form of energy. This leads to a market share reduction of natural gas in overall energy supply.

Underinvestment Storyline

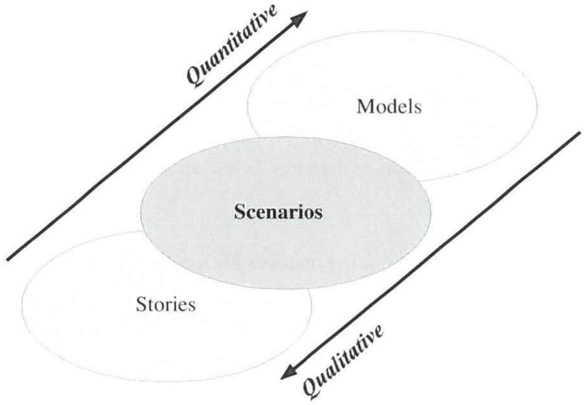
In this storyline it is assumed that for the period up to 2040 there are no clear trends with regard to: economic growth in the various regions, energy efficiency, the use, availability, acceptability, and accessibility of particular energy sources, energy prices, or even the direction of climate and other environmental policies. Consequently, there is a serious lack of certainty and conviction as to when, where, and how much investment would be required to secure a reliable and sufficient energy supply. Taking into consideration the huge amount of resources and finance, as well as long lead times involved with most energy production and transport projects, the lasting uncertainty about energy world development paralyses investment both in exploration/exploitation and international energy transport capacity.

This uncertainty is further increased due to limited information about the size and direction of internationally traded energy flows (and LNG in particular), which is caused by the liberalization trends that increasingly characterize the various national and regional energy markets. The main result of the above will be under-investment, which creates security of supply problems for end-users. Even if potential energy supply remains available at acceptable conditions, it will quite often not be able to satisfy demand because of a lack of infrastructure. Since a reliable infrastructure requires that all links in the chain are equally strong, there is a considerable risk that the overall chain is too weak to serve the market properly.

	Transition (1)	Security of Supply (2)	Coal, Oil and Nuclear (3)	Underinvestment (4)
Economic Growth	medium	high	medium	variable
Economic growth in North	medium	medium	low	variable
Economic growth in South	medium	high	high	variable
Globalization trends	medium	low	medium	variable
Disruptions of economic progress	none	yes	yes	yes
Population Growth	low	high	medium	medium
Urbanization trends	high	medium	medium	medium
Energy Dimensions				
Energy efficiencies	high	medium	medium	low
Primary energy mix	renewables: high	renew. low/gas high	coal/nuclear: high	average
Resources and reserves	modest	high	strong	medium-low
Technological change	rapid	medium	medium/high	medium/low
International cooperation on energy	medium	low	low	low
Energy (infrastructure) investment	high	medium	medium/gas low	low
Energy liberalization and re-regulation	medium	low	low	mixed
Energy end-use patterns, including decentralization trends	high	medium	medium	medium
Access to energy for the poor, energy 'quality' (black-outs)	high	low	medium	low
Decoupling of energy prices of various energy carriers/forms	yes	yes	no	no
LNG growth	medium	strong	modest	strong
Climate Policy Regime				
post-Kyoto regime (strictness)	high	medium	low	medium
post-Kyoto regime (coverage)	wide	low	low	medium
Methane emissions mitigation	high	medium	medium	low
Sustainability Aspects				
Attention to local air quality	high	low	high	low
Initiatives towards green gas	high	low	low	low
Equity concerns	high	low	medium	medium
Gas safety concerns	low	high	high	high
Safety concerns to other fuels	high	high	low	high
Attention for health aspects	high	high	medium	medium
Perception of Gas as Transition Fuel	high	medium	low	low
Perception of Gas Scarcities	low	high	low	low

The report is outlined as follows. The first chapter lists a number of authoritative scenarios and storylines in order to put the subsequent IGU storylines in the broader perspective of the literature. The second chapter lists the key factors that may drive the future gas market and their underlying socio-economic processes. In chapters three to six, the four storylines unfold. A summary is provided at the end.

Figure 1.1 Schematic illustration of alternative scenario formulations, from narrative storylines to quantitative formal models



Source: Nakicenovic et al., 2000.

Examples of some seminal energy and other more general scenarios

The construction of scenarios to investigate alternative future developments under a set of assumed conditions dates far back. Scenarios were one of the main tools used to address the complexity and uncertainty of future challenges, even if they had often different names in the past. In fact, the first and oldest scenarios were designed to help plan military operations, more recently called 'war games' (Nakicenovic et al., 2000).

Scenario analysis as a professional undertaking was also associated with strategic planning and war games during the early years of the Cold War (Raskin et al., 2005), as popularized by Herman Kahn and his colleagues (Kahn and Weiner, 1967). Today, scenarios are used regularly by military organizations around the world for training and planning purposes. Military strategists and teachers often use very sophisticated computer models to develop scenarios for a multitude of different purposes. Sometimes, these are also developed by both military and other security organizations to describe broader socioeconomic, cultural and environmental developments (e.g., Schwartz and Randall, 2003). Most recently, many computer games have sophistication that allows for interactive construction of scenarios, each game being one example of how the future might unfold.

The more direct antecedents of contemporary energy scenarios lie with the future studies of the early 1970s (Raskin et al., 2005). These responded to emerging concerns about the long-term sufficiency of natural resources including energy to support expanding global populations and human activities. This first wave of global scenarios included ambitious mathematical simulation models aimed to forecast the behavior of these complex systems over many decades into the future (Meadows et al., 1972, Mesarovic and Pestel 1974) as well as equally speculative narrative approaches (Kahn et al., 1976). Perhaps, best known was the controversial report of the Club of Rome on Limits to Growth (Meadows et al., 1972). This was perhaps the first attempt to build an integrated global model based on systems dynamics (Forrester, 1977) and thereby generate quantitative scenarios. The Latin American Bariloche world model stressed social, political and equity concerns, rather than physical limits, by positing a normative egalitarian future, characterized by quantitative descriptors of human well being, and by examining the actions required to achieve it (Herrera et al., 1976).

During the 1970s, a number of energy studies that included scenarios have been conducted. Perhaps two best known are the CONAES (Brooks and Ginzton, 1972, Brooks and Hollander, 1979) and Energy in a Finite World (Häfele et al., 1981), conducted by the International Institute of Applied Systems Analysis (IIASA). At this time, scenario analysis based on narratives interlaced with quantitative illustrations was first used at Royal Dutch Shell as a strategic management technique (Wack, 1985), an effort that spawned a small industry of consultants working with major corporations to broaden perspectives on how to position the firm in a changing world (Schwartz, 1991).

A second wave of integrated global scenario analyses began in the late 1980s and 1990s, prompted by the new concerns about sustainable development and global change (WCED, 1987). Many of these were in the qualitative and narrative tradition (Svedin and Aniansson, 1987; Toth et al., 1989; Milbrath, 1989; Burrows et al., 1991; Kaplan, 1994; Gallopin et al., 1997; Bossel, 1998; WBCSD, 1997). In addition, stimulated largely by the climate issue, there has been an explosion of new models that quantitatively link energy and other human activities to atmospheric, oceanic and terrestrial systems. In particular, the long-term nature of the climate change issue spawned almost countless world energy scenarios. For example, scenarios of future emissions played an important role from the beginning of the IPCC work. In 1990, the IPCC initiated development of its first set of GHG emissions scenarios designed to facilitate the assessments of climate-change (Houghton et al., 1990). Two years later, in 1992, IPCC developed a set of six exceedingly influential scenarios, called IS92 (Leggett et al., 1992; Pepper et al., 1992. A subsequent IPCC evaluation of the IS92 scenarios (Alcamo et al., 1995) emphasized the need for analysts to consider the full range of IS92 emissions scenarios, rather than a single 'business-as-usual' reference scenario. In 2000, the IPCC developed a new set of scenarios with six different IAM models based on four narrative storylines (Nakicenovic et al., 2000a) and in 2001 a set of mitigation scenarios that focused on emissions reduction possibilities in the energy sector (Morita et al., 2001). In 2005, the Millennium Ecosystems Assessment developed a set of four narrative scenarios about the future of ecosystems services and human well being supported by an analytical modeling framework (MEA, 2005).

As mentioned, another parallel development is that scenarios are increasingly used by enterprises around the world for many purposes associated with decision-making and more generally as a tool for strategic planning. The most famous are the Royal Dutch Shell energy scenarios developed originally in the wake of the oil crisis of the 1970s. Shell scenarios were used to plan the corporate response strategies (Schwartz, 1991). Today, the use of scenarios is quite widespread in the private sector. For example, the World Business Council for Sustainable Development (WBCSD) developed a set of scenarios in collaboration with 35 major corporations (WBCSD, 1998). Another influential series of energy scenarios was developed by the World Energy Council (WEC, 1993). During the 1990s, IIASA and WEC jointly presented a set of global and regional scenarios in Global Energy Perspectives that were developed with a set of integrated assessment models and then reviewed and revised through 11 regional expert groups (Nakicenovic et al., 1998a).

An important group of energy scenarios from the literature was compiled during the last two decades from two international scenario and model comparison activities. This first group is from the International Energy Workshop (IEW) that involves structured comparisons of energy and emissions scenarios since 1981 (e.g., see Manne and Schrattenholzer, 1996, 1997). The other group is the EMF (Weyant, 1993, Van Vuuren et al., 2006) that also involves regular scenario comparisons, in addition to standardized input assumptions, such as the international oil price or carbon emissions taxes. A third scientific effort that involves scenario comparisons is the Energy Technology Systems Analysis Programme (ETSAP) supported by the International Energy Agency (IEA). The ETSAP work involves scenario analysis by more than 40 scientific groups from about 20 countries using the same modeling approach.

In addition to the many scientific, governmental, and private organizations throughout the world engaged in scenario building, some international governmental organizations regularly develop global and regional energy scenarios. For example, the IEA regularly publishes the very influential global energy outlook (IEA, 2004a).

Today scenarios are being applied in an expanding array of business, community, policy and research contexts with highly varied aims – better management, consciousness raising, conflict resolution, policy advice, and research (Raskin et al., 2005). The methodological approaches and ways of building scenarios are also many. They can be forward-looking, exploring how futures might unfold from current conditions and uncertainties, or backward looking, beginning with a normative vision of the future and asking whether there is a plausible path to it. This is also the method adopted for constructing the four natural gas storylines. The approach to generating scenario can include the active engagement of targeted audiences through participatory processes and game playing (thus the metaphor of playing cards in the four storylines), deliberation among expert scenario panels, and quantitative simulations by modeling groups.

Finally, scenario studies have begun recently to synthesize the quantitative modeling and qualitative storyline approaches, in order to blend structured quantitative analysis with textured and pluralistic scenario narratives (Raskin et al., 1998; Nakicenovic et al., 1998a; Nakicenovic et al., 2000). As mentioned, these developments of methods to effectively blend quantitative and qualitative insights are at the frontier of scenario research today.

The narrative storylines give voice to important qualitative factors shaping development such as values, behaviors, and institutions, providing a broader perspective than is possible by analytical and numerical modeling alone. Storylines are rich in detail, texture, metaphors, and possible insights, while quantitative analysis offers structure, discipline, rigor, and reproducibility. The most relevant recent efforts are those that have sought to balance these attributes. They provide important insights into how current tendencies and trends might become amplified in different future worlds (e.g., across the four methane storylines) and provide a multitude of different details across scales and systems. These new scenarios are often embedded in extensive assessment of the main driving forces and their future developments across scenarios in the literature.

In 1998, a set of three scenarios, based on elaborate narrative stories that described alternative futures, was developed by the Global Scenario Group (Raskin et al., 1998). In the same year, IIASA and WEC published a set of six scenarios developed by a set of integrated assessment models (IAMs) that were based on narrative descriptions of three different future development paths, one of which branched out into three alternative energy systems futures (Nakicenovic et al., 1998a). The IPCC SRES approach was based on an extensive scenario literature review (Nakicenovic et al., 2000). Based on this review, four alternative narrative storylines were developed to cover the range of possibilities characteristic of the underlying scenario literature, from driving forces to energy and emissions outcomes. Finally, the four storylines were quantified with six different IAMs into a set of 40 scenarios. The most recent set of four scenarios to include narratives and models quantifications are the four MEA scenarios. They build on earlier scenarios and modeling efforts and also extend scenario analysis to include ecosystem services and their consequences for the human well-being, which has not been done before (Nakicenovic et al., 2005). The MEA scenarios are rooted in very extensive storylines and were thereafter quantified with one IAM to a large extent based on the IPCC SRES scenarios. Another new development in scenarios is to reach across the global/local gap, with a stronger focus on local analysis of energy systems and services or ecosystems and its services (e.g., MEA, 2005).

The ideal attributes for such scenarios are: integration across social, economic and environmental dimensions; regional disaggregation of global patterns; multiple futures that reflect the deep uncertainties of long-range outcomes; and quantification of key variables linked to ecosystem conditions.

The first decades of scenario assessment paved the way by showing the power – and limits – of both deterministic modeling and descriptive future analyses. A central challenge of contemporary global scenario exercises is to unify these two aspects by blending the objectivity and clarity of quantification with the richness of narrative (Raskin et al., 2005).

Some on-going energy-related studies

Energy perspectives have returned to the agenda recently especially since the rapid increase in oil and other energy prices. This has been compounded with other issues such as energy security and reliability, adverse environmental impacts from indoor air pollution to climate change, and falling of public research and development expenditures in most of the OECD countries. Thus, it is not surprising that global energy studies abound. Suffice it here to mention the InterAcademy Council (IAC) study on the topic "Transitions to Sustainable Energy Systems." (IAC, 2005). The IAC is a multinational organization created by Academies of Sciences of the world to provide a source of in-depth science-based consensus advice on major science- and technology-intensive issues faced by the international community. This IAC study will review the global research and development efforts underway, assesses their adequacy and probable impacts, and outlines an appropriate response. It also includes addressing the public policy factors impacting on the direction and pace of technological transitions to sustainable energy systems, including the role of economic policy instruments. Other broader energy-related initiatives took place in preparation for the 14th United Nations Commission for Sustainable development that was held in New York, 1 to 14 May 2006. Many energy studies were prepared and presented to the CSD-14.

However, there are only a few new scenario studies planned for the future. One of the efforts is by the World Energy Council to develop a set of energy scenarios through 2050 building on a number of earlier scenarios for which the organization is well known. Also the International Energy Agency will produce the new energy outlook this year including a reference scenario to 2030 together with a policy alternative case and possibly also a 'broader brush' outline of longer-term development.

Recently, Global Energy Assessment (GEA) was initiated by IIASA in collaboration with a number of other institutions (GEA, 2006). Although other authoritative publications on different aspects of energy are readily available, they do not adequately address energy challenges in an integrated way. Given this need, GEA was initiated with the aim of not only building upon and extending earlier assessment activities—such as the WEA (Goldemberg et al., 2000) and others—to include more recent information on energy issues and challenges, but also conducting a more integrated analysis accounting for the full range of activities, opportunities and threats linked with energy systems, including region-specific challenges. This integrative approach represents one critical and unique element of the proposed Assessment that, unlike earlier studies, will provide the stronger interdisciplinary policy orientation required for decision-making and capacity building. GEA is planned to last for four years and will be organized in a similar way as IPCC and MEA. One of the main focal themes is expected to be exploration of different energy perspectives based on a comprehensive set of energy scenarios including storylines and a substantial regional and place-specific resolution.

Historical evolution of energy perspectives and the role of natural gas

From resource scarcities to energy security and the environment

During the last decades numerous scenarios have been developed for many of the different purposes mentioned above. Jointly, they describe our changing perceptions about the future and most importantly they provide background for policy decisions about energy developments including for example a wide range of policies from technology to emissions mitigation. As mentioned, energy scenarios in the literature range from a simple Gedankenexperiment (a 'thought experiment') to very elaborate modeling and scenario efforts. Some are sufficiently simple to be developed in a matter of hours while others require whole teams and many person months. Some scenarios are developed with integrated assessment models (IAM) or other elaborate modeling frameworks. It is therefore not surprising that there are numerous scenarios in the literature and that the number of scenarios of regional and global developments is growing by the day (Nakicenovic et al., 2005a).

A historically major motivation of energy studies ever since Jevons The Coal Question of 1865 has been the recurrent fear of imminent resource scarcity (Jevons, 1865). Even if the dominant neo-Malthusian paradigm has largely lost its appeal in comparison to the situation that prevailed during the mid-1970s in the aftermath of the first oil crisis, important concerns on resource availability and resulting impacts on energy markets remain for both short-term (volatility and supply disruptions) and long-term ("running out of oil by when") perspectives. Thus, it is probably fair to say that energy perspectives, as reflected in the future studies, have shifted emphasis from resources scarcity to scarcity of energy services, security, investment needs, market volatilities and so on. Nevertheless, the recent price increases have revamped a number of studies on the so-called oil peak based on the pioneering work of King Hubbart (Hubbart, 1949) during the 1960s.

Before the early 1990s, approaches to resolving energy-related challenges focused on increasing energy supplies (primarily fossil fuel-based) to meet energy demand. Basically, the studies were primary supply oriented looking into energy reserves and resources, conversion, transport and trade and much less into questions of energy end use and provision of services. During the last two decades, it has become increasingly clear that a new approach to energy is needed in order to meet a wide range of social, economic, and environmental objectives simultaneously. This requires, in fact, a fundamental reorientation from strategies that focus on conventional supply expansion towards those that give greater emphasis to energy end-use efficiency improvements, increased use of non-fossil energy resources, and cleaner fossil fuel generation and use. For example, such changing perceptions about energy futures are clearly demonstrated in the WEA (Goldemberg et al., 2000; 2004). The four natural gas storylines presented in the report text the alternative future development from resource scarcities to more abundant gas supplies, from emphasis on energy efficiency and conservation to a shift to alternative energy resources.

In contrast, some of the current resources studies that an alarmist 'running out of resources' perspective is inappropriate in the coming decades. In other words, 'scarcity' is unlikely to be the much-discussed need for a 'sustainability' transition in energy. Such a transition is a matter of social choice and not one of geological determinism. Considering conventional oil and gas reserves[2] suggest that these could last at least some 40 years, whereas fossil fuel resources (including coal and unconventional oil and gas) could last at least several hundreds if not thousands of years[3]. Conversely, renewable energy flows are 1,000 times current global energy use but contrary to fossil fuels are disperse and have low energy density thus requiring elaborate infrastructures for capture, transport, storage and distribution, particularly to areas with high demand density such as cities. This wide disparity of views is one of the main features of the four natural gas storylines that attempt to integrate them in different ways across the four future development paths. The illustrate both the nature of the social choice involved in choosing our collective future as well as the decision options open to the industry and other stakeholders.

During the 1970s, the neo-Malthusian perspectives of 'running out', of oil were persistent despite many studies that have outlined the vastness of hydrocarbon resources. Today, we have the recurrence of this view indicating that the 'oil peak' immanent and likely to occur during the coming decade or two. The logic of the argument is that that there have been very few large new oil discoveries in the recent years. For example, most of the growth of the US reserves is due to the re-evaluation of known reserves, the so-called 'field growth'. Furthermore, demand for oil is perceived to grow very rapidly in the future both due to the 'motorization' of the world and especially in Asia. Rapid economic expansion of China and India in particular are considered to lead to large oil demand growth. Mobility is increasing worldwide and is still growing in the most affluent parts of the world, the OECD countries. At the same time, the world production and refining capacities are becoming very old and overstrained. The recent aftermath of hurricane Katrina illustrated these global bottlenecks in oil production and refining more than aptly. Also, most of the richest oil deposits are limited to a few places in the world located in areas of enormous geopolitical instabilities (e.g. Iraq, Iran or Venezuela). All told, there is a perception that future production will be limited both by oil supply facilities as well as by the lack of large discoveries in the future.

Many of these insights into the finiteness of oil (and other hydrocarbon) reserves go back to the path-breaking work of Hubbard (1949). Hubbard, who worked for USGS at the time, noticed that the cumulative production profiles of major hydrocarbon deposits follow S-shaped, logistic development paths. By implication, the production increases exponentially, reaches a peak and eventually declines also at exponential rates (along the derivative of a logistic function). This phenomenon has been used quite frequently to describe the time path of regional and global oil production profiles. Statistical estimates suggest that the 'oil peak' is near if one assumes

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2 Note in particular the distinction between reserves (known, and technologically and economically recoverable at current prices) and resources (either not yet discovered or recoverable only with future technology and/or prices).

3 This would be the case with postulated hydrate occurrences if one day they become accessable as an energy sources.

King Hubbard's model to hold for the global oil production and reserves e.g., see Campell, 1997 and Campell and Laherrere, 1997. In fact, this worldview is very likely to be correct and hold for current relatively cheap and easy to extract oil reserves. The question that must be asked is whether these reserves will not be replenished in the future from very large resources that are more difficult and more costly to extract. The recent oil price hikes of $70 per barrel would certainly imply that vast oil and gas resources may become economic and extractable if in general the view prevails that oil prices will remain high.

However, social, economic and technological limits for a continued expansion of fossil resource use might be reached much sooner than any physical resource 'depletion midpoints' or 'peaks': Current recoverable reserves amount to approximately 1,000 GtC (billion tons of carbon), and fossil fuel resources range between 5,000 to 20,000 GtC (depending on the scope for 'exotic' hydrocarbon resources considered in the inventory such as methane hydrates) which compares to some 760 GtC carbon in the atmosphere (see Table 1.1). About a third of the atmospheric carbon is due to accumulated fossil energy emissions and is already causing a 'discernable influence' on the climate system. In other words, the assimilative capacity of the planetary processes for ever increasing energy-related emissions seem to be more limited than the geological availability of hydrocarbon resources.
In fact, both coal and methane resources are quite abundant and more widely distributed than those of oil. In particular, natural gas is much more abundant around the world than was estimated just a decade ago. In addition, the more speculative occurrences of natural gas such as methane hydrates are truly vast and, if ever exploited, could supply any conceivable future energy demands for many centuries to come (Table 1.1).

Table 1.1 Global hydrocarbon reserves, resources, and occurrences, in ZJ (10^{21}J)

	Consumption		Reserves	Resources	Resource Base	Additional Occurrences
	1860–1998	1998				
Oil						
Conventional	4.8	0.14	6	5	11	
Unconventional	--	--	6	12	18	> 60
Gas						
Conventional	2.3	0.08	4	8	12	
Unconventional	--	--	5	7	12	> 10
Hydrates	--	--	--	--	--	> 800
Coal	5.4	0.09	45	108	153	> 130
Total	12.5	0.31	66	140	206	> 1000

Data sources: Nakicenovic et al., 1995; Nakicenovic et al., 1998a, Masters et al., 1994; and Rogner, 1997.

Most drastic and very speculative hydrocarbon deposits are the potentially gigantic quantities of methane trapped in ice, the so-called methane hydrates (clathrates). Some estimates indicate that this form of methane might represent an energy resource far larger than all other known hydrocarbon energy resources put together (Table 1.1). The challenge is to understand the conditions that would make some of the enormous resources become future reserves that could be successfully exploited.

Evidently, supply security and price volatility remain important energy concerns given the geographically concentrated production and supply particularly for oil. However, these concerns are shaped more by actual and perceived geopolitical risks and the imponderabilities (or 'exuberances') of the increasingly speculative nature of energy markets rather than by actual physical balances between demand and supply, and hence classical resource depletion phenomena. Nevertheless, local and regional supply disruptions are a reality and should be expected to reoccur in the future accompanied by price flares and periods of volatility. There is no doubt that these developments are closely related to the geopolitical risks associated with many large oil deposits in particular, and increased competition and energy trade as the result of privatization and liberalization of energy markets in general.

This is particularly transparent in the case of electricity grids and the recent increase in incidences of large-scale 'blackouts' and near blackouts. Declining infrastructure investments have increased vulnerability to supply disruptions and also effectively constrain larger market deployment of new energy technologies such as intermittent renewables that are otherwise stimulated by a host of incentive and regulatory policy measures. Liberalization and resulting competitive markets mean that more electricity is traded so that traditional 'distribution' grids are becoming also 'trade' grids, a function that was not a part of their original purpose. The integrated electricity grids of North America and Europe were constructed during the 1960s and the 1970s and are generally not adequate for the large-scale electricity trade and increasing role of intermittent energy sources. More competitive gas markets, in particular through LNG (liquid natural gas), are likely to diversify supply and increase the security and reliability of supply while at the same time probably enhancing price volatilities. Last but certainly not least, the perception of an increasing risk of acts of terrorism is likely to enhance some of

these tendencies and further attract limited investments away from energy sector proper toward security and safety. In the past these concerns were limited more to nuclear power and large-scale hydropower, but are now pervasive in some quarters of the world.
The situation with oil and gas production is not all that much different. Both production and processing capacities are becoming very old and reserve capacities are slim. Any major disruption, whether conflicts in oil-producing regions or natural disasters, lead to price and supply volatilities, amplifying the perceptions that the 'oil peak' is near or even behind us despite huge 'endowment' of hydrocarbons still underground.

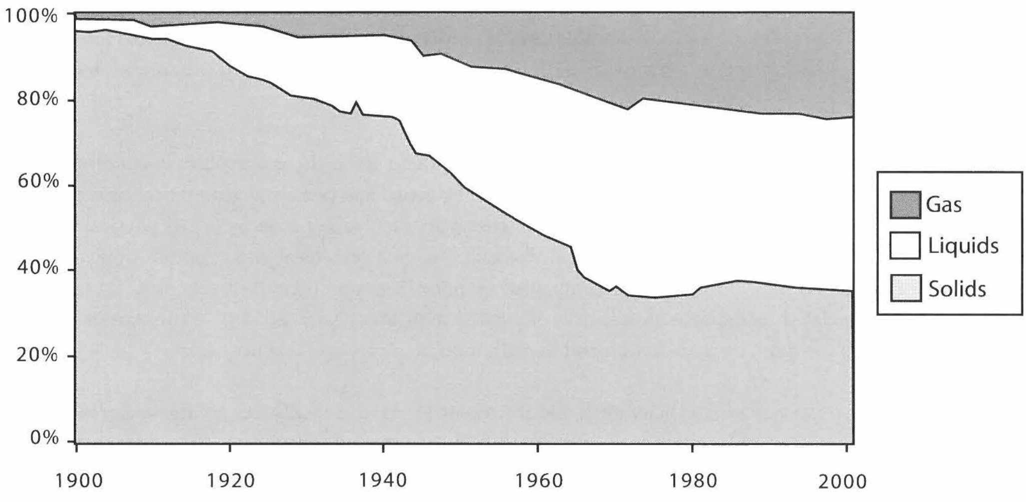
This brief excursion in the controversy about whether we are running out of affordable oil and gas deposits or whether these resources can last longer with appropriate investment and environmental concerns are at the hart of some bifurcations among the four storylines. Gas can become a limited energy source in the future and never be the bridging fuel or fuel of choice. Instead, two distinct, but related possibilities emerge, namely a return to coal (dirty with current technologies and possible clean in conjunction with carbon capture and storage) or a transition away from fossils toward renewables and possibly also nuclear energy. The storylines capture these possibilities in context of broader development paths.

Historical evolution toward energy gases and electricity

In contrast to some of these current uncertainties surrounding energy futures, the long-term historical evolution of the energy systems is continuously being transformed toward lever larger role of energy gases. Nevertheless, natural gas has not played a major role in the global energy system until recently, even though it has been used since antiquity.
Global energy use has evolved from a reliance on traditional energy sources such as fuel wood and coal, and then oil and natural gas, and more recently, but to a significantly lesser extent, on nuclear and hydroelectric energy sources. Traditional energy sources and coal are solids. Oil is a liquid energy source while methane is gaseous. Figure 1.1 illustrates this transformation of the global energy system from solids to liquids and more recently toward gases. Consistent with this long-term transformation and structural change in the energy system, is the shift to methane as less carbon-intensive and perhaps even carbon-free energy source for the 21st century.

Figure 1.1 illustrates the evolution of the global primary energy supply during the last century. The contribution of gas grew only modestly prior to the 1940s, but then experienced rapid expansion during the following three decades. Throughout its history, the market share of gas has been determined by infrastructural bottlenecks rather than by the availability of exploitable geological deposits. Today, this is still the case, gas deposits are more pervasive than those of oil and the unconventional gas resources are truly huge. Figure 1.1 illustrates that the share of gas in cumulative past production is small, but it implies that the future potential contributions may be extremely large and continue expanding for many decades.

Figure 1.2 Global transformation of the energy system from reliance on solid energy sources (traditional fuelwood and coal) toward liquids (crude oil) and more recently toward energy gases (mostly methane)

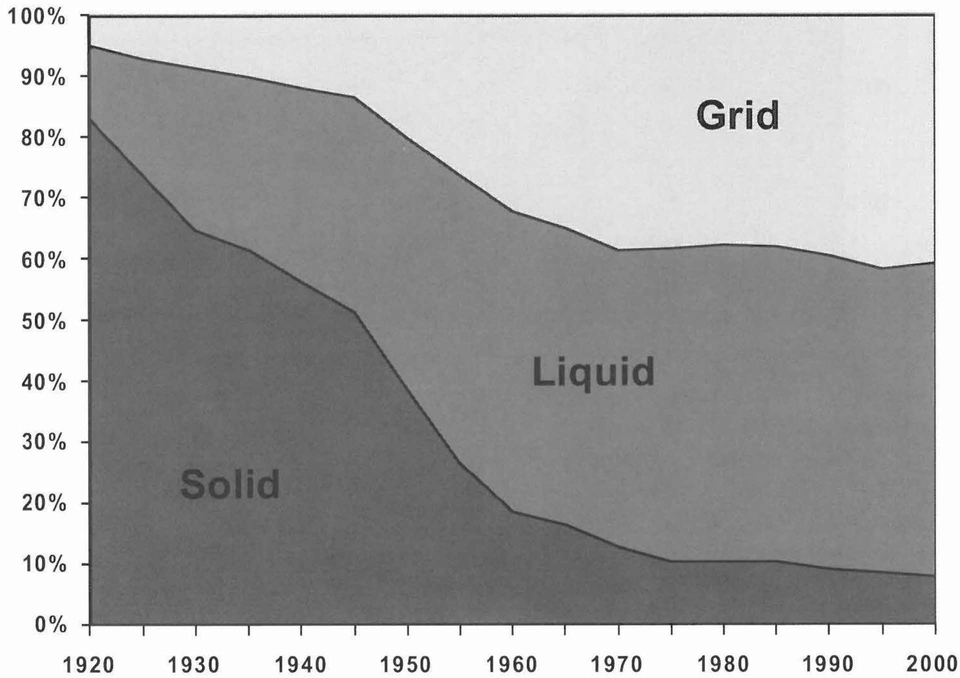


Source: Marchetti and Nakicenovic,1979; Grübler, 1998.

At the beginning of the industrial revolution, traditional biomass and especially wood were the main sources of energy. They were used in the solid form. However, some of the biomass was transformed into work through working animals and human labor. Other, much smaller contributions toward required work were hydrolytic power and wind power (mostly for pumps and mills). With the diffusion of coal (the 'underground forest'), the role of solids was expanded manifold. Some of the coal was used to produce energy gases (city gas) and to generate electricity toward the beginning of the last century. Oil become the dominant energy source some 70 years later and is virtually completely transformed into liquids and little electricity. Gas in contrast is used both directly and is converted to electricity.

Figure 1.3 shows the transformation of energy that reaches the consumer, the so-called final energy. This includes all energy carriers at the point of consumption and shows increasing role of grid oriented energy carriers during the last decades, energy gases and electricity. Figure 1.3 illustrates the development in the United States that is representative for most of the highly developed parts of the world.

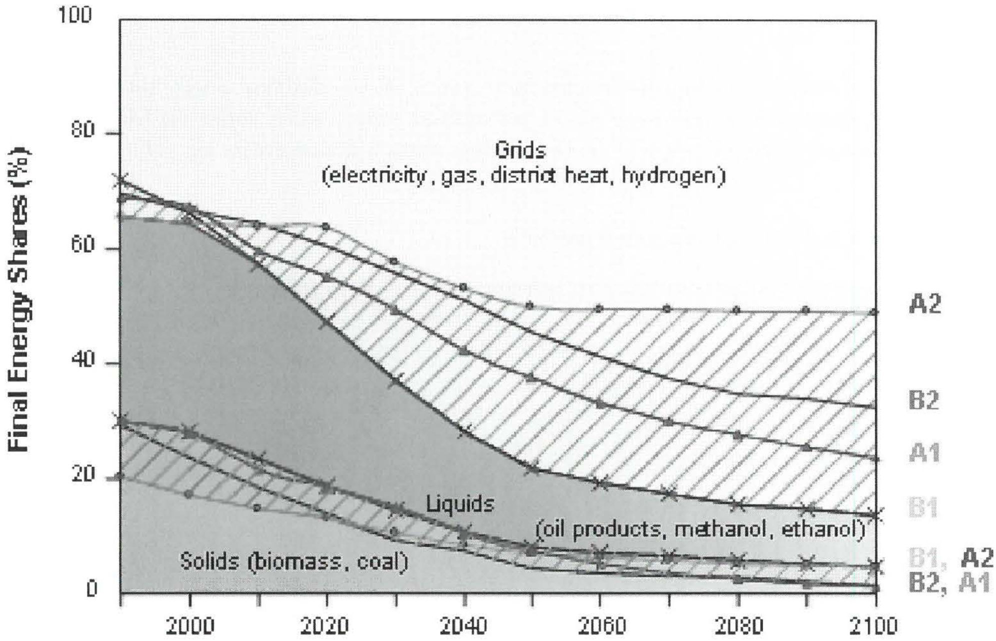
Figure 1.3 Transformation of final energy structure in the United States



From virtually exclusive reliance on solid energy carriers (traditional fuelwood and coal) a century ago, a gradual shift toward liquids (crude oil products) and more recently toward grid-oriented energy carriers (mostly natural gas) and electricity. Many developing parts of the world today have final energy structures resembling those of the more industrialized countries almost a century ago.

Despite all present uncertainties surrounding the future developments in the global and regional energy systems, one of the most pervasive historical tendencies that are likely to continue is the increasing share of grid-oriented energy carriers – gases and electricity. Solids represent direct use of coal and biomass and exclude conversion of coal into electricity (or in principle also conversion of biomass into liquids, but the quantities involved are so small today that this would not be noticeable). Liquids represent crude oil converted into oil products such as motor fuels and exclude liquids used to generate electricity. Analogously, natural gas used to produce electricity is not included under gases but rather only energy gases (mostly natural gas). Electricity represents final consumption from all sources including solids, liquids and gases used in conversion and in addition also other sources of electricity such as hydro and nuclear power.

Figure 1.4 Global transformation of the energy system from reliance on solid energy carriers (traditional fuelwood and coal) toward liquids (crude oil products) and more recently toward energy grids (mostly natural gas and electricity



In 2000, solids, liquids and grids have about equal shares in final energy. IIASA SRES scenarios (Nakicenovic et al., 2000) portray a future shift toward larger shares of gird-oriented energy carriers across a wide range of futures. Liquid energy carriers of the more distant future would constitute methanol and ethanol made from a range of solids in addition to oil products. In a more distant future energy gases would also include increasing shares of hydrogen.

Figure 1.4 contrasts the historical evolution of primary and final energy systems structures with future transformations of final energy across a range of energy scenarios developed by IIASA for IPCC SRES (Nakicenovic, et al., 2000).
Again, like in Figure 1.3, final energy is shown disaggregated into solids, liquids and grid-oriented energy carriers. Definitions are also the same.

Looking into possible future developments across these scenarios there is a surprising degree of convergence toward ever larger shares of gird-oriented carriers. A process very similar to the historical evolution of the final energy in the United States and other now highly developed parts of the world. The main difference is that future liquids would include synthetic liquid energy carriers in addition to oil products. These would include methanol and ethanol made from solids (coal and biomass, respectively). Also the nature of energy gases would change from almost exclusive reliance of natural gas today toward synthetic gases from biomass or coal as well as hydrogen from many different energy sources during the latter part of the century. Thus, a broad trend toward larger role of energy gases and electricity is clearly predominant these scenarios that are based on a broad and varying assumptions about the unfolding of main driving forces form population and economic growth to resource endowments, energy investments or trade.

Future use of energy gases across scenarios in the literature

This study presents four different natural gas futures as they unfold in the four storylines. As a background to those developments, it is relevant to assess the role of natural gas across energy scenarios the literature. They cover a very large range indeed: In some of the scenarios the global gas consumption increase manifold even over the time horizon to 2020, while in others it maintains its current contribution. Figure 1.5 shows the gas contribution across more than 200 scenarios in the literature that were published by the end of 2000. In the lowest gas scenarios, more than 50EJ per year of natural gas are consumed worldwide by the 2020s, while in the highest more than 250EJ per year, well over the half of the current global energy consumption. Going further into the future indicates that in the highest gas scenarios, the consumption continues to increase toward the middle of the century and thereafter flattens off. The reached level corresponds to some 400EJ per year and much more, in some cases well over the present total global energy consumption.

Chapter 2

Driving Forces of Natural Gas Perspectives

Driving forces of natural gas perspectives in general and the four storylines in particular are many. They are captured in phrases like 'natural gas is the fuel of choice', 'natural gas is the transition fuel of the 21st century' and 'natural gas is a fuel of no regrets'. These were some of the many characterizations of the opportunities and challenges for the gas industry expressed at the 22nd World Gas Conference held in Tokyo, 1-5 June 2003, attended by more than 5,000 participants (IGU, 2003). Overall the conference captured some of the salient driving forces leading towards the larger role of natural gas and the possible emergence of the 'methane age'. Some of the driving forces for the emergence of the methane age are discussed below and embedded in the storylines with larger role of natural gas in the future such as the Transition Storyline (presented in Chapter 3).

The theme of the 23rd World Gas Congress in Amsterdam, 5-9 June 2006, Gas; powers the people and preserves the world, amplifies again the need to better capture some of the driving forces that may enable or could hinder a larger role for natural gas in the future. Central to this strategic vision of the industry's future is an environment in which partnerships and alliances must be built with other private and public stakeholders "to mitigate the risks of climate change and to achieve sustainable development" (Urano, 2003), to attract further investment in natural gas industry and technologies including end use, to provide clean and affordable energy services to billions still without access and to future generations. Two of the storylines, notably the Coal, Oil and Nuclear Storyline (presented in Chapter 5) and the Underinvestment Storyline (presented in Chapter 6), illustrate how other futures might unfold where gas does not fulfill the promise of becoming the fuel of choice and the bridge toward future energy transitions.

In the previous section we argued that during the last two centuries, global energy systems have transformed from a reliance on carbon intensive sources of energy such as coal to oil and more recently to natural gas. This has resulted in substantial decarbonization. The gas industry started from synthetic, manufactured gases, but exploration and production activities of the upstream industry during the 20th century has enabled natural gas to become frequently the fuel of choice in electricity production (there where access to gas exists), industry and households and thus contribute to the decarbonization of energy. Enhanced decarbonization is indeed an important driving force for the emergence of the larger role of methane in the future. A larger role of natural gas would be consistent with this trend as well as with the need to reduce the emissions of greenhouse gases that are associated with anthropogenic sources of climate change. "Expanding the use of gas is the best medium-term response to the threat of climate change" (Watts, 2003).

Another driving force is the need for clean and affordable energy services. Access to affordable energy services is crucial for economic development with more than 1.3 billion people living in poverty (with less than $1 per day) and with some two billion without access to modern energy services. In general, a larger role of natural gas, enhanced with modern biogas, in developing countries would help towards meeting their needs for energy services and towards reducing adverse environmental impacts from indoor air pollution to regional acidification. Asia, in particular, where the emerging markets of China and India between them account for a third of the world's population, is expected to experience a surging need for clean and affordable energy services that can be provided by natural gas. Natural gas principally offers the possibility of environmentally friendly energy from vigorously growing Asian economies. However, such a future requires development of large infrastructures including natural gas and electricity grids, LNG and pipeline

transport systems as well as availability of geopolitically stable and ample gas resources. Again, we have captured the unfolding of these development-related driving forces across the four storylines.
The perceptions about natural gas resources have changed during the last decades. Current estimates of gas resources present a perspective of abundance compared to oil that appears to be much more limited (see previous section, Chapter 1). Unconventional resources would extend centuries in the future while the more speculative deposits of methane hydrates are truly gigantic. The gradual growth of natural gas production, declining costs and technological change have already led to the development of part of the unconventional gas resources, sometimes with previously considered unconventional resources (e.g. gas from very deep structures or very low permeability rock) now being proven reserves that are in production). That is, what were once classified as unconventional resources are now proven gas reserves that are in production. Development of such unconventional gas sources as natural gas hydrates; dense gas-bearing reservoirs and coal bed methane, could provide humanity with vast reserves of clean and environmentally friendly energy for centuries. Unconventional natural gas sources are a very important topic for future studies within IGU (2003). For example, methane hydrates are so vast that they would render natural gas into a virtually inexhaustible source of energy (see hydrate resource estimate given in Table 1.1 above).

It is fair to say that the current energy situation in the world is a bit 'gloomy' and could be characterized as one of chronic deficit in energy investments from R&D to infrastructures, exclusion from access to energy services by many or as one of supply security treats and exceedingly volatile prices. The continuous degradation of energy investments is illustrated in Underinvestment Storyline (Chapter 6). In contrast, some of the perceived natural gas perspectives are optimistic indeed, such as the Transition Storyline (Chapter 3). They can be characterized as an evolving vision that we may be on the brink of the methane age and a new kind of responsibility for the world that poses new challenges and offers new opportunities to the energy business.

Another aspect of this evolving vision is the recognition that a longer-term perspective needs to be taken in the future, a perspective that 'encompasses the whole century' (as called for by the Japanese Crown Prince in his Opening Address, IGU, 2003). The main driving forces of this transition towards a larger role of natural gas in the future is the perception of more abundant methane resources, including hydrates, technological innovation, protection of the environment, e.g. climate change, and sustainability transition in general. These driving forces are played out in all four storylines but to varying degrees unfolding into four distinct futures.

The methane age can serve as bridge towards the hydrogen and electricity (hydricity) era. (For this to become a reality a whole host of new technologies needs to be developed and deployed at affordable prices. They would also need to be socially acceptable and safe. Finally, the vision of a methane age provides a perspective towards future zero emissions energy systems with universal access to energy services by all.

In addition to these more qualitative drivers that are to an extent associated with a whole paradigm change toward future energy developments and perspectives, there are also driving forces that can be quantified and thus offer some hints how large the future energy demands could be and how large the role of natural gas might be in these perspectives. In the following four chapters, we will tackle in detail both the qualitative and quantitative aspects of four alternative natural gas futures captured by our storylines. In the following we focus both on the quantitative and some qualitative driving forces. We start this assessment with population and economic development. They are indeed some of the most fundamental drivers of demand for energy services and thus for future transformations of the whole energy system including that natural gas industry.

A simple scheme captured by the so-called Kaya identity can serve to illuminate the linkages of quantitative drivers such as population and economic development. This hypothetical identity represents the main emissions or energy driving forces as multiplicative factors. It establishes a relationship between population growth, per capita value added (i.e., per capita world product, the sum of all regional gross domestic products, GDP), energy consumption per unit value added, and emissions per unit energy on one side of the identity, and total CO_2 emissions on the other side (Yamaji et al., 1991)[4] . Alternatively, the last two terms can be dropped and the identity would show on the other side the total primary energy requirements. The basic idea stems from the broader literature on so-called IPAT analysis (see Holdren, 2000; Ehrlich and Holdren, 1971) where environmental impacts ('I' such as the CO_2 emissions) are assumed to correspond to the product of population ('P'), 'activity levels' ('A') usually measured by some per capita indicator such as income and technology ('T') that represents unit emissions per unit activity. In this form, the Kaya identity is virtually identical to the IPAT analysis.

The advantage of analysis employing the Kaya identity is that it is simple and facilitates at least some standardization in the comparison

4 $CO_2=(CO_2/E)\times(E/GDP)\times(GDP/P)\times P$, where E represents energy consumption, GDP the gross world product (or global value added) and P population. Changesin CO_2 emissions can be described by changes in these four factors or driving forces. Alternatively, the identity can be shortened by dropping the emissions into: $E=(E/GDP)\times(GDP/P)\times P$.

and assessment of many diverse emissions scenarios. An important caveat is that these driving forces are not independent of each other. In fact, in many scenarios they explicitly depend on each other. For example, scenario builders often assume that high rates of economic growth lead to high capital turnover. This favors more advanced and more efficient technologies resulting in lower energy intensities. Often a weak inverse relationship is assumed between population and economic growth. Thus, the reader should note that the scenario ranges for these main driving forces are not necessarily independent of each other. This is an important caveat also raised in the previous assessment of emissions scenarios in the literature (Nakicenovic et al., 1998b and 2005).

In the following we present the scenario ranges for each of the factors in the Kaya identity representing the main (energy-related) driving forces of emissions: population, GDP and carbon intensity of energy. Table 2.1 gives all driving forces from the Kaya identity including absolute quantities and growth factors. We chose this sequence to present the main scenario driving forces because it corresponds to the way they are represented in the Kaya identity without implying a priori any causal relationships among the driving forces themselves and between the driving forces and energy or CO_2 emissions.

Table 2.1 illustrates possible future developments of these main driving forces. It shows the future ranges across IIASA SRES (Nakicenovic et al., 2000 and Morita et al., 2001) baseline and mitigation scenarios and presents those in the historical context. The development of population, economic output (GDP measured at purchasing power parities, see below), primary energy and carbon emissions indicate enormous rates of growth since the beginning of the industrial revolution two centuries ago. Global population has increased from 1 billion to 6.5 billion people in 2006 (6 billion in 2000) and is likely to increase to between 7 and 15 billion by the end of the century. Factors of growth given in the table suggest a characteristic S-shaped pattern of growth with levelling off of the growth rates during the next decades. Economic output portrays similar historical and future paths, but with much more pronounced rates of growth. It has increased some 18 times during the last century which translates into average annual growth rate of about 3 percent. Primary energy requirements have increased at a lover rate and this same is expected in the future indicating large historical and even larger future rates of energy intensity improvements. The same is the case with carbon emissions. In both cases of primary energy and carbon emissions, have and are expected to increase at substantially lower rates than economic output indicating substantial energy and carbon intensity improvements. These indicative quantifications illustrate possible ranges of main scenario characteristics that would correspond to the ranges of the four natural gas storylines.

Table 2.1. Historical increases of global population, economic output, primary energy and carbon dioxide emissions compared to their future ranges across IIASA SRES scenarios

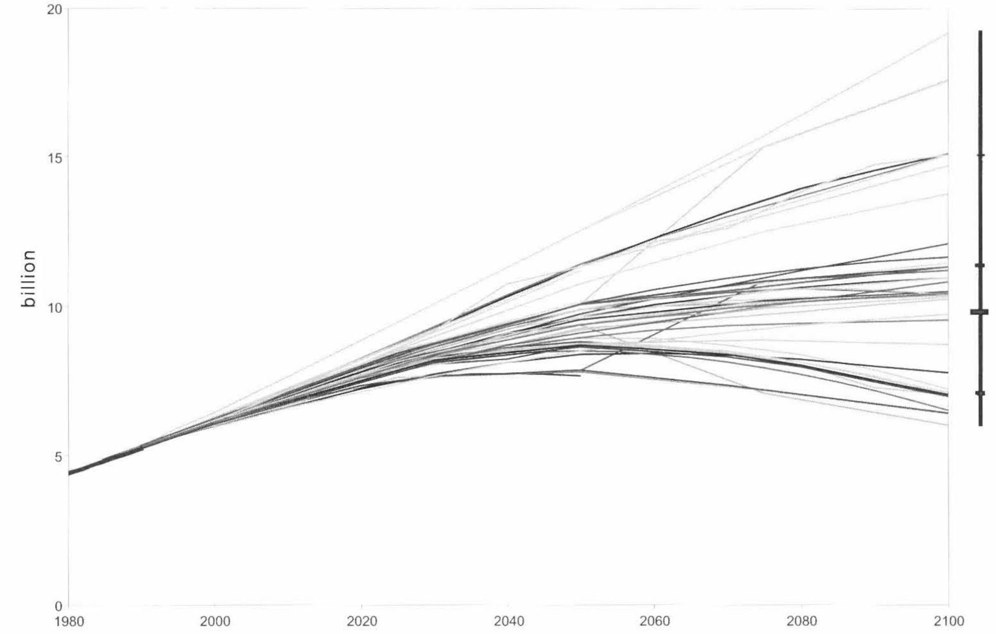
	1800	Factor	1900	Factor	2000	Factor	2100
Population (billion)	1	x1.6	1.6	x3.8	6	x1.2 x2.5	7- 15
GDP PPP (trillion 1990$)	0.5	x4	2	x18	36	<x3 x18	85- 530
Primary Energy (EJ)	13	x3.3	40	x11	440	x1.1 X5.6	500- 2500
CO_2 Emissions (GtC)	0- 0.3	x3.0	0.5- 1.0	x6- x12	6.4	<0.5 x5	3- 33

Source: Nakicenovic et al., 2000 and Morita et al., 2001.

Recent demographic trends and future perspectives

Population is one of the fundamental driving forces of human development. Today there are three main research groups that project global population – United Nations (UN, 2003), World Bank (Bos and Vu, 1994) and IIASA (Lutz et al., 2001). Most of the central population projections (common to demographic developments in scenarios of all three research groups) during the early 1990s led to a doubling of global population by 2100 to more than ten billion people compared to 5.3 billion in 1990. The current global population is larger by a billion people (6.5 billion in April 2006), indicating the tremendous momentum behind global population growth. Toward the end of the last decade (the 1990s), central population projections for the year 2100 have declined somewhat but still were not too far from a doubling by 2100. For example, the United Nations (1998) medium-low and medium-high projections indicate a range of between 7.2 and 14.6 billion people by 2100, with the medium scenario at 10.4 billion. The IIASA central estimate for 2100 is also 10.4 billion with 95 percent probability that world population would exceed six and be lower than 17 billion (Lutz et al., 1997).

Figure 2.1 Global population: Historical development and scenarios.



Data sources: Durand (1967), Demeny (1990), UN (1996), Morita and Lee (1998) and Nakicenovic et al. (1998a)

Figure 2.1 illustrates global population projections for a wide range of scenarios in the literature. The range is from 6 to 19 billion with a median of about 10 billion people by 2100 compared to some six billion in 2000 (6.5 billion in April 2006). It is interesting to note that more recent scenarios in the literature portray quite different development paths from the older ones. The most striking feature is that population projections published since 2000 envisage at least two billion less people by the end of the century compared to the earlier literature. The highest of these newer projections leads to some 15 billion (compared to 19 in pre-2000 scenarios). This represents a very significant change in our perceptions of the future of global. Another important aspect is that scenarios with lower population lead to higher rates of economic growth because, generally, the population transition occurs during the next decades even in the world regions with still high population growth today. However, the very low global populations of four billion by the end of the century, two less than today, pose new challenges concerning aging, as many services traditionally have been provided by the younger people and also concerning the need for considerably longer working life. Some of the current low population projections in the range of four or so billion by 2100 will no doubt lead to fundamentally new perspectives on future energy services and other human needs to assure the well being of future generations.

Finally, it should be noted that the range of population projections is my narrower by the middle of the century, the main time horizon of this study, compared to the strong divergence thereafter; from declining to still growing trends. Thus, the demographic differences among the four storylines are smaller by the middle of the century compared to the possibility of strongly diverging trends thereafter. However, this also means that the seeds of the post-2050 developments are latent in the more short-term storyline tendencies.
Even though the range of global population projections in Figure 2.1 reflects the scenario assumptions in the underlying literature, it is interesting to note that the population projections used in scenarios are not evenly distributed across the whole range. Instead, they are grouped into three clusters. The middle cluster is representative of the central projections with the range of about 9 to fewer than 12 billion people by 2100. The other two clusters mark the highest and the lowest population projections available in the literature with about six billion on the low end and between 14 and 19 billion at the high end. This feature of the population projections has stayed invariant during the last years.

An interesting question is how these population projections in the literature correspond to the (implicit) assumptions behind the four natural gas storylines. We postulate that the Transition Storyline is consistent with the lowest population projections represented by the third cluster of scenarios shown in Table 2.1 that range from say 6 to 8 billion people by 2100. The main reason is that lower populations levels and even declining ones (after the population transition is achieved) are generally associated with high levels of affluence and high rates of capital turnover. This is consistent with the Transition Storylines with its economic growth rates in the median region in absolute terms but very high on per capita basis. In contrast, Security of Supply Storylines is consistent with the highest levels of future populations; say between 12 and 15 billion people by 2100. This is so because this storyline implies relatively low economic base (levels of affluence) that in turn lead to high growth rates in general but relatively modest ones on per capita basis. The other two storylines are consistent with median population projections; say in the region between 8 and 12 billion people by 2100. This is also so because for example economic development assumptions fall in the median range as well.

Geopolitical, cultural and social driving forces

Energy futures and prospects of natural gas are embedded in the larger question of how combined social, economic and environmental systems interact and shape one another over many decades. There are multiple links. For example, economic development depends on maintenance of ecosystem resilience; poverty can be both a result and a cause of environmental degradation; material-intensive life styles conflict with environmental and equity values; and extreme socio-economic inequality within societies and between nations undermines the social cohesion required for effective policy responses (Morita et al., 2001).

It is clear that energy policy, and its impacts on human well being, will have significant implications for future development patterns at both the global and sub-global scales. Affordable and adequate access to energy services is essential for the sustainability transition and it is also essential for the eradication of poverty and further development. In addition, policy and behavioral responses to sustainable development issues may affect both our ability to develop and successfully implement energy policies, and our ability to respond effectively to energy challenges the humanity is facing.

The issues raised by a consideration of development, equity and sustainability are of particular relevance to the natural gas storylines discussed in this report. Because they are necessarily based upon assumptions about the socio-economic, geopolitical and cultural conditions (that give rise to future developments), the four storylines implicitly or explicitly contain information about culture, development, equity and sustainability.

Some of these assumptions are documented within the 13 salient assumptions specified (playing cards) for each of the natural gas storylines in the following four chapters. In principle, each storyline or scenario describes a particular future world, with particular cultural, economic, social and environmental characteristics. Because of their integrative nature, storylines provide a framework for exploring these links, the dynamics of the whole socio-cultural systems and the possibilities for abrupt transitions at critical branch points. Beyond this analytic function, normative scenarios can posit development visions characterized, for example, by the achievement of goals for equity and environmental sustainability. Then, the appropriate policies, actions and choices for approaching such a multi-objective future can be considered. Given the strong interactions between development, environment and equity as aspects of a unified socio-cultural system and the interplay between provisioning of energy services and development, equity and sustainability and policies, in this report storylines are formulated as an aspect of broader process of human development and improvement of human well being. The four natural gas storylines do not explore extensively the possibility of achieving broader goals of sustainability or equity. This is neither the purpose of this study nor is this likely to be achieved even in the most of the optimistic transition scenarios over the next few decades, the main time horizon of this study.

Storylines assess and simulate possible pathways of long-range global development that meet specified targets for aggregate energy needs and their environmental and other consequences. In general, based on given demographic and economic growth assumptions, scenarios can be used to explore the technological and environmental management changes that are required for meeting energy patterns that maintain atmospheric concentrations of greenhouse gases below specified thresholds and that provide affordable energy services and thereby support improvement of human well being.

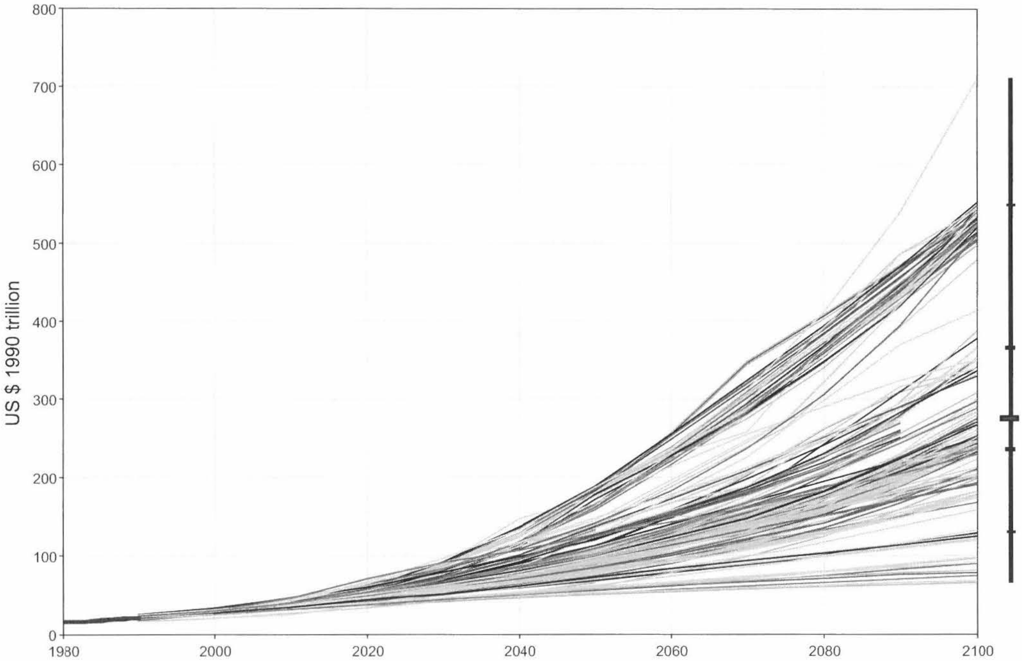
The provisioning of human needs should be tailored precisely to the unique characteristics of each particular location and environment. The high qualities of natural gas as a source of energy would be compatible with these growing needs for sustainable energy services. Therefore, the many important economic, environmental and societal dimensions of sustainability together with its global context provide a huge opportunity for natural gas industry to be positioned as a modern and forward thinking industry (IGU, 2003).

Economic growth and development

Economic growth and development are fundamental driving forces of any emissions scenarios. Energy requirements are directly linked to the nature and structure of economic activities so that the assumptions about the economic development constitute among the most important determinants of scenarios in general and their energy services in particular. Thus, population and economic development assumptions are central to any scenario. At the same time, the economic growth prospects are among the most uncertain determinants of future perspectives. As shown above, population trajectories range by about a factor of three. In contrast, Figure 2.2 shows a very wide range of economic development paths assumed in the scenarios.

The historical GDP (gross domestic product, in this case the global economic product) growth rate has been about three percent per year since the 1950s; in the scenarios the average growth rates to 2100 range from 1.1 percent per year to 3.2 percent per year, with the median value of 2.3 percent per year. This translates into a GDP level in 2100 that varies from 2.6 to more than 25 times the 2000 levels. The 2000 GDP was about US$35 trillion, which translates into the range of about US$65 to more than US$700 trillion by 2100.

Figure 2.2 Global economic development across scenarios in the literature



Data sources: UN (1996), Morita and Lee (1998), Nakicenovic et al. (1998b) and http://www-cger.nies.go.jp/cger-e/db/enterprise/scenario/scenario_index_e.html, and http://iiasa.ac.at/Research/TNT/WEB/scenario_database.html.

Figure 2.2 clearly indicates some clustering of scenarios into three ranges, a low one around about $100 trillion, a median one around $300 (with a wide range from about $200 to about 400) trillion and the high one around about $500 trillion by 2100. If, on the basis of these GDP projections, the per capita GDP range would be specified, then this would show a similar pattern, i.e. that the upper bound has shifted downwards from about US$80 thousand to US$50 thousand, and that the median has been moving from US$46 down to US$23 thousand respectively. This corresponds to annual GDP growth rates of about 0.6 percent per year in the lower case, about 1 percent per year in the median case and about 2.7 percent per year in the high case. The Security of Supply Storyline is assumed to fall in the highest growth range (medium in the North and high in the South). However, this storyline also has high population levels so that per capita growth rates and standards of living would be similar compared to the other two more median economic-growth storylines (Transition and Coal, Oil and Nuclear Storylines), except for the Underinvestment Storylines that is assumed to be characterized with substantial volatilities making its economic growth rates rather indeterminate or in the worst case rather low. The average global standards of living by the end of the century would be comparable to those of the most affluent parts of the world today with abut $30 thousand per capita compared with the current global average of less than $6 thousand.

One of the contended issues is whether the economies should be measured in terms of market exchange rates or purchasing power parities. Market exchange rates are to used for tradable commodities such as oil or coal. These are important in energy scenarios. Finally, data for energy technologies, inputs and outputs and other important model parameters are readily available measured at market exchange rates. On the other side, there is the argument that purchasing power parties are the appropriate metric for comparison of incomes and affluence across countries and regions. The larger the informal economy the larger will tend to be the underestimate of economic activities if market exchange rates are used instead of purchasing power parities. We will not venture here in the intricate arguments concerning these issues or what is the preferred way of measuring economic activities except to state that the current living standards in the developing parts of the world would appear to be about 6 times higher when measured at purchasing power parities compared to the market exchange rates. All told, the economic growth rates across scenarios and in the four storylines would appear to be significantly lower in terms of purchasing power parities. However, an interesting finding is that the upper range of GDP values is quite similar going to about US$700 trillion, as shown in Figure 2.2.

Technological change, innovation diffusion and new energy paradigms

We have shown (see Chapter 1) that in a large number of energy scenarios, natural gas demand could double by 2030 driven primarily by increasing energy demands in all parts of the world. Generally, natural gas is the fuel of choice for power generation wherever access to gas is available and this is likely to continue to be the most important growth segment, although today the high oil and gas prices are translating in substantially higher electricity prices. Nevertheless, natural gas is the right fuel to meet electricity generation and other demands because of its environmental benefits, the increasing efficiency of gas-fired technology, and the shorter lead times to build plants and the lower life cycle costs (IGU, 2003). The importance of appropriate regulatory frameworks was emphasized for building new generation capacities and maintaining existing production and use levels.

Stationary uses of methane or biogas for cooking or in small-scale electricity generation are important for many developing countries that do not have universal access to electricity today. Higher shares of natural gas as (public) transport fuel would be another priority as it can result in a substantial reduction of urban air pollution. Fulfillment of these large technology needs would require closer collaboration among many countries and close industry and public partnerships especially to develop energy infrastructures such as pipeline grids and to develop and deploy new energy technologies. Governments have the primary role in creating the necessary legal and regulatory conditions in the development of gas markets, especially in smaller customer markets, as well as for the quality and efficiency of the service that should be guaranteed (IGU, 2003).

Looking into the longer future perspectives, fuel cell technologies are considered to be an important and essential component of future energy systems and would play an essential role in the 'Methane Age' and beyond in conjunction with hydrogen. Fuel cells are a generic technology as there are many types, from low to high temperature, from mobile to stationary. What they have in common is modularity and the possibility of small-scale distributed generation of electricity and cogeneration of heat. This is a decisive advantage as it may lead to substantial cost buy-downs along learning curves and render this technology economical in coming years and decades. The challenge today is the high cost compared to other alternatives, such as the internal combustion engine for automobiles. For example, including fuel cells in newly built houses could meet the environmental objectives of reduced energy use and emissions, while providing an early market for a high cost product. However, it appears that no major technical breakthroughs are required before fuel cells can be introduced into the stationary energy sector – although a lot of engineering development and especially cost reduction will be necessary. In the automotive sector the challenges are perhaps greater, as transport is much more homogeneous than power or heat generation in terms of both fuel use (only gasoline or diesel in significant quantities) and the ubiquitous internal combustion engine. So the introduction of the fuel cell to meet environmental goals also requires changes in fuel provision, and the simultaneous development of both fuel cells and infrastructure. Fuel cells are expected to be one of the core technologies for motor vehicles in the 21st century as an integral component of the Methane Age (IGU, 2003).

In the meantime, the so-called bridge technologies, such as compressed natural gas, bio-fuel, GTL and DME vehicles would diversify the fleet, help reduce emissions and provide enabling infrastructures for fuel cell vehicles with hydrogen propulsion in the very long term. Emissions free or close to emissions free vehicles will be required as mobility continues to increase during the century.

A larger role of natural gas would also result in an even higher share of global emissions of greenhouse gases and especially carbon dioxide. This means that some of the technologies for carbon capture and storage would need to be developed and deployed. 'Global Energy Scenarios', the third Special Project of this IGU triennium, has shown that moderate carbon mitigation measures and policies tend to favor natural gas in conjunction with carbon capture and storage (IGU, 2003). Already today, carbon dioxide is separated and stored in a sub seabed aquifer below the North Sea (Sleipner and Snowhit gas fields) and carbon dioxide serves as an agent for enhanced hydrocarbon recovery. However, very high levels of carbon taxes would also make carbon capture from coal more economical as well as the introduction of nuclear and renewable energy sources. This is one of the central features of the Coal, Oil and Nuclear Storyline and also a major alternative to the Methane Age if the opportunities are exploited in a timely and appropriate manner by the industry.

In either case (Transition or Coal, Oil and Nuclear Storylines), the amounts of carbon dioxide to be stored would be truly enormous, ranging from a few to perhaps even more than 500 GtC (billion tons of elemental carbon) cumulated by the end of the century

(Morita et al., 2001). The potential storage capacity in underground aquifers, depleted oil and gas fields and underground coal mine seams are all large and would suffice for storing captured carbon. The exhausted oil and gas fields represent a particularly good medium for carbon dioxide burial and storage. At the same time, injection of CO_2 can enable enhanced production of residual oil, gas and gas condensate. Oceans are today one of the largest carbon reservoirs and could potentially store vast amounts in the future, but this option is very controversial because of the uncertain environmental and ecological impacts. Humanity has changed global climate during the last two centuries so that we are already beyond the point where a new energy regime and transition is required. Carbon capture and storage in conjunction with renewables and possibly also nuclear energy could in principle reduce global carbon emissions to virtually zero. Hydrogen and electricity could become pollution-free and renewable energy carriers. Achieving a hydrogen and electricity age has never been more urgent.

Today, the economics of hydrogen as an energy carrier are unfavorable, primarily because the external costs associated with the impacts of climate change are not considered in the cost calculations. However, once these external costs are included, the situation might change significantly. This is an argument for why governments should play a greater role in providing the necessary frameworks and incentives. There has already been a move towards the use of hydrogen in some countries, notably Japan, where natural gas is a source of hydrogen, and in Iceland where geothermal and hydropower are used to produce hydrogen.

Today, methane steam reforming is the most economical route for hydrogen production. Industry has considerable experience with hydrogen production by methane reforming, which can be seen as the transition route to the Hydrogen Age. Unfortunately, the economic opportunities for carbon capture and storage are only possible on a large scale. Another challenge is how to make small-scale reforming technology cheap and reliable, especially for use on board vehicles. First steps in this direction already exist and during the International Exhibition that accompanied the conference, hydrogen vehicles were demonstrated along with refueling stations. Another possibility during the transition toward the Methane and Hydrogen Ages would be to mix hydrogen and methane (hythane), which would reduce carbon emissions to the atmosphere and would not require new pipeline and distribution grids. In the medium term, there would be an opportunity to develop small hydrogen distribution networks for stationary fuel cells producing heat and power, and refueling stations for hydrogen fuel cell vehicles.

Central hydrogen production with steam reforming of methane in conjunction with carbon capture and storage and from intermittent renewable sources, such as wind and hydropower, and the development of hydrogen transmission and storage are expected only in the much longer term. Thus, there are many possible technological synergies between natural gas and renewables as complementary sources of electricity and hydrogen. The gas industry should participate in the development of such perspectives in order to better understand what this could mean in the future, and what the role of natural gas, and of the gas system, could be beyond the next decade or two. The Transition Storyline explores such futures where these opportunities are translated into a larger role of natural gas as the transition energy source. Other three storylines explore to a varying degree future worlds where these opportunities are not taken leading to emergence of barriers that block natural gas from many markets and future uses.

Investment needs in energy systems and infrastructures

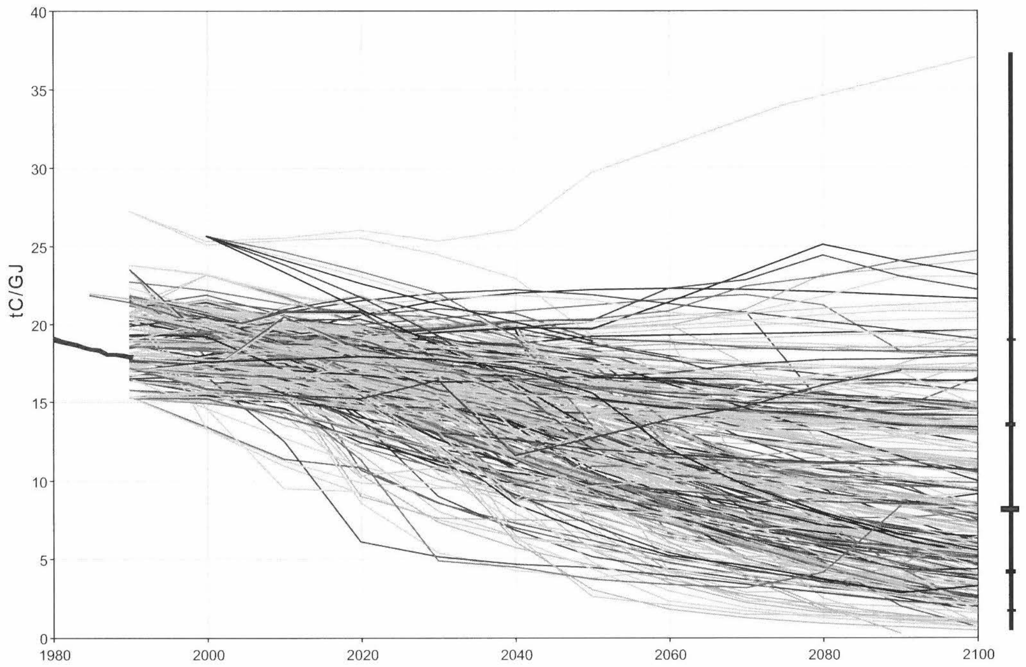
All of the infrastructure and technology requirements imply high R&D needs. Some of these are not necessarily the highest priority for the more developed regions of the world, e.g., technologies for efficient conversion of biomass cellulose into energy gases. Public and private partnerships are essential for achieving these challenging development needs.

The natural gas industry is entering a fundamental transition that is characterized by liberalization of markets, an increasing need for safety and energy security, and concerns about climate change. At the same time, the demand for natural gas is likely to double by mid-century. The diffusion of new and advanced technologies is a corner stone of this transition. The highest technological priorities facing the industry are concerned with the reduction of carbon dioxide emissions through carbon capture and storage, the production of hydrogen as an emissions-free energy carrier and the development of vast methane hydrate deposits. In contrast to these large technology and methane resource development needs are the declining public R&D efforts throughout the OECD countries and the ever increasing competitive pressures facing the natural gas industry that further reduce the availability of R&D efforts. Public and private natural-gas partnerships for technology innovation are essential for paving the road toward the Methane Age and fulfillment of the Transition Storyline.

In general, governments should provide strong support for research and development (in technology but also in socio-economic disciplines), with fiscal and policy incentives for demonstration projects. Governments should not try to pick the 'winners'. However, very clear policy objectives must be articulated so that appropriate technologies are chosen in competitive environments and within a 'level playing field'. This will require a vision of the future. Facilitating transboundary transportation of methane and promoting R&D are two of the major challenges on the road towards the Transition Storyline.

propriate, also nuclear power will not become commercially viable and attractive unless there is a great improvement in their technical and environmental performance, universal availability and perhaps foremost a significant reduction of costs. The current advantage of natural gas is that the combined-cycle gas turbine is such a technology. However, development is underway that might change this current advantage of natural gas in electricity generation markets, for example, by radically reducing the costs of renewables or adverse environmental impacts of coal. This further indicates the need to develop new methane technologies. Again, the four storylines explore these alternative future possibilities, from decarbonization with more gas and with substantially less gas to re-carbonization of the global energy system.

Figure 2.4 Decarbonization of energy as the ratio of carbon over global primary energy, from 1980 to 2100



Source: updated from Nakicenovic, 1996.

Methane resources such as hydrates are potentially so abundant that they could provide a lasting source of hydrogen and electricity thereby achieving decarbonization of energy with carbon sequestration and permanent storage. Thus, natural gas could be the bridge to carbon-free energy sources, such as solar or fusion energy, or even hydrogen extracted from the vast clathrate resources. Decarbonization of methane from clathrates, and other gas sources in general, will require the development of new technologies and innovative schemes for carbon sequestration and storage in the future to produce carbon-free energy gases such as hydrogen and other carriers such as electricity.

In the meantime, the natural gas share in total primary energy should continue to grow at the expense of dirtier energy sources – coal and oil. This transition to the methane age and beyond to carbon-free energy systems represents a minimum-regret option because it would also enhance the reduction of other adverse impacts of energy-use on environment in addition to substantial reductions of carbon dioxide emissions.

Chapter 3

Transition Storyline

3.1 General description

The transition storyline describes a future world in which: world population grows at a relatively low rate; economic growth slows down to rates varying from 2 per cent on average in the industrialized world, to 4 per cent on average in the developing world; worldwide energy efficiency increases by 2 per cent per annum; and life styles are adjusted worldwide to a greener and more sustainable economic system. After a series of disasters, which are attributed to global climate change, particularly in developing countries, the environmental issue is considered one of the key priorities for global policy action. Therefore, a wide range of policies and measures to address this priority are readily accepted almost everywhere, including market-based incentives for GHG mitigation. In their strategies to expand energy production, developing countries adopt 'Western strategies' to reduce carbon emissions through energy efficiency improvements and via the introduction of renewables at a surprisingly quick pace. Simultaneously, a large-scale introduction of decentralized energy systems takes places. There is a common understanding that both local pollution, especially in urbanized areas (where over 60 per cent of world population is projected to live by 2030, based on the 2004 UN World Population Prospects medium variant), and the emissions of greenhouse gases need to be reduced. Natural gas is seen as the transition fuel par excellence, which leads to great optimism in the sector, significant investment in all segments of the gas chain, and an increasing market share of natural gas in primary energy supply.

3.2 Assumptions and rationale of the Transition Storyline

Assumption 1 **Future world production will be significantly lower.**

This storyline assumes that the world will face a serious risk in that supply of oil will be insufficient to meet demand. Due to oil reserve depletion, oil prices remain rather volatile and on average show a rising trend in real terms during the next few decades. This leads to serious worldwide demand-side responses and eventually a slowdown of the global economy. The high average oil price also explains why oil remains the largest internationally traded product, both in volume and value terms. Since the prices of other fuels remain broadly linked to the oil price, directly or indirectly, (abrupt) changes in the price of oil affect all energy prices and thus have wide-ranging ramifications for both oil-producing and importing countries. The latter may regularly be pushed into substantial economic slowdown due to surging and volatile oil prices. This would also adversely affect the considerable economic growth momentum of industrializing countries, which economic growth trends would slow down. The potentially powerful impact of oil price hikes on economic growth can be illustrated by the fact that some projections indicate that the 2004/05 oil price doubling has already slowed down global output in 2005 by about one percentage point.

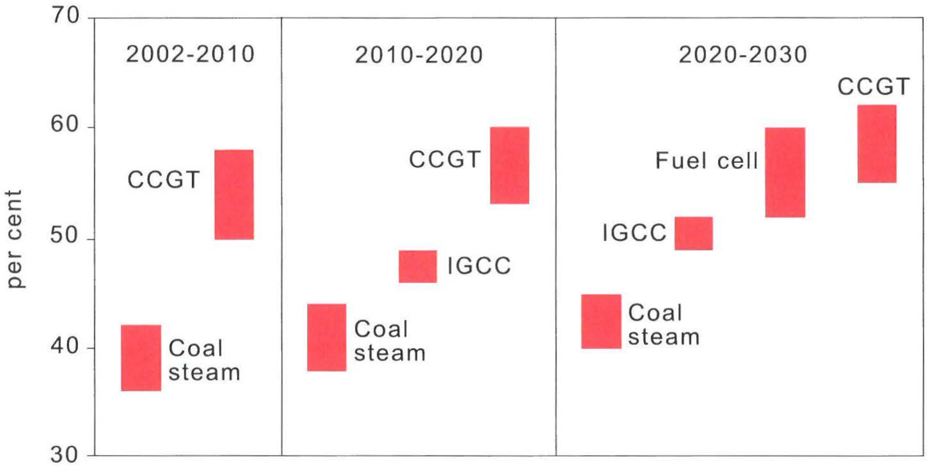
Next to the adverse impact of energy price hikes on economic growth, a more general lack of basic materials will increasingly manifest itself and slow down economic progress. Moreover, in this storyline, environmental problems, both globally (e.g. climate change, desertification, abundant fishing, erosion, deforestation) and locally (local air, water and soil pollution), give rise to major concerns a slower pace.

Assumption 2 **Energy efficiency rates will show a rising trend towards levels clearly beyond those seen in the past.**

In line with a trend of high and rising energy prices, the obvious advantages of energy efficiency improvements are increasingly being recognized and commercially applied on a worldwide scale. It is likely that a large number of breakthroughs in energy efficiency improvement will be reached. A few examples illustrate the impact of such improvements already in the short run: calculations show that replacing all light bulbs in the USA with the presently most efficient ones could already close 40 large coal-fired power plants and save the nation $10 billion a year. A similar calculation for the construction of new office buildings shows that the most energy-efficient constructions would save capacity equivalent to 85 power plants and two Alaska oil pipelines, at no increased cost (Sustainability Institute, 2005).

Tremendous scope for energy efficiency improvement exists as well within the electricity sector. Much progress has already been achieved in converting methane or liquid and solid carbonaceous materials into electricity and other energy carriers. The latest designs of CCGTs[5], for instance, can achieve efficiency levels of over 60 percent (Nakicenovic et al., 2000: 37). Furthermore, as this figure has been rising by over one percent per year for over a decade, it seems unlikely that it would slow down in the foreseeable future. Large-scale implementation of such highly efficient power production units would significantly increase energy efficiency worldwide. This process may be enhanced by the high gas prices projected in this storyline. Furthermore, the low capital costs and high availability of combined cycle turbines may also speed up their rapid introduction by power station operators. Figure 3.1 shows projections by the IEA of the 'business as usual' efficiency improvement potential of a number of technologies. It seems fair to assume that substantially higher energy prices combined with sizeable emission penalties will speed up the evolvement of energy efficiency and the implementation of CCGTs in the course of time.

Figure 3.1 Commercial availability and efficiency improvements of key technologies (2002-2030)



Source: IEA, 2004a: 205.

If such efficient power production capacity were introduced at a large scale worldwide, this would add to the growing importance of natural gas as a fuel in general, and as a fuel for power production in particular. After all, recent developments in energy efficiency of electricity generation capacity favor natural gas turbines and combined-cycle power plants as the technology of choice throughout the world because of their cost and environmental advantages and their very high efficiencies and modularity. In conjunction with the high hydrogen-to-carbon ratio of natural gas, high efficiencies lead to low emissions of all pollutants (see Figure 4.9, including CO2, while high modularity is compatible with the flexibility required in competitive, privatized energy markets. Combined-cycle technology is therefore seen as a hedge against the uncertainty about future environmental policy priorities.

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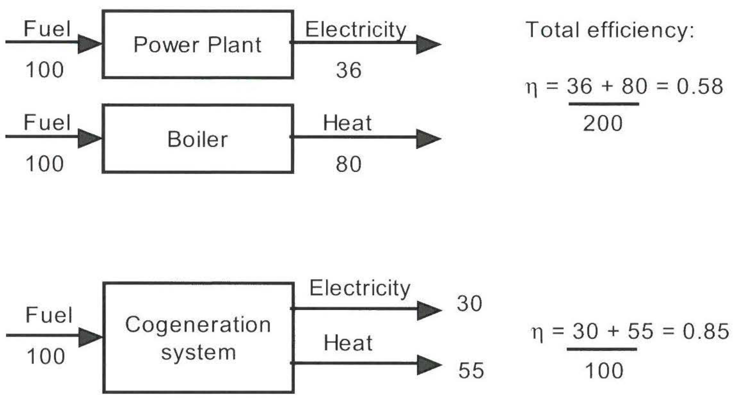
[5] A technology which combines gas turbines and steam turbines, connected to one or more electrical generators at the same plant. The gas turbine (usually fuelled by natural gas or oil) produces mecahnical power, which drives the generator, and heat in the form of hot exhaust gases. These gases are fed to a boiler, where steam is raised at pressure to drive a conventional steam turbine, which is also connected to an electrical generator. This has the effect of producing additional electricity from the same fuel compared to an open cycle turbine.

An increasing share of decentralized energy (DE) systems in the production of power and heat spurs energy efficiency improvements as well. Figure 3.2 illustrates the scope for efficiency improvements through cogeneration strategies. Future market prospects all around the world critically depend on the removal of electricity market regulatory barriers and long-standing incentives/subsidies for central generation. This storyline assumes considerably stronger incentives for DE systems than nowadays in many regions (for incentives, see also Table 3.4 on countries' cogeneration strategies).

Figure 3.2 Efficiency rates of separate and cogenerated production of electricity and heat
Separate production of electricity and heat Cogeneration



Source: WADE, 2003.

For a more thorough overview of cogeneration and its implications for the gas industry see assumption 3.6 and 3.9.

Assumption 3 **Awareness of climate change risks increases, based on an increasing number of climate change disasters; abrupt climate change is no longer ruled out. So, in the course of time, the 550 ppmv stabilization target is no longer considered acceptable. Instead, the target is to stabilize at lower levels to prevent temperatures from rising by more than 2°C above pre-industrial levels.**

The past few decades have shown that awareness of and action on big environmental issues, such as climate change or ozone layer depletion, can develop rapidly. During approximately one generation time, roughly the period 1985-2005, the world community, based on information from the research community, notably IPCC, not only became convinced that climate change poses a serious threat to mankind, partly due to the effect of anthropogenic greenhouse gas (GHG) emissions, but also established a widely accepted international climate change policy regime (the 1992 UNFCCC/ 1997 Kyoto Protocol (KP)/ 2001 Marrakech Agreement) based on an absolute ceiling of GHG emissions for at least the committed industrialized world. The Kyoto Protocol entered into force on 16 February 2005 after it was ratified by the Russian Federation in 2004. The committed Parties will have to take new climate policy initiatives in order to comply. It is well conceivable that the next few decades will show a similarly strong development, in which the first steps of the present will turn fairly quickly into a much stricter regime with a broader coverage and more active participation.

There is a common understanding that the Kyoto Protocol regime is only a small first step in the direction of a decades-long tradition of a clear, well-focused and increasingly stricter regime that successfully deals with the problem. This perception and sense of direction may be supported by popular action based on private and/or voluntary initiatives (for an example see Box 3.1) and will be helpful in further shaping an international climate policy framework. In fact, governments have already developed, or are in the process of devising, long-term strategies to limit GHG emissions even after 2012.

Box 3.1 Green Goal concept

This year's soccer World Cup in Germany is aiming to be the first-ever climate neutral event of its kind. Although the FIFA World Cup is expected to generate additional GHG emissions of around 100,000 metric tons CO_2-eq., 80,000 of which are accountable to the transportation of the estimated 3 million spectators, emissions are to be balanced by investing in climate protection schemes in other parts of the world. A call for projects has been issued in October 2005 for 60.000 so-called 'Gold Standard' Certified Emission Reductions (CERs).The organizing committee is reviewing possible projects particularly originating from South Africa; host of the 2010 World Cup.

Such initiatives are a.o. encouraged by recent scientific insights countering criticism on Michael Mann's hockeystick shaped figure representing the warming up of the earth from a historical perspective (1000-2000). Now, instead of four studies as conveyed in the 2001 IPCC report, twelve independent climate reconstructions are available all showing the anomalous temperature development of the 20th century. At a session convened by the UN Commission on Sustainable Development (May 2006), the Chair of the IPCC – Mr. Pachauri – emphasized that the earth's atmosphere can heat up from 1.4-5.8°C by the end of this century. Moreover, sea levels can rise from 9 to as much as 88 cm over the same period and the frequency, intensity and location of extreme weather events is expected to change. The last two years were illustrative with respect hereto.

This storyline also assumes that the USA will become seriously involved in the international climate policy framework, thereby accepting the need for strict targets. First, actual disasters with a perceived link to climate change may add to the public understanding and acceptance of the need for determined action; recent examples are hurricanes in Florida and extreme precipitation in California, most likely to be followed by additional disasters (droughts, storms, forest fires, erosion, floods, etc.) in the foreseeable future. Publications such as the Millennium Ecosystem Assessment (2005) may further raise the public's concerns that without serious climate policy action, things can go seriously wrong for future generations. Second, US awareness of the need for climate policy action is already growing, illustrated by the large number of concrete initiatives taken at state and local level. To mention just a few recent ones: 192 American mayors (representing 40 m Americans) have promised to comply with eventual requirements under the Kyoto Protocol in 2005 through a so-called 'Climate Protection Agreement' and are actually pressing to go beyond the federal government's efforts in addressing global climate change; California and New Mexico, among other states, have set ambitious state-level emission reduction targets; in 2005 New York is to introduce the same legislation on GHGs from vehicles as California did in 2002 (see Box 3.8); moreover, a so-called Regional Greenhouse Gas Initiative (RGGI) is in the process of development planning a regional emissions trading scheme covering seven north-eastern states in the US; [6] the Chicago Climate Exchange (CCX, a private initiative serving the voluntary market for emission allowances) has announced that it will extend and expand the program for an additional four years, from 2007 through 2010, etc.

In this storyline there is also a rapidly growing awareness that the most serious climate change risks are probably related to the chances of abrupt climate change (ACC). Public and policy makers' attention for the issue have thus far remained limited (e.g. the movie 'The Day after Tomorrow'). This could, however, quickly change, even quicker than the fear for a rapid depletion of the ozone layer during the 1980s. As far as the risk of ACC is concerned, recent scientific insights suggest that there is a risk of reversion to the potentially catastrophic unstable regime of intermittent ACC, comparable to what preceded climate stabilization about 12,000 years ago. While the drivers and thresholds are not yet fully understood, it is clear that non-linearities, e.g. triggered by oceanic warming, may cause large changes in temperature and precipitation in just a few decades. Such processes may be related to a shutdown of the thermohaline circulation (the 'Gulf Stream'), which, once activated, may turn out to be irreversible. The possible implications of such developments can be so far-reaching that also in the policy arena there will be an increasing perception that a rapid development towards much lower, or even zero-emission energy systems should be initiated within a few decades.

Assumption 4 **A global climate change policy regime is accepted worldwide.**

First, one of the lessons learned from designing the KP regime has been that rigidities in the system, such as the use of absolute ceilings and only nationally assigned amounts as yardstick for compliance, may be counterproductive in trying to deal with the free-rider problem. This storyline assumes that developing countries start to accept some weak commitments because of the introduction of more flexibility in the KP regime targets and ways of achieving those. This will trigger the US and some other countries (such as Australia) that have not ratified the KP, to join the global coalition. The Vision Statement for an Asia-Pacific Partnership on Clean Development, issued in July 2005 by its initiators: Australia, China, India, Japan, South Korea and the US, may be a precursor of a broader acceptance of worldwide climate policy action.

Second, another reason why support for climate policy action may gradually grow to worldwide acceptance is that one of the main approaches to raise or even optimize the cost-effectiveness of climate policy action, the possibility of international trading of GHG emission reductions or carbon sequestration action - an option typically propagated by the US administration during the Kyoto negotiations - not only seems to have been broadly accepted, but also increasingly implemented worldwide. All kinds of frictions and problems associated with the introduction of such trading schemes are presently being dealt with, which makes further introduction

6 Participating states are: Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont. Legislation signed in April 2006, requires Maryland to become a full participant in the process by June 30, 2007. In addition, the District of Columbia , Massachusetts, Pennsylvania, Rhode Island, the Eastern Canadian Provinces, and New Brunswick are observers in the process.

and wider application probably much easier. This may add to a further acceptance in the future of climate policy initiatives, because under the assumption of large-scale international trading, the overall mitigation costs will, according to IPCC (2001c), be anywhere between 25-75 per cent lower than without trading.

Emissions trading is already a serious business indeed, especially with the coming into effect of the largest scheme worldwide so far, the EU Emissions Trading Scheme (EU ETS) as of January 2005, which includes nearly 11,500 installations throughout the EU and covers about 45 per cent of total EU GHG emissions. Under the scheme, countries are committed to translate mitigation targets into allocations to individual installations on an annual basis. Over 2005 an estimated 362 million tCO_2 has been traded at a financial value of €7.2 billion (Point Carbon, 2006a). Although prices have halved to about €14 per tCO_2 after publication of a number of countries' verified emission reports at the end of April/beginning of May 2006, showing the still immature stage of the European credit market, the market is expected to become more liquid and mature as one approaches the KP commitment period. The trading scheme may well become tighter as allocations will be less lenient with a likely future tightening of allowance allocations for the second commitment period. Compliance is enforced by fines ranging from €40/tCO_2 during the first commitment period (2005-2007) to €100/tCO_2 applicable during the second commitment period (a period which coincides with the 2008-12 KP commitment period). These fines have to be paid per excess tCO_2 over and above compliance. Some advocate that the EU ETS could in time be linked with schemes in other regions, most likely based on credit conversion schemes or mutual recognition, but this is still uncertain. At the moment, different trading systems co-exist. Future projections point at an ever-increasing trend of various forms of emissions trading reaching some €40 billion in 2010 according to some sources.

Project-based emissions trading, particularly through the KP Clean Development Mechanism (CDM) that allows countries with an emissions limitation or reduction commitment under the KP to set up GHG reduction projects in non-Annex I countries (or developing countries), truly took off as well in 2005. The so-called CDM project pipeline [7] contains as of May 2006 some 740 projects that may abate about 1 billion CO_2-eq. Considering the fact that Annex I countries to the KP need to abate at least 3000 Mt of CO_2-eq. over the first commitment period, the market seems well on its way to accommodate here for. Out of these 740 projects, 172 are already registered with the CDM EB.[8] Those registered projects are projected to abate about 340 Mt CO_2-eq. up to the end of 2012.

Third, it seems likely that one will gradually accept more effective means to deal with the free-rider problem of international environmental treaty initiatives, such as international climate policy regimes. This could imply that trade policy measures are increasingly accepted as a way to discipline such free riders in broadly accepted multilateral environmental agreements. If effective, such agreements eventually could practically have a global coverage, e.g. obliging all countries to accept commitments at the risk of facing trade sanctions. In the so-called 1998 shrimp-turtle WTO case, a first step was taken: the WTO Appellate Body overruled the WTO Panel's view by implicitly indicating that it does not categorically disallow using extra-jurisdictional processes and production methods (PPMs) as an argument in WTO-appeals. Although the ruling did not refer to important questions, which could be relevant to the interaction between WTO and UNFCCC/KP, several analysts suggest that it would imply that PPMs no longer violate the WTO by their very nature. This could open the door to anti free-riding measures based on GHG emissions from production.

Finally, although cautiously avoiding any reference towards the option of commitments under a post-Kyoto regime, high-growth developing countries in Asia are seriously reconsidering their development strategies. Increasingly, environmentally sustainable economic growth or 'green growth' is promoted as illustrated by the interest of countries like India, China and South Korea to participate in the Asia-Pacific Partnership on Clean Development as referred to above. This may mark first steps in the process to embark on multilateral environmental treaties based on true commitments.

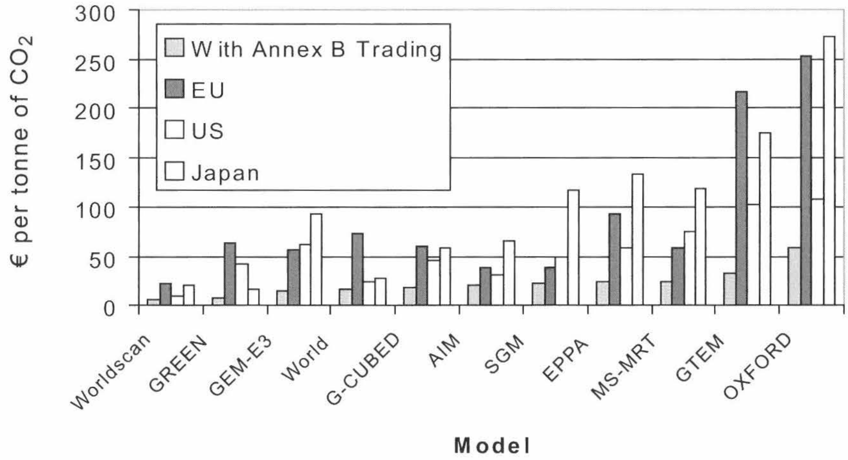
Assumption 5 **The prices of carbon credits (per tCO_2-eq.) or equivalent mitigation incentives increase rapidly.**

A large number of model simulations have been carried out preceding the start of actual emissions trading under the Kyoto Protocol and other trading schemes (e.g. SO_2-based) in order to try to project the most likely future credit prices. Although all studies clearly indicate that projections are rather sensitive to trading conditions (e.g., allocations, trade restrictions, compliance regimes, country coverage, etc.), most model projections with regard to the KP regime suggested credit prices substantially higher than those seen in the real market so far (< €10/tCO_2 for non-Gold standard JI and CDM-based credits at least until 2006): most simulations projected prices to range between €10 and €30 per tCO_2 for a full trading regime, and much higher if only regional trading were possible (see Figure 3.3).

[7] The CDM project pipeline is defined on the basis of projects under validation by a Designated Operation Entity (DOE).
[8] As of the beginning of May, 2006.

This raises the question why the simulations have been so wrong so far. One explanation may well be that in fact the Kyoto mechanisms are still under development, so that a clear perspective on the modalities that need to be satisfied for formal acceptance of credits is still lacking. The operationalization of the CDM, for instance, was particularly delayed partly because of the sudden introduction of a project additionality test and only slowly developing acceptance of the required baseline methodologies. The future looks, however, bright as a sudden massive 'outbreak' of accepted and approved CDM-projects was seen at the end of 2005 and 2006. As far as JI is concerned, credits will only be accepted for mitigation after 2008, so that also a full-blown JI credit market has not yet come to existence either. Here also progress could be unexpectedly fast, however, with the installation of the JI Supervisory Committee (JI SC). Finally, in the absence of any clear sign as to how the expected major suppliers of assigned amount units (AAUs), Russia and Ukraine, will behave on the credit market, it is also unclear how such behavior would affect credit prices. So, by the beginning of 2006, the Kyoto Protocol flexibility mechanisms can be perceived of as still being in an embryonic stage of implementation, which may explain why perceived credit risks are still (very) high and KP credit prices therefore low. Things can, however, change rapidly.

Figure 3.3 Estimated prices per metric ton of CO2 based on different models



Source: OECD (1998); Capros (1999).

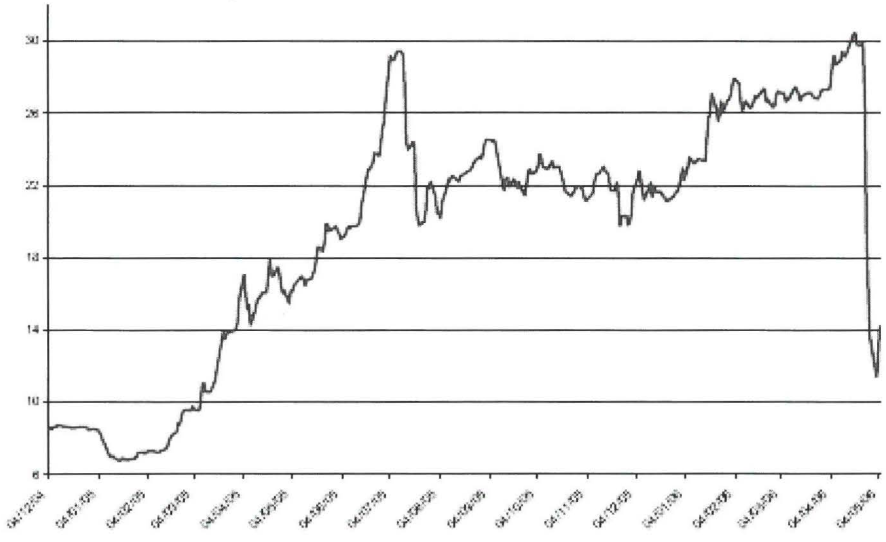
The EU ETS could probably deliver better information about how credit prices can surge, (although it must be realized that credits are generally scheme-specific units that cannot easily be exchanged between schemes). Bearing that in mind, Figure 3.4 illustrates the price development of the credits in the EU ETS, being the largest allowance market worldwide,[9] partly based on forward trading in an emerging market. Because, based on an EC directive, the Kyoto credit market is linked (at least under specific but not very strict restrictions per individual installation) to the EU ETS allowances market, prices on both markets should, in theory, tend to converge. The fact that this has not yet happened by the beginning of 2006, is another illustration of the still immature status of the KP credit markets in which even the software to link the KP flexibility mechanisms with the EU ETS credit market has not yet been fully developed. [10]

The Figure illustrates that the EU ETS allowance prices have fluctuated heavily since the market started. This was a.o. caused by the launching of National Allocation Plans (NAPs) by EU member states during this period, which were submitted for approval to the European Commission. The information about the individual NAPs turned out to have a strong impact on the credit market prices. The experiences so far have shown that small changes in individual NAPs could already trigger a fairly strong market response. This experience supports the theory which suggests that with marginal cost functions of virtually all abatement technologies rising with their scale of application, and with fairly low average energy demand elasticities, credit prices may rise fairly soon as the climate policy regime increasingly becomes stricter. In July 2005 a historically high price level of almost €30,- per metric ton of CO_2 was reached. With more national registries online and a still increasing supply from industries with excess allowances (e.g. the cement and steel industry), pressure on the system may temporarily be somewhat reduced, but the overall price hike has nevertheless been impressive, with further hikes probably not unlikely. Moreover, a ceiling of €40/tCO_2 based on a penalty-fee level only applies until 2008. After 2008, a penalty fee of €100 per tCO_2 will apply, so that allowance prices could then also technically increase beyond €40 levels.

9 There are five active markets for GHG allowances as of May 2006: the EU ETS, the UK Emissions Trading system, the Norway emissions trading system, the New South Wales trading system and the Chicago Climate Exchange (CCX); a private initiative serving the voluntary market for emission allowances between firms.

10 However, now that prices on the EU ETS collapsed and more than halved at the end of April 2006, prices may have started a conversion process.

Figure 3.4 EUA 2006 prices



Source: Point Carbon, 2005c.

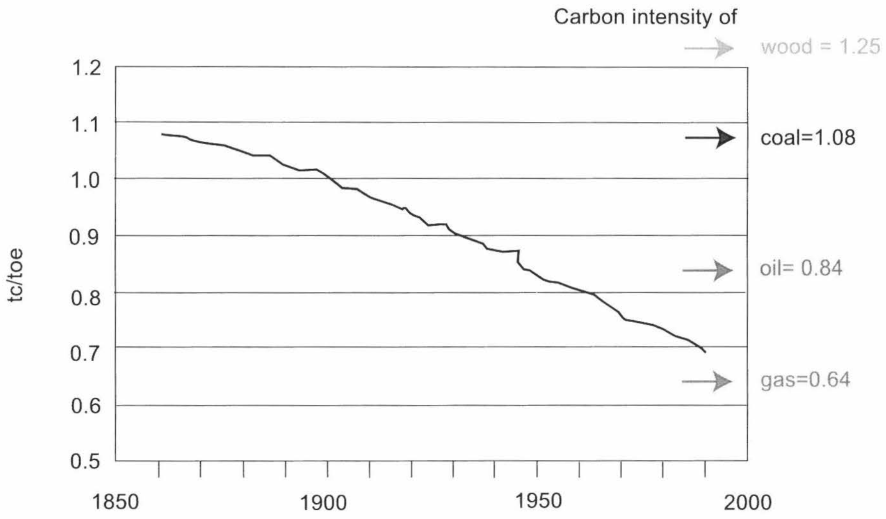
Assumption 6 The energy sector is convinced that, although some applications of natural gas will be replaced by renewables, this development will be overshadowed by the increasing role of natural gas due to a fuel switch (i.e. substitution among fossil fuels towards natural gas). The resulting increase of the market share of natural gas in energy consumption triggers self-confidence, investment and innovation in the sector, which smoothens the potential of the sector to adjust to new market circumstances and policy regimes.

Some observers notice that compared to the oil sector, the gas sector still shows some lack of self-confidence about its potential role in a future world. This may date back to the times in which gas was primarily seen as a by-product of oil production, or to quote Vivienne Cox, Chief Executive (Gas, Power & Renewables) of BP "...we appear to be somewhat 'behind the curve' on gas supply in competition with other fuels...despite its apparent maturity, this industry is really barely out of its teenage years compared to oil." Indeed, most experts expect natural gas to gain an expanding share of domestic energy production at least through 2020 (e.g., IEA, 2004a; McGarvey, 2002).

In addition, in line with the expectation that there will be serious post-Kyoto initiatives with worldwide coverage, a wide variety of further and/or more far reaching policies and measures can be expected to be introduced or reinforced, most of which will have in common a direct or indirect introduction or increase of levies on the use of fossil energy and/or GHG emissions. Insofar as CO_2 emissions will be confronted with higher charges, one may expect a change in the fuel mix based on substitution. Assuming that substitution among fossil fuels will dominate substitution between fossil fuels and non-fossil-based primary energy, the role of gas as a source of energy will be supported, as its associated emissions (in tC/toe) are less (0.64) than those of oil (0.84), coal (1.08), or timber (1.25). This would strongly support the ongoing long-term decarbonization trend of the last 150 years (see Figure 3.5).

11 The graph shows weekly bid-offer close EUA 2005 and 2006 prices from July 2003 in the over-the-counter (OTC) market (see www.pointcarbon.com for the OTC methodology).

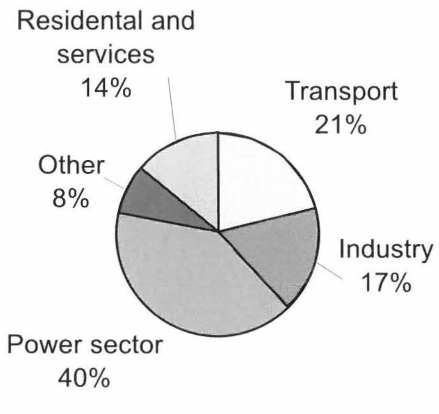
Figure 3.5 Global decarbonization of energy, historical development from 1860 to 1990, as a ratio of carbon to primary energy (tC/M).



Source: Nakicenovic, 1996.

An assessment of the future role of natural gas in a fuel switch-based storyline will probably gain substantially from a sector-specific approach, since the scope and potential for fuel switch differs from sector to sector. Figure 3.6 clearly illustrates that over 60 per cent of all energy-related CO_2-emissions can be attributed to the power and transport sector. An analysis of the possible scope for fuel switch in these two sectors can thus be vital. The potential role of gas in the transport sector will be discussed under assumption 3.12. Below, some issues with regard to the power sector will be raised.

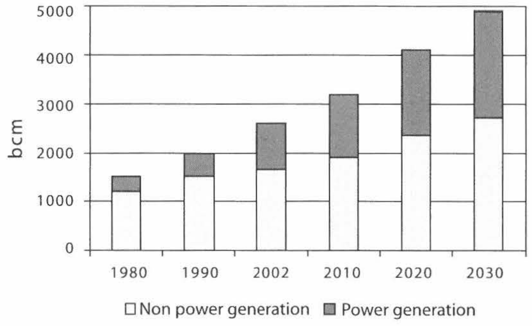
Figure 3.6 Energy related CO_2 emissions, 2002 (million tonnes)



Source: IEA, 2004a.

There are a number of reasons why it seems sensible to assume a substantially more significant role of natural gas in power generation: gas to power, as also projected by IEA (2004; see Figure 3.7).

Figure 3.7 World natural gas demand (in power generation)



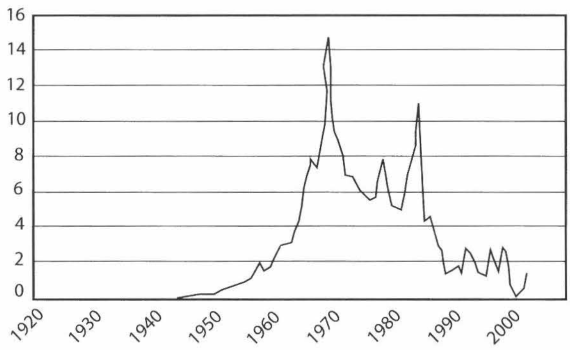
Source: IEA, 2004.

First, as mentioned above, CCGTs reach efficiency levels that are superior to virtually all other power generation technologies. Moreover, such efficiencies are projected to rise even further (see Figure 3.1), which makes a wider CCGT application an attractive option for many power producers, raising demand for natural gas.

Second, climate change policy regimes will also support the use of natural gas for power production where it can replace oil and particularly coal. An example of this is the EU where a CO_2 emissions trading scheme is operational since January 2005. A number of calculations have tried to estimate the commercial feasibility of switching from oil/coal to natural gas, depending on allowance prices. Obviously, there is no single, unique shift level; shifts will occur at different levels depending on all parameters involved, such as, next to allowance prices: efficiencies of the actual power stations and gas, and prices of oil and coal. Assuming a 53 per cent plant efficiency and prices of around 27p/therm for gas and $66/tonne for coal (actual levels by mid-March 2005), the allowance price level at which a switch from coal to gas becomes beneficial has been calculated at €11/tCO_2 (Point Carbon, 2005a). It should be mentioned in this regard that such efficiency levels are not (yet) representative for the gas plant arsenal within the EU. This explains why another source suggests that: "...only an EUA price of €16/tCO_2 or more would induce a switch from oil to gas in continental power generation..." (Point Carbon, 2005b). Whatever the calculated price levels, 2005-early 2006 allowance prices have consistently surpassed the higher €16 per tCO_2, level (see Figure 3.4), at which gas is an economically more attractive fuel. This reinforces the projected growth of gas to power.

An important additional factor for actual fuel switch in power production is, next to the development in time of new power generating capacity, including gas-fired cogeneration capacity, how plant-building activity will develop in the course of time, given the expiration of lifetimes of existing plants. According the the IEA, in Europe alone around 700 GW of electricity generation (equivalent to the currently installed capacity and of which 50 per cent constitutes the replacement of old plants) needs to be installed by 2030. For example, more than half of all operating coal-fired power plants in the EU are older than 20 years (see Figure 3.8); assuming an approximately thirty-year lifetime, a large number of such power plants will have to be replaced within the next 5-10 years. The scope for switching to gas-fuelled power production in the foreseeable future is therefore substantial (as graphically illustrated in Figure 3.7), which may further boost the future demand for gas to power generation.

Figure 3.8 European Coal Fired Power Plant building activity (1920-2000)



Source: UDI, 2003.

Another advantage of natural gas for power production is its flexibility in use, which may explain why some authorities show an increasing interest in natural gas for power production to meet sudden shortages of power supply. Box 3.2 gives some recent examples from Asia introduction of renewable energy would further increase, there could be stronger and more broadly applicable incentives, as compared to the present situation. Also, several countries (both developing and developed) have explicitly adopted renewable energy promotion policies and/or targets in terms of the market share of renewables in energy production, either in general, or for particular sectors (e.g., transport or power production) (see Table 3.3 for an overview). Such targets could also become more widespread and based on higher ambition levels in a world that is strongly in favor of an energy transition. For example, China's Renewable Energy Law adopted in February 2005, required renewables to supply 10 per cent of total energy supply by 2020. In November of that same year, this figure was already adjusted upwards to 15 per cent.

Table 3.3 Renewable Strategies

	Directive/Policy	Target*	Means
EU	Electricity Directive 2001/77/EC	12% by 2010 (share of biofuels: 5.75%)	Member States are responsible for the further implementation.[13] Fuel tax exemptions; biofuels obligations; promotional tariffs for RES and other promotional campaigns; feed-in tariffs; etc.
	Biofuels Directive 2003/30/EC of 8 May 2003	21% of electricity production by 2010	Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity
USA	Clean Air Act Amendments (CAAA, 1990)	Share of alternative fuels consumed by light duty vehicles in 2010: 30%	Tax deductions (investment tax credits/production tax credits/excise tax exemptions)
	Energy Policy Act (EPACT, 1992)	Tripling of the use of bioenergy and bioproducts in 2010, compared to 1999 (coming into effects of the law)	R&D Mandatory targets Promotional campaigns / public awareness campaigns
	Increased use of Bioenergy (executive order 13134)		Guaranteed prices (feed-in tariffs at state level)
	Climate Change Action Plan (CCAP)		Voluntary programs
Japan	New Energy Indicator	3% (excl. hydroelectric and geothermal energy)	Renawable portfolio standards, capital subsidies, grants/rebates, tradable renewable energy certificates, net metering, R&D
China (see as well Box 3.4)	Renewable Energy Law (adopted February 2005; to be effective from January 2006)	10% of electricity production by 2010** 15% of primary energy by 2020	Renewable energy development fund Low interest loans Special tax treatment Mandatory purchase regime (feed-in tariffs)
India	2003 Electricity Act Planning/indicative target; not backed by specific legislation	10% of added electric power capacity during 2003-2012 (expected 10 GW)	Feed-in tariffs (state level) Capital subsidies, grants/rebates, tax credits/reductions

* Unless otherwise indicated as percentage of total primary energy.

** Excluding large hydropower.

Note: This enumeration is not exhaustive; rather it provides an illustration of some of the most proclaimed commitments, showing current interest in the further development and application of renewables.

Source: EC, 1997; IEA Global Renewable Energy Policies and Measures Database [accessed 17 November 2005]; Martinot, 2005.

13 Under current conditions in EU Member States, targets are unlikely to be met. The 2% market share of biofuels in 2005 was, for example, not achieved.

Besides policy targets, other policies and measures are increasingly embraced. By 2005, at least 32 countries and 5 states/provinces had adopted feed-in policies, more than half of which have been enacted since 2002 (Martinot, 2005: 4). Although their effectiveness has to be proven over a longer time frame, feed-in tariffs did increase interest among the business community and spurred investments accordingly. In Germany, having implemented feed-in policies in 1990, power from eligible forms of renewable generation more than doubled between 2000 and 2004. Other policies and measures include 'renewable portfolio standards' (RPS), tax incentives and credits for renewable energy. Adoption of the former shows a country's commitment towards renewables for energy production as these are legal mandates. Sweden, for example, sets penalties for non-compliance at 150 per cent of the average certificate price of the prior period (Martinot, 2005: 23).

Although some initiatives try to generically promote the further development of renewables, such as the 'Bonn Action [14] Programme' and a yet to be established 'Global Renewable Energy Fund of Funds',[15] most of the initiatives taken are country-specific. This is why some of the information in the illustrative boxes below concerning a few of such initiatives has been broadly summarized for a number of individual countries.

Box 3.3 China's law on renewables

China is expected by some to become leading in renewable energy having passed the first Renewable Energy Law in February 2005. The Law, effective as of January 2006, guarantees grid access for renewable energy producers as well as spreading the costs of new technologies across the sector. Moreover, the law offers financial incentives, such as a national fund to foster renewable energy development, and discounted lending and tax preferences for renewable energy projects, thus substantially improving the conditions for renewables to be considered from a commercial point of view. Being the world's second largest emitter of CO_2 without binding obligations under the Kyoto Protocol, this law provides a positive signal. The projected potential of renewables is enormous; even without the new law, the market for wind energy in China grew by 35%. Enactment of the law is a signal of China's commitment to cleaner air and energy security. Thus, it helps the country meet its ambitious targets for the uptake of renewable energy; culminating in a desired 15 per cent share by the year 2020, compared to a mere 3 per cent in 2003. According to the law, renewable energy includes hydroelectricity, wind power, solar energy, geothermal energy and marine energy, all of which should be taken into consideration in state and local development plans. Fulfillment is ensured through the inclusion of specific penalties for non-compliance with the law.

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[14] Adopted at the 2004 Renewables conference in Bonn, Germany, by 170 countries. Its goal is to add 163 GW of renewable electricity capacity (compared to today's total of 160 GW, excluding large hydro), wich requires total investments of $326 billion.

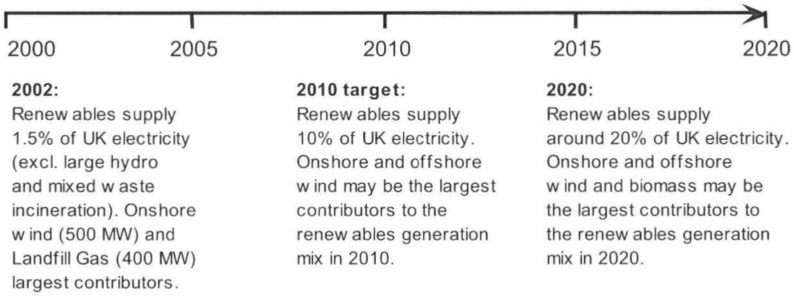
[15] The EU, together with the Johannesburg Renewable Energy Coalition (JREC) pledged approximalety €75 million for the establishment of such a fund.

Box 3.4 The UK's energy future

In its white paper on energy "Our Energy Future – Creating a Low Carbon Economy" (2003), the UK government expresses the need for new domestic energy policy in light of changes observed. These include climate change, reduced domestic energy resources, and the need to update or replace much of the energy infrastructure. Four goals have been established to enable the UK to meet these challenges:

- Reducing CO_2 emissions with 60% from current levels by about 2050;
- Maintenance of reliability of energy supply;
- Promotion of competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve productivity; and
- Adequate and affordable heating of every home.

In order to reach the targets set, the UK prefers to create a market framework, reinforced by long-term policy measures, which will give investors, business and consumers the right incentives to find the balance (and thus the fuel mix) that will most effectively meet the overall goals. Also, diversification of energy needs is considered important to secure energy reliability. Furthermore, the UK energy policy will be based on energy efficiency and renewables (see Figure below) and does not make any commitments to nuclear power. However, the possibility that at some point in the future new nuclear plants might be necessary to meet the carbon targets set is not ruled out and in fact has become a reality by 2005.



Source: DTI, 2003.

With respect to coal-fired generation it is stated that this will have an important part to play in widening the diversity of the energy mix, provided ways can be found to reduce its carbon emissions. Although the UK seems committed to reducing GHG emissions unilaterally, it emphasizes the need for an international approach, as it contributes about 2% of total world CO_2 emissions.

Box 3.5 Czech Republic renewables act

The Czech parliament has passed a renewables act in the end of March 2005, supporting the production of electricity from renewable energy sources. The Renewables Act will ensure an 8 per cent share of renewable energy in the Czech Republic's gross domestic electricity consumption by 2010, a target agreed on with the European Commission upon accession to the EU. In the short run (up to 2010), new investment in renewable capacity is expected to exceed €1.5 billion, while saving approximately 4 Mt CO_2-eq. annually. In order to provide a sound investment climate, a 15-year guarantee of solid feed-in tariffs is provided. Besides, producers are presented with the option of switching to the so-called 'green boni' support system, where a bonus will be paid for green power on top of the market-sold electricity.

Assumption 8 **Fossil fuel use based on coal and oil levels off because of: carbon emissions, insufficient technological breakthroughs (including CO_2 capture and storage remaining too costly and perceived as unsustainable) and, as far as oil is concerned, insufficiently reliable access and relative prices. The nuclear option remains to be viewed as risky in most countries although its market share will slightly increase.**

The combination of high energy and carbon credits prices (or high carbon emission penalties), which characterizes this storyline, promotes fuel switching (for an extensive discussion, see also assumption 3.5). This will probably be the most important driver behind reducing the share of coal and oil in favor of natural gas.

Second, a powerful impact may come from an active policy engagement to phase out traditional subsidies on the use of coal and to create disincentives instead. In fact, a significant number of countries have already ruled out, or have at least significantly reduced domestic power production based on coal, unless it uses CCS, because of concerns about CO_2 emissions, acidification and local air pollution. Japan, to just give an example, introduced changes to its energy tax regime in 2003, which included a tax on coal consumption. Other countries have already announced similar plans for the near future

Unlike storyline 3 (chapter 5), this storyline assumes that CCS will not develop into a widely accepted technology to introduce clean fossil energy systems. First, capture, transport, and storage costs are too high to make a large-scale introduction feasible. Second as the scope for considerable cost reductions in the CCS chain is limited, such costs will also remain too high to enable a feasible implementation even in the next few decades. The explanation for this is that much of the CCS technology has already been developed, so that the impact of learning on cost reduction remains limited. As most of the cost estimates for CCS, if applicable at all given the preferred nearby presence of storage capacity, suggest costs to amount to at least € 50-100/tCO_2 for most applications, even tight post-Kyoto regimes may fail to successfully activate the CCS option. If governments instead favor the support of renewables, a broad support for CCS does not seem obvious, at least not in most countries where serious exploration of coal is absent.

A separate factor that may slow down the development of CCS activities is the perception that the option is not safe and environmentally unfriendly. This may feed the general public's resistance against accepting CCS in nearby storage facilities, which makes it increasingly difficult to set up CCS projects, especially in densely populated areas. Acute, accidental releases of CO_2 at the well-head, together with leakage through failed cap-rocks seem to be the main hazards to be dealt with. Indeed, elevated atmospheric concentrations of CO_2 can result in both acute and chronic health effects in case meteorological conditions do not disperse CO_2 released to the atmosphere. Then, high concentrations (at approx. 10 per cent) if released in sufficient quantities under particular conditions will lead to suffocation of humans due to a lack of oxygen (asphyxiation). An example is provided by the 1986 Lake Nyos disaster in Cameroon. A large limnic eruption resulted in the death of approximately 1,800 people in the surrounding area and up to 27 km away (CO_2 FEP Database, 2004). Water acidification and degradation of marine ecosystems as a consequence of leakage into fresh groundwater and into deep oceans, respectively, are other sources for concern (for a comprehensive assessment of risks associated with the option of carbon sequestration and storage see the CO_2 FEP Database, 2004).

In this storyline, the nuclear option does not come off the ground either. Besides being considered risky, based on life-cycle analysis, the public at large and policy makers increasingly realize that if all aspects throughout the energy chain are considered carefully, the nuclear option will not be able to provide the GHG-neutral option that proponents claim it to be. In fact, calculations suggest that each dollar invested in energy efficiency displaces approximately seven times as many GHG emissions than if it were invested in nuclear power.
In addition, nuclear power's potential to combat global warming is considered limited because it only provides electricity, which accounts for just one-third of fossil-fuel use. Moreover, fossil fuel use accounts for only about half of the GHG problem (the rest of the problem is caused by deforestation and non-CO_2 GHGs).

The most important factor that may prevent a further rapid development of nuclear power production is probably the public's perception of nuclear energy being dangerous. For instance, an opinion survey on energy revealed that nuclear safety is the predominant concern in Europe and thus is still not considered by most Europeans an option to be included in the future energy mix (EORG, 2002). Indeed, nuclear sources involve a risk of radioactive releases in case of an accident. In December 2005, an explosion at a Russian nuclear plant affirms such views, even though it was communicated that no increased radiation was measured. At the same time, highly radioactive wastes are accumulating, for which no generally acceptable disposal route has yet been established (EEA, 2003; NEA/OECD, 2000). Similar concerns exist worldwide, e.g. throughout 2003 the Tokyo, Tohoku and Chubu electricity companies temporarily shut down much of their nuclear electricity generation capacity for safety inspections in order to reduce community concerns over the safety of nuclear power in Japan (Hester et al., 2004).

Brazil) were maintained until 2025[19], additional biomass supply should, depending on the scenario, range from 60 to 145 EJ (2050: between 95-220 EJ). Estimates indicate that in order to achieve some intermediate position by 2025 (about 150 EJ additional supply), an additional land area of about 150 million ha. Would be required for that purpose. Although such an area is large, its availability does not seem to pose a problem that cannot be overcome, especially when some developing countries can gain a substantial welfare increase from commercial energy crop production, which may allow them to increasingly import food products from other countries, including those in the northern hemisphere.

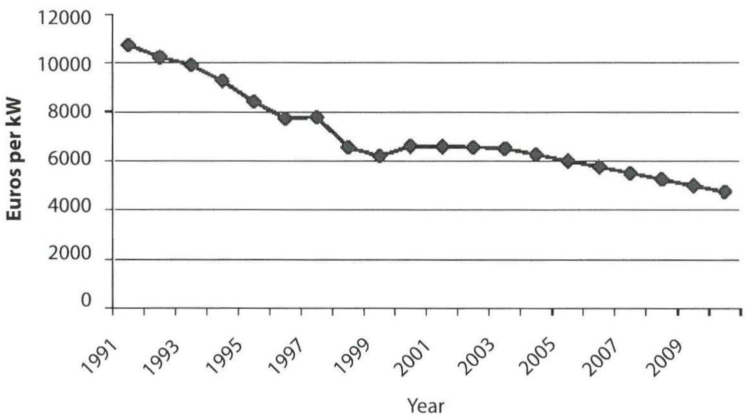
Box 3.6 The Brazilian biofuel program

Its increasing dependency on fossil fuels originally triggered the Brazilian Government to support the use of bio-ethanol for transportation in the 1970s, when oil prices were high and sugar prices low. Now, bio-ethanol is used on a large scale within Brazil's transportation system and supported through its ProAlcool program. In 2004, there were more than 300 sugar mills/distilleries producing ethanol and 39 new distillers were licensed in early 2005 making Brazil a major ethanol exporter. In that very same year, Brazil's first refinery for biodiesel was opened, scheduled to produce 12 m liters (3.2 m gallons) annually. Biodiesel from this plant will be mixed with diesel at a 2 per cent ratio only to make technological adaptation of engines not necessary. Moreover, it is hoped that bio-fuel production can benefit the country's farmers. Dependent on the methods applied, the sector is estimated to be responsible for job creation in the range of 400,000-700,000. Based on life-cycle analysis, the abatement impact of the Brazilian bio-fuel production sector is estimated at about 20 per cent of the CO_2 emissions of its petroleum industry (Negrão and Urban, 2004).
Because prices of biodiesel still surpass those of diesel, incentives correcting for the externalities are necessary to support its use. In fact, in Brazil the use of biodiesel may become mandatory by the end of 2007. Byproducts of the process may be responsible for the further decrease of production costs, thus attracting additional interest from the industry.

Assumption 11 Solar energy becomes increasingly popular.

Photovoltaic (PV) cells directly convert the light from the sun into electricity and represent an ideal form of decentralized power generation (see assumption 3.9 and 6.5). Up to now, the high cost of PV cells is the main barrier preventing its widespread application although costs have fallen 15 to 20-fold in less than 30 years time and panels are now available at between € 4,500 and 6,000/kW (see Figure 3.11). The costs of PV-based power generation have also considerably come down and are in the order of $0.34-0.46/kWh (see also Figure 3.9). Efficiencies for commercial PV cells range from 7 to 17 per cent (dependent on the type employed).

Figure 3.11 PV System Prices



Source: WADE, 2003.

Nevertheless, PV has turned out to be attractive in certain circumstances, especially in the absence of a reliable fuel supply at affordable prices and a grid connection, and in the presence of stable and sufficient sunshine. In this context, the development of dye-sensitized solar cells is interesting as it presents a potentially inexpensive and more flexible alternative to present semiconductor technology. According to a projection by WADE, PV applications are expected to become truly competitive if capital costs for PV applications drop below $1,000/kW (2003). Impressive price decreases (of about 25 per cent over the period 2000-2004) are being registered in, for example, Germany, as a consequence of growing demand.

[19] This is in line with a number of projections, e.g. WEC, Shell, IPCC, IEA 2004.

In various countries the use of solar energy is actively promoted in the spirit of increasing the share of renewables in energy supply. Typical examples of implementation can be found in city design. Some notable examples in Europe are 'Nieuwland' in the Netherlands and 'Solarsiedlung' in Freiburg, Germany. The former is one of the world's biggest townships powered by solar energy with an installed capacity of 1 MW, which is enough to meet 44 per cent of the community's electricity needs. In the latter example, each house produces more energy than the inhabitants consume. PV on the roofs have turned each house into a mini power station with a capacity to generate between two and three kW of electricity, which is then fed into the grid. Moreover, the houses are faced southwards and have: large, triple-layer glass windows that soak up the heat; 40 cm-thick exterior walls providing extra insulation; and a refined ventilation system which cools the house during the summer and heats it during the winter.

Another example is the Suria 1000 project in Malaysia, which is to be launched by the Malaysian Ministry of Energy, Water and Communications. The program will offer building-integrated PV (BIPV) systems at discounted prices to make the technology accessible and affordable for the public. Suria 1000 is part of the wider five-year Malaysia Building Integrated Photovoltaic (MBIPV) project which is to develop the local solar energy market launched in July 2005. The project will promote BIPV technology – which covers PV that can be incorporated into building structures such as roofs, façades, walls, windows and shades instead of the traditionally mounted solar PV. Solar energy can be used directly, and excess energy generated can be fed into the electricity grid. Presently (2005), PV installations in rural areas in Malaysia have a capacity of 2.5 MW while urban installations connect 55 kW to the grid. The project aims to add a minimum of 1.5 MW of solar energy to the grid.

The further implementation of solar energy will be strongly supported if, in the spirit of this storyline, governments keep pursuing their legal and regulatory measures in support of the introduction of solar energy. Because of their flexible use, PV seems especially attractive when governments will set clear energy efficiency targets in residential buildings and offices (in Europe responsible for over a third of the total final energy consumption). The European Commission's 7th framework program for research and development priorities for the renewable energy sector states, for instance, that more ambitious R&D and related legislation will help realize the following roadmap:

- By 2010 new residential buildings in the EU will not need more than 60 kWh of external primary energy per year per square meter for heating, cooling, lighting and other building services. Office buildings will not need more than 100 kWh/year/m2;
- By 2020 40 per cent of all buildings in the EU will be below 100kWh/year/m2, which also implies an ambitious retrofitting rate for the existing building stock. The standard for new residential building in 2020 will be 45 kWh/year/m2;
- By 2050 new buildings in the EU will not use more than 30 kWh/year/m2. At the same time, 50 per cent of the existing building stock will reach values below 60 kWh/year/m2.

It is clear that PV will most likely play a role in the mix of measures to fulfill such targets; this may in fact support large-scale PV implementation. Between 1999 and 2004, the installed solar thermal capacity in the EU already grew from 5,600 to 9,800 MWth (14 million square meters of collector area). During the same period, the photovoltaic industry grew by about 45 per cent per annum, so that the value of installed capacity in Europe increased to approximately €1 billion in 2004. If the EU is serious in its aim to reach its target, which by 2020 would amount to 20 per cent of the primary energy consumed in Europe and which will come from renewable energy sources, the worldwide PV industry is believed to potentially represent a future value of €60 billion.

Another example can be found in countries that do not dispose of any, or little, fossil fuel reserves but which have, instead, favorable climatic conditions. Several of these countries are increasingly supporting solar energy initiatives apart from an observed switch of oil and diesel-fired generators to natural gas. Israel, for instance, is a world leader in solar technology and relies heavily on solar energy for water heating. The use of solar systems in the final demand is expected to grow by 0.05 Mtoe until 2010 and by 0.38 Mtoe in the decade 2010-2020 (equivalent to a 760 per cent increase when compared with the present decade).

Assumption 12 The role of compressed natural gas (CNG) and gas to liquids (GTL) as fuel in transport systems becomes much more significant, particularly in (mega) cities throughout the world.

In 1950 there were only 70 million vehicles (cars, trucks, and buses) on the roads worldwide. In 2003 there were about ten times as many: 700 million vehicles (RRI, 2004). This explains the transport sector's significant share in energy-related CO_2 emissions: 21 per cent worldwide (see Figure 3.5).

In the USA transportation alone emits even more CO_2 than any other nation's total CO_2 emissions, except China (RRI, 2004). Road transport generates more than one fifth of all CO_2 emissions in the EU, with passenger cars being responsible for more than half of these emissions. Since 1990 emissions from road transport have risen by 22%. Its share in world total CO_2 emissions is rising the fastest compared with other sources, most notably in the developing world where urban population is expected to double by 2030.

According to the IEA, worldwide emissions from transport activities will increase by almost 170 per cent during the period up to 2030, which is the highest figure among the sectors for which projections have been made.[20] This projection is, however, based on the assumption that during this period the transportation sector will continue to rely on oil and that little competition from alternative fuels is to be expected.

The question is whether this is a realistic assumption. This storyline leads to the conclusion that it is not. First, the capacity to increase fuel-efficiency of engine is not unlimited, so that other solutions will need to be sought for compliance with new environmental policy regimes tackling the transport sector.

Second, local air quality concerns are becoming stronger. Due to an increasingly unacceptable local pollution (NOx, SO_2¬, particulates), particularly in mega-cities in the developing world, mandatory introduction of clean fuels (including CNG and GTL) in city-transport is very likely to become a common trend in Latin America, Africa and Asia. Starting with public transport, these trends will probably increasingly be taken over in industrialized countries. In some mega-cities, e.g. New Delhi and Buenos Aires, some spectacular policy initiatives have been taken to make the local transport system cleaner, in part by prescribing the use of CNG by the public transport system (see also Box 3.7). It seems obvious that the use of CNG and GTL in public transport will increase their acceptability in the course of time (if only because the number of CNG/GTL-stations will expand, adding to the fuels' attractiveness), even in the private transport sector. Currently, the number of natural gas-burned vehicles amounts to about 3.5 million in 60 countries.

Box 3.7 The case of CNG uptake in Argentine

In countries like Brazil, Egypt, Italy and Pakistan, driving CNG fuelled cars has become increasingly common. However, Argentina leads the world in the number of CNG vehicles in operation, with some 1.25 million as of March 2004, and more than 1,000 service stations in 18 of its 23 provinces offering CNG fill-ups (IANGV). Moreover, an estimated average of 25,000 cars are being converted to natural gas every month.

Impetus was provided by bad air quality in combination with abundant natural gas reserves. The government can be discerned as the catalyst that acted to begin the CNG commercialization process.

Strong resemblance seems to exist between factors as distinguished by the European Energy Agency (EEA, 2001) determining the extent to which renewable energy technologies are successfully deployed and those of paramount importance for the successful adoption of driving CNG. These are:

- Political support;
- Legislative support;
- Fiscal support;
- Financial support;
- Administrative support;
- Technological development; and
- Information, education and training.

Third, a substantial number of countries are presently adopting policies and measures to stimulate the use of alternative fuels in the transport sector, either for CO_2 emission reasons or for other environmental reasons (for an overview see Table 3.5). Some examples are presented below.

Within the EU-15 voluntary agreements exist to among others enhance CO_2 emission reduction from cars with a (voluntary) target determined by the European Commission of 140 g of CO_2/km by 2008/9. The annual report on CO_2 emissions from new cars shows that the car industry has made progress in fulfilling this target. Between 1995 and 2003, emissions from new passenger cars sold in the EU-15 have decreased by 11.8%, which implies a progress of 1.2% compared to 2002. The ultimate EU goal is to limit emissions to 120 g of CO_2/km by 2010. Environment Commissioner Dimas: "...To respect the Kyoto commitments and reduce our oil dependence, we must reduce CO_2 emissions from transport, the sector whose emissions keep growing." Other measures include

[20] The power sector in the developing world takes a second place with a 167% increase (IEA, 2004).

consumer information (fuel efficiency labeling) and fiscal incentives. Similar initiatives have been taken by the Canadian automobile manufacturing industry via a pact which commits its signatories to reduce the overall GHG emissions from vehicles sold in Canada by 5.3 Mt, about 25 percent, up to 2010.

New Japanese energy policy guidelines (expected to be adopted in June 2006) will be the first to contain specific targets for biofuels and GTL usage. The aim is to replace 20 per cent of petroleum products in Japan – the world's third largest oil consumer - by 2030. These highly ambitious targets (for example when compared with the European Union target of 5.75 per cent biofuel content by 2010) should be approached with some caution, though. For example, the introduction of auto fuel containing 3 percent bioethanol countrywide by April 2005 proved hard to reach.

In Sweden a whole different approach is chosen. Apart from providing incentives through taxation, specific incentives were put to work. Such incentives include free parking in Sweden's larger cities and particular privileges for cab drivers such as preferential treatment at taxi stands. The private sector joined in as well and, for example, provides loans at lower interest rates for an 'Eco-car'. Now (2006), 2.7 per cent of transportation fuels in Sweden are biofuels (mostly ethanol) and last year the number of cars that drive on biofuels has doubled. For the future, the Swedish government is planning to make the road tax dependent on the amount of CO_2 a car emits.

Table 3.5 Strategies to curb transportation emissions

	Means	Target	Status (2004, unless otherwisse indicated)	Projected avoidance of CO_2 emissions (Mt)
EU	Voluntary	120 g of CO^2/km	-11.8% between 1995 and 2003	
US	California (subsequently adopted by New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermontand Maine) Renewable Fuels Standard (RFS) Alternative Motor Fuels Act (1988), the Clean Air Act Amendments (1990); Energy Policy Act (1992);	-22% in 2012 culminating in 30% in 2016, starting in 2009		
		replace 30% of petroleum based motor fuels by 2010		
	Corporate Average Fuel Economy (CAFÉ) program, JOBS bill (biodiesel tax incentive			
Japan				
Canada	Voluntary	-25% by the end of 2010		5.3
Brazil	• Program of Incentive to Alternative Sources for Electric Energy (Proinfra), guaranteeing to accept electricity delivered to the grid by co-generation using sugarcane bagasse (Law 10,438 of April 26, 2002); • Law 4,353 of August 30, 2002 that establishes measures that strengthen the process regarding the storage and acquisition of fuel alcohol regulating stocks and the mechanisms for financing the sugarcane agriculture business; Tax incentives			

Source: WADE, 2005; EU; Negrão and Urban, 2004; Boyle, 2004.

Box 3.8 Legislation to curb greenhouse gas emissions from cars and light trucks

In 2002, recognizing that global warming would impose compelling and extraordinary impacts on California, Governor Gray Davis signed legislation (AB 1493, Pavley) that would curb greenhouse gas emissions from cars and light trucks. This bill enables the state's Air Resources Board to set limits for auto emissions of carbon dioxide and other contributors to global warming, and gives car manufacturers until 2009 to comply with tighter regulations. California, the world's fifth largest economy, is home to 24 million motor vehicles, which are responsible for about 40% of the state's greenhouse gas pollution.

Nowadays, even the industry joins in on the momentum. Californian transport company AC Transit is the first to join the California Climate Action Registry, thus committing to track (and report) its emissions of GHGs.

In the USA, through the Energy Policy Act (EPA) of 1992, 30 per cent of petroleum-based motor fuels has to be replaced by 2010 in order to reduce the nation's dependence on foreign oil and to increase its energy security through the use of domestically produced alternative fuels. Measures to support this process are tax deductions and provisions, as well as mandatory Alternative Fuel Vehicles (AFV) purchase agreements in order to meet a specific AFV percentage requirement. In October 2004 the 'JOBS' bill was signed containing the first ever federal biodiesel tax incentive, which will be applicable for two years. In order to ensure compliance with these laws (e.g. EPAct), so-called Executive Orders have been issued. Despite these incentives and Orders issued, targets set have not been fully reached. For example, only ten out of 18 covered agencies met the 75 per cent requirement of AFV light duty vehicle acquisitions (RRI, 2004). Those agencies that purchased more than the required accumulated credits can trade their surplus with agencies that have failed to comply. Other federal initiatives include:

- commodity Credit Corporation (grants for bioenergy production);
- partnership for a New Generation of Vehicles (increasing fuel economy); and
- freedomCAR and Vehicle Technologies (FCVT) Program (elaborate research effort with government/industry wide participation).

Although the Federal Clean Air Act (CAA) prohibits states to adopt or enforce standards for new motor vehicles or engines, California is exempted from this prohibition because of its severe air pollution problems (Section 209(b) CAA) (for some expected policy in California, see Box 3.9). Other states are permitted the same as long as their motor vehicle emission regulations are identical to those in California.

Partly because of such an active policy, 510,805 AFVs were operational in 2003, representing an average 9.6 per cent increase per year since 1995 (EIA). The AFVs used a variety of alternative fuels,[21] with a share for CNG, the typical focus of this study, of about 25 per cent. In 2004 approximately 130,000 CNG-fuelled vehicles and 1,300 refueling stations were in operation in the USA (IANGV). CNG-fueled vehicles are especially popular with buses, and medium and heavy-duty trucks. CNG use in public transport buses increased more than 25-fold between 1993 and 2003, so that in 2003 10.7 per cent of all buses used CNG (RRI, 2004). In January 2003, more than 20 per cent of all new public transit buses on order use the CNG technology. For example, the US Postal Service, traveling 1 billion miles annually with 208,000 vehicles, operates more than 7,500 CNG vehicles. Fleets will continue to be the biggest consumer of AFVs in the future. According to the EIA, in 2000 23.7 per cent of all automobiles sold were for fleet use.

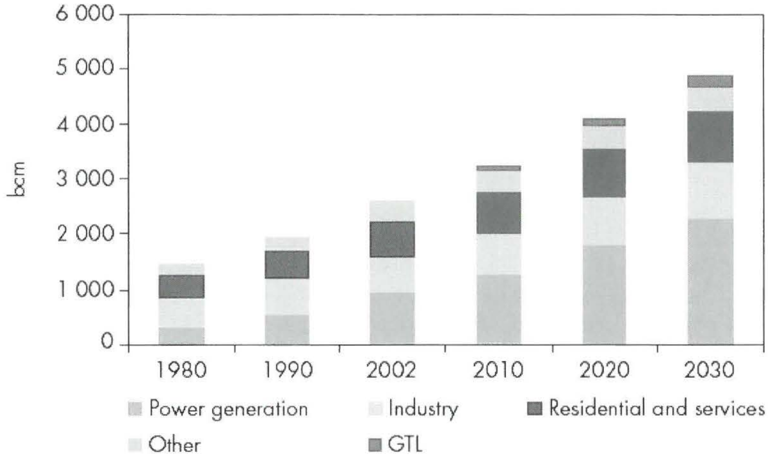
Especially fleet owners have switched from petroleum to natural gas because of the clear advantages in terms of reducing the emissions of CO2, NOx, and other gases, as well as particulates, and in terms of noise reduction, and thanks to an increasing network of fueling stations. Although light-duty vehicles have not yet been converted on a large scale, car manufacturers such as GM and Honda plan to introduce such vehicles running on natural gas in 2005.

It remains yet to be seen what role the various energy carriers, including CNG, will play in the possible future mix of alternative fuels. Another possibility is to use of gas-to-liquids (GTL) in the transport system. GTL technology processes natural gas to make clean fuels such as low-sulphur diesel. GTL plants are expected to emerge as a new market for natural gas, thereby using cheap reserves located far from traditional markets. Technological advances have reduced production costs in the past and will continue to do so in the future, as companies will increasingly become interested in developing GTL projects. Moreover, further technological improvements could

[21] Electric vehicles have grown most quickly for non-fleet sales, with hybrids (HEVs) being responsible for the lions share.

also reduce the energy intensity of GTL processes. GTL can be considered an alternative or a complement to LNG and may provide the industry with a viable alternative to store natural gas. From 2010 onwards, a further introduction of GTL is foreseen, which will increase natural gas demand (see Figure 3.12). However, the GTL conversion process is rather costly, consuming about 45 per cent of the gas supplied to GTL plants (IEA, 2004a).

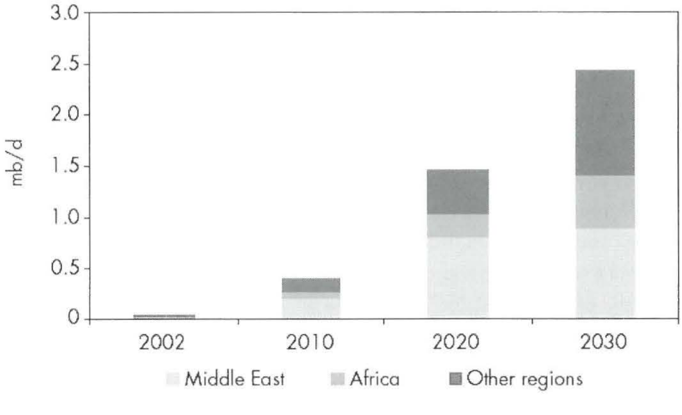
Figure 3.12 World Natural Gas Demand by Sector



Source: IEA, 2004a.

Currently (2005), only two commercial GTL plants are in operation: the 22,500 b/d Mossgas facility in South Africa, which has been operational since 1991, and Shell's 12,500 b/d Bintulu plant in Malaysia, commissioned in 1993. Several other plants are currently under construction or have been planned, most of them in Qatar, using gas from its huge North Field.[22] [23] If indeed, these projects were completed, global GTL capacity could exceed 800,000 b/d by 2011, which is almost equivalent to 1 percent of world output of refined products. The IEA foresees a production potential of 2.4 mb/d in 2030, compared to 0.4 mb/d in 2010 (for the projected size and regional distribution of GTL production, see Figure 3.13).

Figure 3.13 GTL Production by Region



Source: IEA, 2004a.

Assumption 13 **New gases, such as green gas based on biomass, hydrogen and mixes of gases are successfully introduced in niche markets, among others through well-focused incentives and successful marketing campaigns.**

In this storyline alternative gases will increasingly be introduced in various applications. Although natural gas is seen as the transition fuel par excellence, political pressure will remain to stimulate this transition, among others by trying to introduce other, especially hy-

[22] The world's largest non-associated gas reservoir with some 900 trillion cubic feet of gas.

[23] For example, Shell is in the process of developing a project in Qatar: the Pearl GTL project. This project is estimated to produce over ten times Bintulu's current capacity with about 140,000 b/d towards the end of this decade.

drogen and biomass-based, gases, which are possibly mixed to the feasible extent with natural gas. The development of both hydrogen and biogas for large-scale application is still at its infancy, but there is a rapid progress. Biogas has a clear advantage in that, if converted to the required quality standard, it can be used in the existing transportation system. As far as hydrogen is concerned, research on the issue to what extent hydrogen can be mixed with natural gas for being used in the existing transportation system is still ongoing, but suggests that the scope will probably remain limited.

Nevertheless, this storyline expects governments and business firms to seriously develop these gases and to analyze how and when implementation could be feasible. The fact that serious initiatives in this regard have been taken already in a number of countries seems to make it likely that such green gases will, during the next few decades, become a common feature of overall gas supply worldwide. This is especially likely as gas in itself will increasingly dominate the energy system and as emission penalties will increase.

As far as biogas is concerned, initiatives have thus far remained limited, but there is a strong progress. One of the countries that takes a frontrunner position in this regard is Germany. According to the German industry association, Fachverband Biogas, in 2005 the use of biogas will reduce German CO_2 emissions by about 2.5 Mtons. Moreover, until the year 2020, this volume is expected to grow to 60 Mt. In this sector, 1 kW of installed power generation capacity represents a reduction of 7,000 kg of CO_2 per year according to the association's calculations.

As far as hydrogen is concerned, several countries are presently starting to implement hydrogen programs. The European Commission's proposed Hypogen project, a €1.3 billion project to generate hydrogen and electricity produced from fossil energy sources, is just one example. Of all known fuels, hydrogen has the highest energy content per unit of weight (RRI, 2004). In addition, pure hydrogen contains no carbon and thus burns to form water with no hydrocarbon or CO_2 emissions and can thus be considered a zero- or near zero emission technology. Hydrogen can be used as an alternative fuel in transportation with the fuel cell.

Especially promising in this regard is a hybrid system that seeks to integrate gasification with a fuel cell (IGFC). These so-called IGFC hybrids have the potential to achieve near zero emissions, with the concentrated CO_2 being removed by separation or other capture means.

Chapter 4

International Security of Supply Storyline

4.1 General description

In this storyline, the strong economic growth shown in Asia and parts of Latin America during the last decades will sustain throughout the next decades. This compensates for a gradual decline in economic growth in the Western world and, due to the increasing weight of the fast-growing 'newcomers' in world economic growth, contributes to a continuation of the worldwide economic growth trend of about 3.5 to 4 per cent per annum. World population keeps growing in accordance with the high end of the UN population scenario by 2040. Concern about climate change is overshadowed by great optimism in Asia about economic progress and an increasing international political role. Also after the Kyoto commitment period, subsequent treaties show a low mitigation ambition, continuous scope for free riding, and weak overall compliance regimes. The trend in energy efficiency improvements therefore shows no significant difference with the past, so that the worldwide demand for energy keeps growing with about 2 per cent per annum, leading to a doubling of demand each period of about 35 years. There are insufficient incentives to achieve a significant breakthrough in renewable technology; governments increasingly tend to rely on a phasing out of coal and fuel switch in order to meet their post-Kyoto mitigation commitments. The option of nuclear energy remains subdued because of public concerns and resistance.

In this storyline fossil fuels, notably oil and gas, remain the backbone of energy supply in a market which faces significant increase in demand. Realizing that oil reserves deplete rapidly, at least against acceptable production cost conditions, many countries try to secure their energy supply on the international gas market. With Europe, NAFTA, Japan, China and India all increasingly competing for the available gas (and oil) resources, the world increasingly faces geopolitical tensions around Middle-East and Russian gas (and oil) fields. Suppliers of natural gas on the international market may use their increasing market power to further boost prices by restricting their supply. The security of supply issue becomes a dominant factor on the foreign policy agenda of most countries. Countries increasingly try to secure their supplies via bilateral contracts, and the world cannot avoid increasing hostility between the various blocs on the issue of access to energy in general and to natural gas in particular.

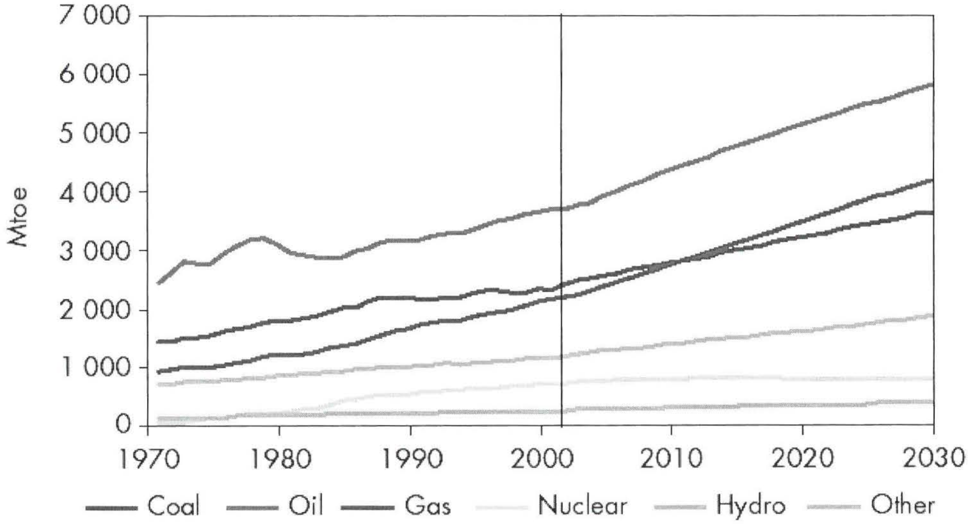
4.2 Assumptions and rationale of the Security of Supply Storyline

Assumption 1 **World economic growth and related growth in world energy demand remain high, mainly due to the continuous rapid expansion of Asia and the failure to decouple energy use from economic growth.**

This storyline assumes that the world economy keeps growing at a rate which is at the high end of most projections. For instance, future growth projections for the period until about 2100 as outlined in chapter 2 suggest a worldwide growth ranging between about

As a consequence, the IEA expects natural gas to overtake coal as a fuel in world primary energy within a decade (see Figure 4.4).

Figure 4.4 World primary energy demand by fuel



Source: IEA, 2004a.

A number of governments have announced that they will attempt to decouple economic growth from growth in traditional energy use and associated emissions. However, due to the limited scope for a significantly different trend in energy efficiency improvements (see also assumption 6.3), such a decoupling seems very hard to achieve, although some successes will probably materialize in specific sectors or at industry levels (see Box 4.1).

Box 4.1 Policies and measures delinking economic growth and energy demand

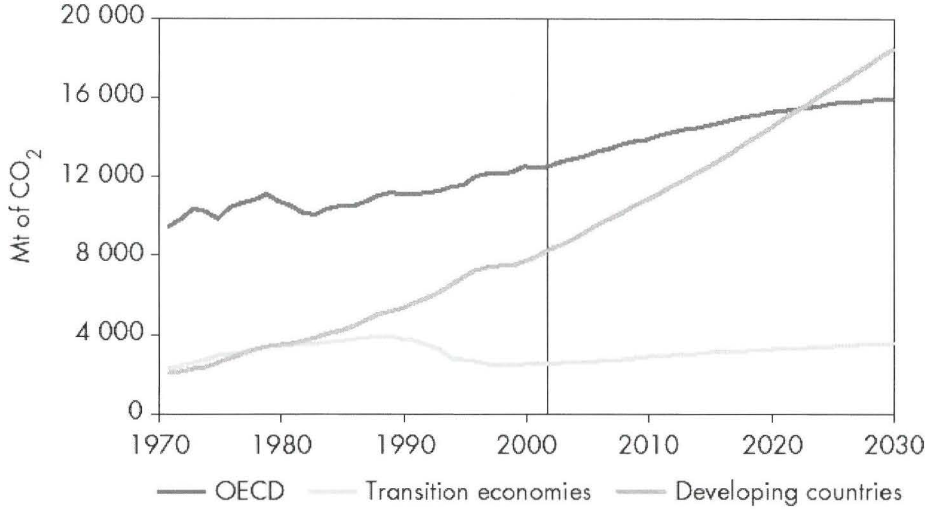
Policies and measures in order to achieve abatement are increasingly effective, amongst others based on experience in using them. Just to illustrate how effective policies aimed at decoupling growth and energy use can be: CAFÉ standards on automobile use in the US since the early 1980s caused per capita US gasoline consumption to rise by only 7 per cent while per capita income grew with 50 per cent. In the UK, overall energy consumption has increased by around 15 per cent since 1970, while the size of the economy has doubled. UK policy communicates the need to continue and accelerate this trend to decouple economic growth from energy use and pollution to reach its targets as elaborated upon in its White Paper on energy (see Box 3.4).

The most recent initiative with respect hereto aims at preserving the world's rapidly depleting oil reserves: The Uppsala Protocol or 'Oil Depletion Protocol.' Such a protocol would provide a framework for major consumers to use less oil and develop alternatives, while preventing major producers from benefiting as oil supplies become scarce. It would also help poorer nations share more equitably the world's remaining oil to meet their developing needs. According to Mr. Campbell, a Board member of the London-based Oil Depletion Analysis Centre, "...a managed approach is needed through international agreement. The alternative is ever-soaring oil prices with destabilizing effects on the world economy..."

Assumption 2 **Climate change concerns are somewhat overshadowed by the great optimism about Asian economic progress and its increasing international political role. The post-Kyoto regimes are therefore characterized by a mild regime in terms of commitments, compliance, and dealing with free riders; the rapidly growing Asian economies can, however, no longer retain their non-Annex I status.**

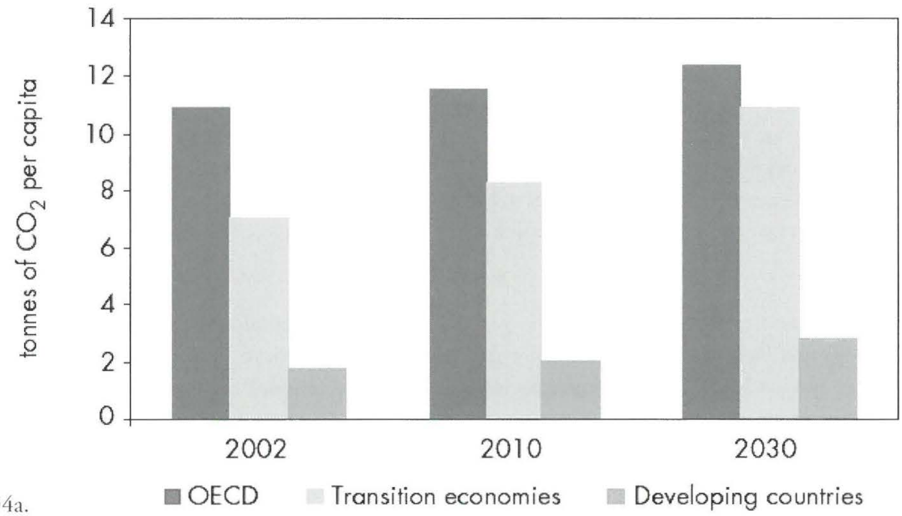
This storyline is based on the assumption that the presently strong coalitions between groups of developing countries are maintained during the next decades in several international negotiation forums, including international climate policymaking. As a result, these groups of countries (including the rapidly growing Asian economies) will stick to the position that the industrialized world remains primarily responsible for mitigation activities. This is based on the argument that despite rapid growth in developing country emissions (see Figure 4.5), even in 2030 the average per capita emissions in the developing regions still are considerably lower than those in the industrialized regions (see Figure 4.6). Consequently, the rapidly growing economies will only be willing to adopt weak abatement concessions, primarily based on international technology transfers to their regions. This position subsequently undermines the willingness of industrialized countries to adopt substantially stricter commitments.

Figure 4.5 World energy-related CO2 emissions by region



Source: IEA, 2004a.

Figure 4.6 Per capita energy-related CO2 emissions by region



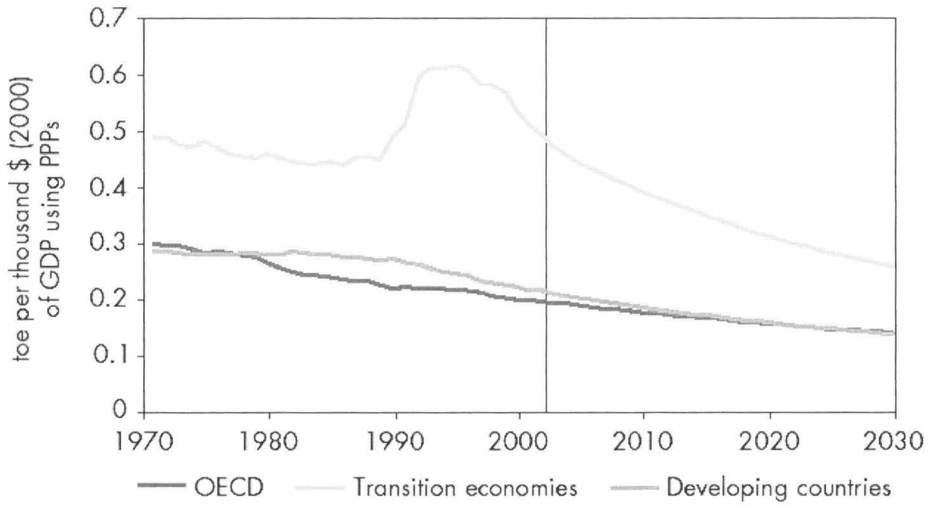
Source: IEA, 2004a.

As a possible precursor of such a future development, reference can be made to the Vision Statement for an Asia-Pacific Partnership on Clean Development, issued in July 2005 (in Asia!) by Australia, China, Japan, South Korea, and the USA. Both perceived as an alternative, as well as a complement to the Kyoto Protocol, the Partnership lists a number of technology options that should be given priority, without being legally binding. Interesting is Japan's participation as a signatory to the Kyoto Protocol.

Assumption 3 **The past trend in energy efficiency improvements of about 1% per annum does not change significantly; the share of renewables remains limited because credit prices provide insufficient incentives for serious breakthroughs towards massive implementation.**

The points made in argument 6.3, a substantial deviation from the long-run trend in energy efficiency improvement is unlikely, apply here as well. This is also in line with the IEA projection, as illustrated in Figure 4.7 below, which shows the trend in primary energy intensity in the IEA 2004 Reference Scenario (note that in the IEA Alternative Policy Scenario, the impact of the 'modern' policy mix on the energy efficiency trend is still rather limited). To illustrate some past figures, during 1980–2000, the average annual worldwide energy intensity fell with about 1.5% (Europe 1.4%; USA: 1.8% non OECD: 0.8%) with a wide variety across countries.

Figure 4.7 Energy efficiency trend, 1970-2030



Source: IEA, 2004a: 63.

As shown by the former argument, energy demand in developing countries will strongly increase during the next decades. It seems likely that this growth will be typically accommodated by fossil fuels.

First, coal reserves, which are located in or near the main Asian economic growth centers and which can be mined at relatively low cost, are very large. The likely introduction of clean coal and Carbon Capture and Storage (CCS) technologies in these areas may contribute to the fact that coal will remain an important fossil fuel at least in those regions.

Second, in the absence of clear incentives for a large-scale introduction of renewables due to a lasting relatively weak post-Kyoto regime, the rapidly growing energy demand will primarily be met by oil and natural gas, next to coal.

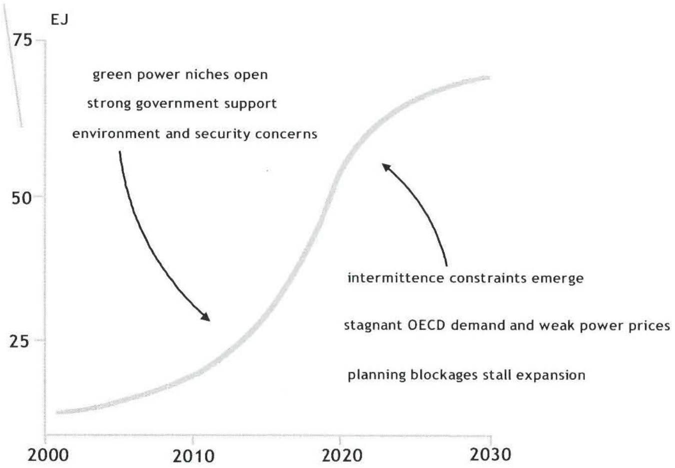
Third, another reason why a clear transition trend, except from the increasing share of natural gas in the fossil fuel mix, will not materialize could be the little political support, due to the prime focus on economic progress and modernization, for allocating resources to the difficult and lengthy process of organizing the institutional framework and coalitions that are required for setting up alternative energy systems in the various sectors.

The above trend of a strong growth in energy demand with a dominance of fossil fuels will not only prevail in the rapidly growing developing regions, but also, albeit to a lesser extent, in the OECD countries. In the latter countries, in the absence of a strong post-Kyoto regime, the transition towards carbon-free energy systems is equally difficult to get off the ground in this storyline.

Although the demand for renewable energy will first increase somewhat, in the course of time its development will stall due to: a lack of incentives; increasing resistance against the use of subsidies to promote renewables, particularly open-end policies and measures; and increasing public resistance for a.o. aesthetic reasons (for an illustration, see also Figure 4.8 derived from Shell's scenarios). The limited penetration of renewables can also be explained by a number of significant practical and economic barriers. One of the problems is that renewable energy forms both tend to be intermittent or unpredictable by nature and 'site dependent', i.e. they are primarily available within particular, but not necessarily optimal, time intervals and at particular sites. The share of renewable energy use will therefore reach a level of 5 per cent in some small green energy niches, but its share in overall energy consumption in most regions will remain at a level of approximately 1 per cent only through 2030.

Because of the lack of success with the introduction of renewables in the main industrial areas, climate policies in those areas will increasingly rely on fuel switch and therefore lead to a rapid increase in natural gas demand.

Figure 4.8 Renewables growth and boundaries

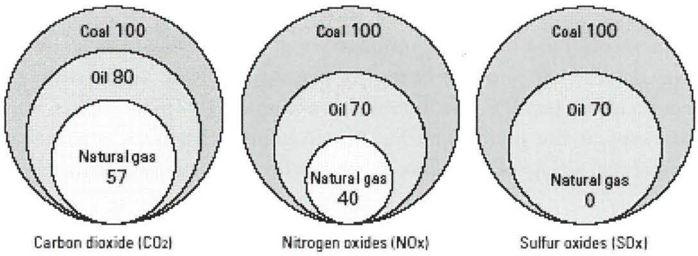


Source: Shell, 2001.

Assumption 4 **The post-Kyoto compliance is mainly based on: replacing or even phasing out the use of coal, at least in the industrialized economies; and a fuel switch, i.e. replacing the use of oil and/or coal with the use of gas. Therefore, the rapidly increasing demand for energy must largely be met by supply of oil and, in particular, of natural gas.**

In terms of emissions, natural gas is clearly superior to coal and oil in almost all applications (see Figure 4.9). Another significant advantage of using natural gas is that its emissions do not contain particulate matter, which is extremely detrimental for the human respiratory tracts. Moreover, it does not seem likely that a shortage of supply will take place during the next few decades.

Figure 4.9 CO_2, NOx, and SOx emissions of coal, oil and natural gas when used as a fuel for thermal power plants.

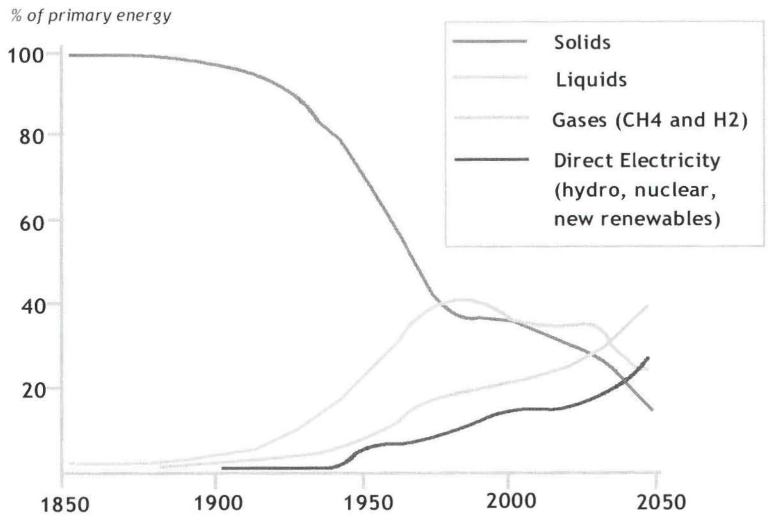


There is evidence that local air pollution is increasingly perceived of as a major health issue throughout the world. This perception is most likely to grow further due to: public availability of more information about the adverse health implications of bad air quality; increasing attention to local air quality policy measures; an increasing number of people living in (mega) cities (almost 5 billion by 2030, see Figure 4.1); and an increasing share of emissions from transport in overall emissions. The combination of global climate concerns on the one hand, and local air quality concerns on the other, is likely to further support the increasing use of natural gas for a number of applications, especially in power generation and city transport.

In addition, the attractiveness of natural gas is enhanced because of its low cost and high efficiency as compared to coal and oil. This may also explain why the 2001 Shell scenarios 'Exploring the Future: Energy Needs, Choices, and Possibilities' expect for the period

after 2010 that: about two thirds of the US coal-fired power plants of over 40-years old will be replaced with gas-fired plants; China will most likely increase its gas consumption by initiating major gas import projects; and Latin American and Pan Asian gas grids will emerge after 2010.
Another factor which may enhance the fuel switch process in favor of gas is the impact of a substantially increasing availability of LNG (see as well assumption 6.10). One advantage of LNG is that it enables gas transport by vessels across oceans and delivery everywhere from remote locations if compressed and refrigerated into liquid form. Another advantage of LNG that may contribute to the expected increasing popularity of natural gas is that it can be provided in a flexible manner, which is in line with the greater flexibility demanded by the (end) users in liberalized markets (see also Figure 4.10).

Figure 4.10 Primary energy demand in terms of solid, liquid, gas or direct electricity



Source: Shell, 2001.

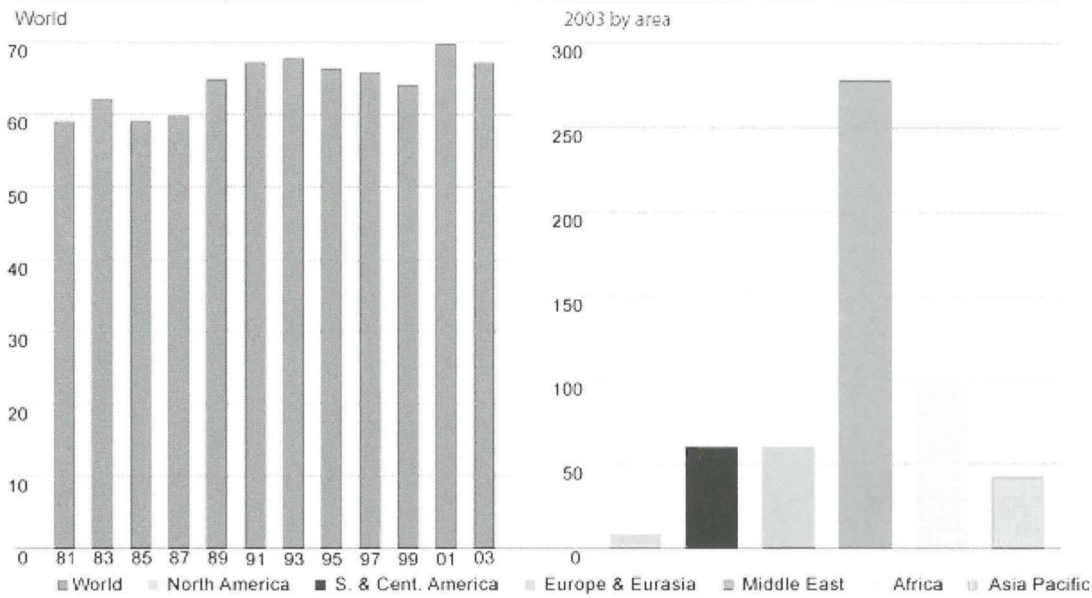
Assumption 5 **Post-Kyoto-based fuel switch incentives and rapidly increasing oil production costs lead to a decoupling, or at least less clear coupling, of prices of natural gas and of other fossil fuels, which leads to a relative price decline of natural gas.**

In the past there has been a strong tradition of linking gas prices to oil prices. One reason for this was the perception that gas should primarily be viewed as a side-product from oil production. Second, unlike oil, there was no worldwide spot market for gas. Third, in a large number of applications gas and oil were substitutable. Probably a fourth reason was that the contractual linking of gas prices to oil prices was considered to be convenient. It should be mentioned in this regard that in the 'decoupled' markets (e.g., the USA and the UK), gas and oil prices nevertheless showed a comparable price development pattern over time, with, however, recently clearly much stronger fluctuations of gas prices.

In the mean time, the situation has changed considerably. The importance of gas as a fuel has increased tremendously: as shown in Figure 4.3 it is well possible that within a decade or so natural gas will take coal's second position as energy fuel. Moreover, gas and oil are increasingly perceived as different fuels because of the differences in emissions (see Figure 4.9). In other words, environmental concerns make gas and oil look increasingly different. Also, a flexible world gas market is gradually evolving, and along with it a number of spot markets where prices do not necessarily have to be in line with corresponding oil prices.

Finally, present low-cost oil reserves as compared to annual demand are significantly lower than gas reserves. In fact, despite the 75-percent increase in gas production since 1983, the world's gas reserves-to-production ratio has risen over the last 20 years to almost 70 years (in 2003, see Figure 4.11)! If the scarcity of the two fuels is perceived as different, according to economic theory, there is no reason why the prices of the two commodities would behave similarly. All these arguments may well become stronger in the future, which could lead to an increasing tendency of gas and oil prices to show no longer quite similar patterns. In fact, with a view to a further development of an international and integrated gas market, it seems likely that spot and future gas prices, rather than oil prices, will increasingly be used as the basis for indexing gas prices in long-term contracts.

Figure 4.11 Natural gas-to-production (R/P) ratios for the world and particular regions



Source: BP, 2004.

The tendency of gas and oil prices to get 'decoupled' may be supported by the increasing negotiation power of the trading community, which is characteristic for a liberalizing gas market. For instance, the present European Commissioner for energy, Piebalgs, has argued in favor of abandoning the international gas contract clauses which link gas prices to oil prices.

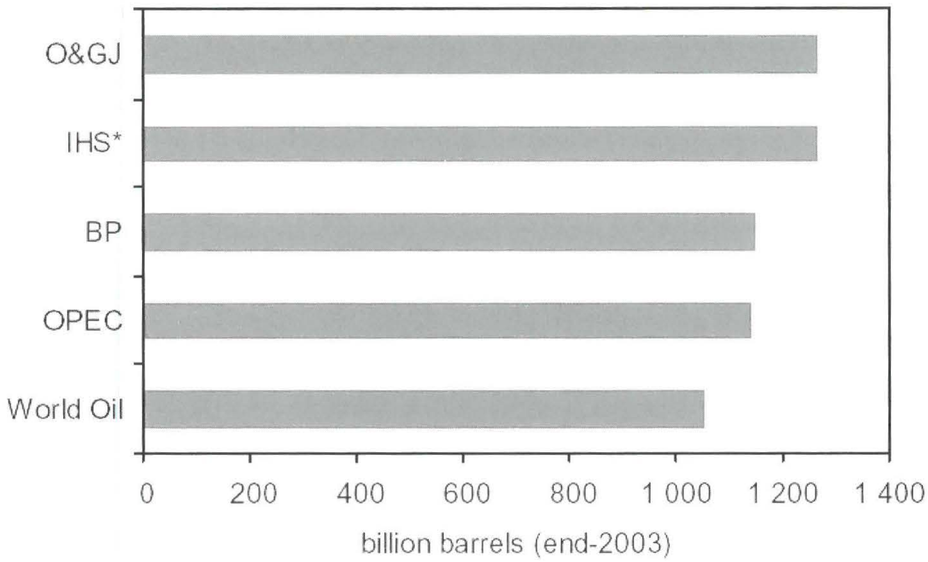
Assumption 6 **The concerns that oil reserves, at least if defined against acceptable prices and reliability of supply conditions, deplete relatively soon becomes widespread. This perception, as well as the gradual introduction of decentralized energy systems based on the combination of natural gas and renewables, triggers policy initiatives to try to secure natural gas-based energy supply.**

On a global scale, there is a heavy debate on the question whether or not the world will run out of oil within a number of decades, and therefore out of projected reserves.

Evidence from the International Energy Agency based on a summary of information from a range of sources, suggests that the current reserves are in the order of magnitude of about 1,200 billion barrels (roughly two thirds of which is located in the Middle East) (see Figure 4.12). If this amount is compared to the 2004 annual worldwide consumption of 28.7 billion barrels, and assuming that the demand for oil keeps rising and may well double within a number of decades, the scary picture emerges that the end of an era of cheap available oil is in sight. In fact, even if the demand for oil would not further increase from the present level, the world would still run out of oil in about 40-45 years if the oil reserves would not increase at all. This also assumes that the reserves are made available by producers to satisfy demand, which is not certain either. To illustrate, in 2000, the USA had only 64 percent of its 1972 reserves at its disposal (McGarvey, 2002).

Irrespective of whether the data on future oil reserves are completely reliable, there is an increasing perception in the market that the world is gradually running out of oil that can be produced at modest costs, and that it is fairly irrelevant whether this will be the case in three, four or five decades. Even oil companies have started to raise that awareness amongst the public at large. Chevron, for instance, started a campaign in 2005 through the following advertisement in the Financial Times (19 July 2005): "It took us 125 years to use the first trillion barrels of oil. We'll use the next trillion in 30." [25]

Figure 4.12 Proven oil reserves (estimates)



* Includes probable reserves
Source: IEA, 2004a.

It seems likely – also in view of the limited success in finding significant new oil reserves over the past few years - that the perception of the world running out of oil may well get stronger during the next few decades. Although it is difficult to already speculate about how this perception will affect the position of natural gas as an alternative fossil fuel source in the eyes of both the public at large and policy makers, as well as the investors in the sector, it seems rather obvious that all this will further support the trend towards a clearly stronger and more dominant role of natural gas in the worldwide energy system.

Assumption 7 **The nuclear option does not come off the ground seriously in most regions because of the perceived high security risks and associated costs.**

Several studies point at the importance of public acceptance when considering the potential of some energy options. For instance, a survey conducted in the former fifteen EU Member States revealed that Europeans are clearly in favor of clean and sustainable energy production from renewables although it is widely acknowledged that a well-balanced energy mix is needed to secure energy supply (EORG, 2002).[26] These findings correspond with the result that nearly nine out of ten respondents (or 88 per cent) considered global warming and climate change serious problems that require immediate action. Another example, a US study by MIT (2003) on the future of Nuclear Power, also discerns public acceptance as a critical parameter for the further development of this sector, especially with respect to factors such as nuclear waste, safety, and costs. Moreover, as seems the case in Europe, people do not connect global warming concerns with carbon-free nuclear power.

As far as nuclear energy is concerned, the general public safety concerns have clearly been raised by the 1979 Three Mile Island and 1986 Chernobyl reactor accidents, but also by accidents at fuel cycle facilities in the USA, Russia and Japan. There is also growing concern about the safety and security of the transportation of nuclear materials and the security of nuclear facilities with a view to terrorist attacks (NEA/OECD, 2000). In addition, there are security concerns related to the possible misuse/abuse of commercial or associated nuclear facilities and operations to obtain technology or materials as a precursor to the acquisition of a nuclear weapons capability.

[25] See www.willyoujoinus.com for Chevron's platform on this issue.

[26] They voted, for example, for renewables-related research far ahead of fossil and nuclear energy research.

A final major public concern relates to nuclear waste management, the challenges of which remain unresolved to date. No common rules on nuclear reactor safety or radioactive waste disposal haven been agreed upon until today, although the EC has proposed directives on the safety of nuclear installations and on the management of used nuclear fuel and radioactive waste (EC, 2003).

Given the major role of public acceptance of some specific forms of energy, it seems rather unlikely that nuclear energy will become a dominant energy carrier in the near future in the Western world. Limited R&D efforts in this sector may also contribute to stagnation in the development of nuclear power facilities, as well as long lead times involved in the full operationalization of a nuclear plant. Moreover, nuclear power cannot prevent the large CO_2 emissions from, for example, transportation systems.

Another obstacle to the possible expansion of nuclear capacity are its high overall lifetime power production costs compared to natural gas (e.g. with combined cycle turbine technology, CCGT) or coal, at least in the absence of a carbon tax or an equivalent mechanism (see Table 4.1). The real levelized cost for nuclear power production have been calculated at $6.7 cents/kWh for a Light Water Reactor (LWR). Moreover, the nuclear cost structure is driven by high up-front capital costs which may be an obstacle for additional investments in itself.

Table 4.1 Power costs with carbon taxes (Coal & Gas)

Carbon Tax Cases Levelized Electricity Cost cents/kWe-hr	\$50/tonne CO_2	\$100/tonne CO_2	\$200/tonne CO_2
Coal	5.4	6.6	9.0
Gas (low)	4.3	4.8	5.9
Gas (moderate)	4.7	5.2	6.2
Gas (high)	6.1	6.7	7.7

Source: MIT, 2003: 7.

In 2002, nuclear power satisfied 17 per cent of world electricity consumption (see Figure 4.3). If public resistance, or at least reluctance, persists in a major part of the Western world, the projected increase in nuclear capacity will be only marginal compared to the substantial increase in electricity demand. In that case, demand for fossil fuels, contrary to non-fossil fuel demand, is projected to grow above average growth of energy demand, and its share in overall energy needs will grow to over 80 per cent in 2030 (EC, 2004: 155) (IEA, 2004a). In fact, without a clear expansion of the roles of nuclear energy and renewables in the foreseeable future, fossil fuels, and natural gas in particular, are projected to satisfy some 90 per cent of the growth in energy demand between now and 2030!

Assumption 8 **The energy and thus the gas markets become increasingly nervous due to: the increasing perception that we are running out of oil; the increasing sense of insecurity of energy supply; the more regular shifts in the destinations of international gas flows; the limited substitutability of natural gas; the general lack of incentives to stabilize the market; and the domestic energy supply concerns in the main producing countries, which makes their export supply less predictable. This may lead to more price volatility and unexpected price hikes.**

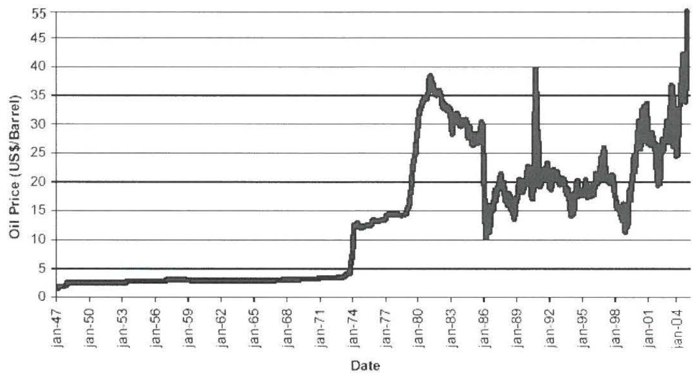
When discussing the chances of increasing market volatility, a clear distinction should be made between volatility in the short run (e.g. within a month, week or even on a daily basis), medium run (e.g. on a seasonal or yearly basis), or in the long run (over the years). As far as the short and medium term is concerned, there is clear evidence that in the course of time the gas price volatility on the existing spot markets has significantly increased (see also Figure 6.2). In fact, in the liberalized markets, gas price volatility has been much higher than the volatility of oil prices, to which gas prices have in fact been linked. This suggests that a further liberalization of gas markets may make gas price volatility more widespread.

Another major development that may have clear implications for gas market volatility is the gas market integration itself, spurred by increasing demand, technological advances, cost reductions in producing and delivering LNG to markets, and market liberalization.

Since a shift to a truly global gas market will make each major consuming or producing region more vulnerable to events in any other region, market integration may well lead to volatility that spreads around the world more easily and with a more pervasive impact.

Although the gas price is expected to be gradually increasingly 'decoupled' from the oil price, the latter's volatility can be expected to feed into the gas market for still a long time. This may also lead to typical patterns of long-term volatility. One should remember that since 1970s the oil price has increased from about \$3/bbl to about \$50/bbl (see Figure 4.13); during the 1970s, within less than a decade, the price increased by a factor of 10 from \$3/bbl in 1973 to over \$30/bbl in 1980, which illustrates how quick oil prices can increase. In the 1980s, the oil prices, in real terms, collapsed again and decreased to much lower levels. Although worldwide inflation has come down significantly, a further rise in oil prices (but possibly collapsing oil prices thereafter) towards the earlier real oil price level could not be ruled out beforehand, especially with a view to the clear recognition of increasing oil scarcity and likely increase in market share of OPEC.

Figure 4.13 West Texas Intermediate Oil Price 1947-2004



Note: the most recent price hike to levels over \$70 per bbl has not been included in this Figure.

Source: Global Financial Data Inc. and authors' addition

In fact, in a recent study, IEA pointed at the expectation of a real price increase, unlike the stable trend in real oil prices since the 1980s, for oil from \$27/barrel in real terms in 2010, via \$31/bbl in 2020 to \$34/bbl in 2030. During the same period, oil demand is expected to grow, according to the same IEA source, to 90 million bbl/day in 2010 (from 82.4m bbl/day in 2004) and 121 million bbl/day in 2030, which reflects that the impact of increased efficiency and structural shifts is more than offset by the increasing volume of demand.

In 2030 OPEC's share in global oil supply will be more than half of what the world needs (2004: 37% only). Since the political stability in a number of large OPEC countries may well remain problematic, and with about 2/3 of the oil reserves located in the Middle East, intermediate shocks in oil supplies seem almost inevitable. The picture for natural gas may not be much different, because over 70 percent of the international gas reserves is located in Russia and the Middle East (notably Qatar and Iran).

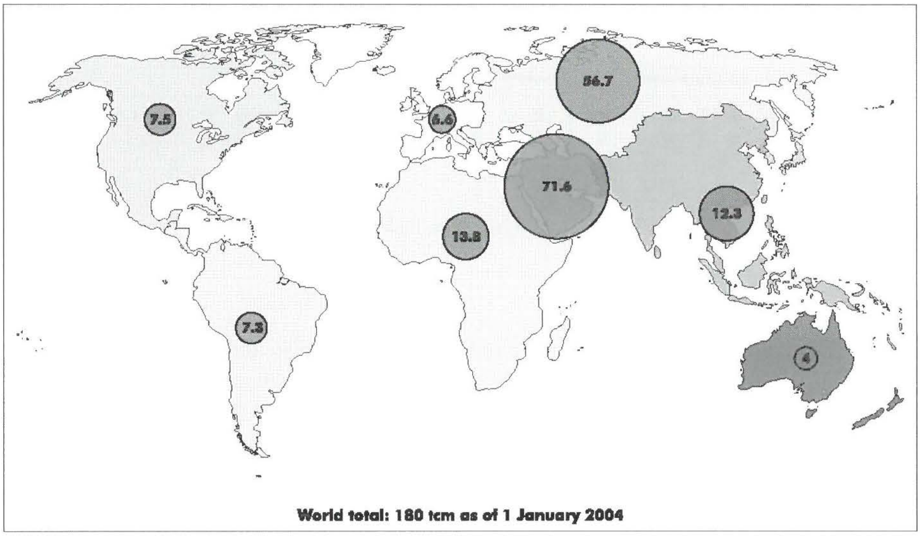
Assumption 9 **The main natural gas producing countries in the Middle East and Northern Africa, Russia, and the FSU states start to exploit their market power by restricting their supply to the world market, which not only adds to the increasing price instability, but which also causes, during considerable intervals, significantly higher prices. This adds to the sense of unpredictability of international natural gas market conditions, and thus raises concerns about security of natural gas supply.**

[27] One may question if the strategic oil reserves can have a serious impact in cases of considerable market disturbances. Although, for instance, the US Strategic Petroleum Reserves, that amounted to about one day of net petroleum imports in 1977, have been expanded to levels covering about two months worth of imported oil, such reserves seem insufficient for serious lasting market disequilibria.

There are a number of reasons why the risk of a limited number of suppliers using their market power to raise prices cannot be ignored.
First, evidence from a number of successful cartel-like actions, including OPEC during the 1970s, suggests that driving up prices by restricting supply, whether or not unexpectedly, may generate a rent, at least temporarily, for the producers if they, as a group, represent at least roughly half of total supply. The reason why such a market dominance seems imperative for successful cartel action is that such coalitions, if smaller, will usually disintegrate when their success is too limited or too short-lived. OPEC's success was based on about its 70 per cent market share during the 1970s (in terms of oil production); its successful market power more or less disappeared as soon as its share declined to less than half.

The question is whether in the foreseeable future comparable conditions may be fulfilled in the international gas market. During 2004 of the overall volume exported by pipeline, or contracted as LNG (502 and 178 bcm respectively, together 680 bcm), 154 bcm was supplied by Russia and the FSU states, 45 bcm by the Middle Eastern countries;[28] and 63 bcm from Northern African countries,[29] which in total amounts to 263 bcm or approximately 40 per cent of total exports. However, the share of these countries' proven reserves (at the end of 2004) in the world's total reserves amounted to: 32.4 per cent,[30] 40.6 per cent[31] and 4.3 per cent respectively, or, when taken together, over 77 per cent (see also Figure 4.14)! Given that future supply of gas on the international market will increasingly reflect underlying reserves, the basic conditions for successful action to drive up prices could be fulfilled, possibly already during the next few decades. The six countries in the above group[32] with the largest proven reserves together have a market share of practically two third.[33]

Figure 4.14 World proven reserves of natural gas



Source: Cedigaz, 2004.

Second, the chances of being able to increase gas prices may become larger once gas prices are convincingly decoupled from other energy prices and substantial investments in the gas infrastructure including LNG have been made so that gas demand will automatically grow. It seems that also these two conditions will increasingly be fulfilled.

28 Oman, Iran, Qatar and UAE.
29 In particular Algeria, Egypt and Libya.
30 Of which Russia has 26.7%.
31 Of which Iran and Qatar represent almost 30%.
32 Russia, Iran, Qatar, Saudi Arabia, UAE, and Algeria; the market share of the 'big three' of them, Russia, Qatar and Iran, is 56.4%.
33 Russia is expected to remain the world's largest gas exporter in 2030. By then Iran is projected to control reserves the size of which represents about half of Russia's reserves.

Third, in a liberalized world there may be considerably fewer long-term contracts and contractual certainty with more competition on the demand side. Flexible infrastructure facilities will support such competition and make it physically possible that the direction of international gas flows change almost instantaneously, as soon as some party anywhere in the world makes a better offer. In such a world, where the sense of urgency with regard to the security of supply will anyhow be stronger and markets may more easily become nervous on that aspect, there seems to be a fertile breeding ground for successful cartel-like action.

Assumption 10 **The substantial and increasing share of LNG in the internationally traded volumes of natural gas, the destination of which is perceived by the demand side as being determined by anonymous market forces, contributes further to the perceived lack of security of supply.**

Security of supply (SoS) can be defined as the availability of energy (in whatever type or form) at all times, in sufficient quantities, and at reasonable and/or affordable prices; or the perception that nothing is going wrong with regard to such factors. Keeping this in mind, it is understandable that the quickly growing role of LNG in the international gas market strongly affects the feeling of increased or, instead, reduced security with respect to deliveries of gas by the international market. How LNG deliveries will affect the SoS perception will probably strongly depend on the question whether the market can be seen as a sellers' or a buyers' market. In the first case, a limited supply, given a certain demand, gives sellers a strong bargaining position vis-à-vis demand, which could make the demand side feel insecure. The opposite obviously applies if potential supply is large as compared to demand.

It is hard to predict whether the future LNG market will develop into a buyers' or a sellers' market. Much will depend on the overall supply and demand balance of natural gas, investment in LNG infrastructure and pipeline systems, and of the number of sources of supply vis-à-vis sources of demand. Current evidence shows that the LNG market is developing from a sellers' market to a buyers' market, which is driven both by volumes and destination flexibility, as well as by the diverse groups of LNG projects and new countries entering the export business.

The increasing role of LNG is anyhow likely because it has a number of perceived benefits: the opportunity for companies to commercialize reserves which are currently considered too remote to exploit economically; and the opportunities for traders to benefit from price fluctuations and to influence local markets by arbitrage transactions. As of 2003, 169 billion cubic meters [34] (or 27% of the total volume of internationally traded gas) of LNG was traded internationally, whereas 455 billion cubic meters were transported internationally via pipelines. Due to a continuous trend of an increasing efficiency of the option, LNG's share in the total is projected to increase, which will further change the trade and investment environment of natural gas. According to IEA projections, 250 bcm will be traded in 2010 and 680 bcm in 2030; a 272 per cent increase. The same source suggests that in 2030 more than 50 per cent of all inter-regional gas trade will be in the form of LNG (IEA, 2004a).

Whether such a projected growth of the LNG market will materialize, strongly depends, however, on the willingness to invest: a sincere LNG commitment within the sector at large is needed to sustain current growth figures. Huge investments are needed, not only to build LNG tankers, but also terminals and liquefaction plants. A Shell official [35] recently emphasized the importance of 'shared trust' within the industry and the institutional setting to allow for the expansion of LNG trade. He mentioned the following list of risks: the reservoir risks attendant on all oil and gas developments; the political risks in exporting and importing countries; the execution risks in undertaking such costly, complex and technologically-intensive projects; the market risks of fluctuating demand and price; and the credit risks, where buyers are not confined to strong utilities and aggregators (Brinded, 2004).

It is questionable whether the commitments of the stakeholders mentioned above will actually materialize and whether the risks discerned can effectively be mitigated given the many uncertainties that characterize the future natural gas market. At the beginning of 2004, there were 15 LNG export terminals, 43 import terminals and 154 LNG tankers operating worldwide. Eight liquefaction terminals were being expanded and five new ones were under construction. In addition, eight new import terminals were being built in the OECD region, 54 new LNG ships were on order and some 30 new LNG supply projects were planned (IEA, 2004a). Most of the new terminals to be built in the next decade and a half will be in the USA and Europe, shifting the current LNG destination focus from the Asia-Pacific region to the Western region (for the 2003 situation, see Figure 4.15). Consequently, LNG trade destinations will become much more widespread. It is uncertain though if the same will also apply to the supply side: in 2004, only four countries, Qatar, Algeria, Indonesia and Malaysia, were responsible for about 63 per cent of the globally traded volume of LNG. Adding the next largest suppliers, Trinidad & Tobago, Nigeria, Oman, and Brunei, to this list increases the share to 87 per cent.

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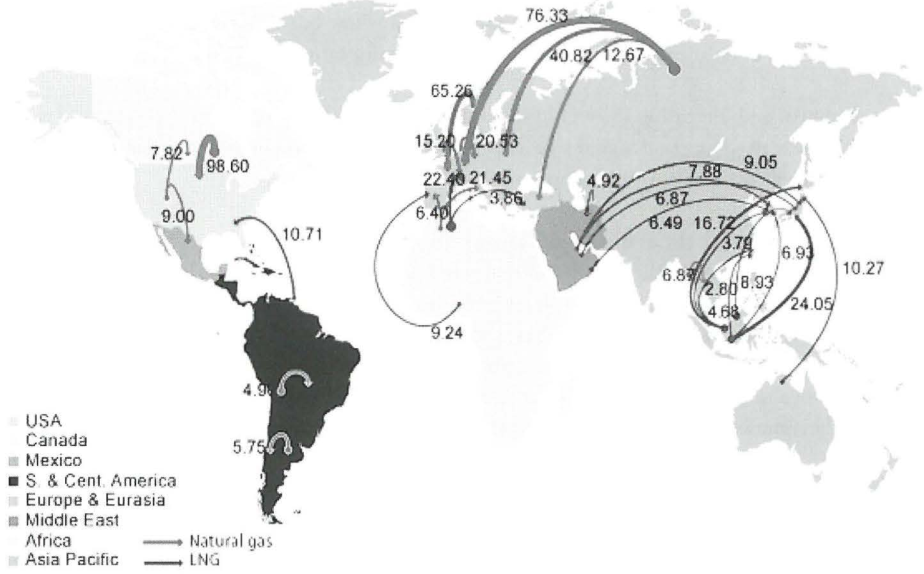
34 Flows are on a contractual basis and may not correspond to physical gas flows (BP).

35 Malcolm Brinded, Group Managing Director of Royal Dutch Shell plc.

Figure 4.15 Worldwide natural gas trade flows, 2003 (bcm)



Source: BP, 2004.

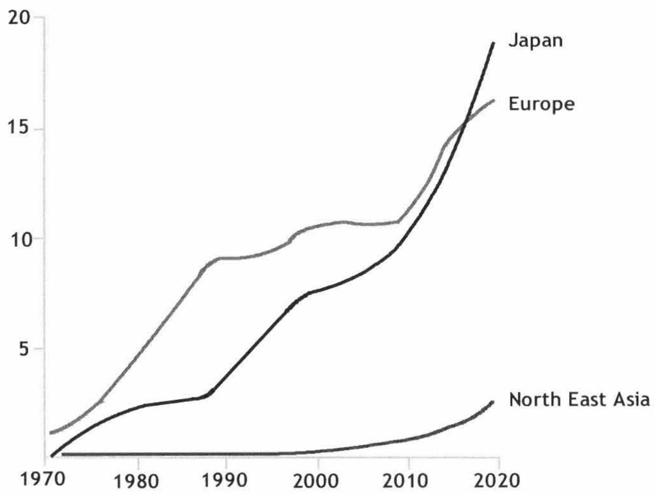
Although the natural gas industry has traditionally been developed on the basis of long-term sales agreements, LNG export is projected to be less dependable on those agreements, as LNG is increasingly traded on the spot market. According to the IEA, LNG spot sales, short-term or single cargo sales, are expected to become more important (2004a). Spot trading represented almost 11% of global LNG trade in 2003 up from less than 2 per cent in the late 1990s. Furthermore, several ships now being built are not earmarked for particular projects and could thus be available for spot-trading opportunities. In addition, older tankers will be freed from their current assignments when long-term contracts expire and part of the capacity of some liquefaction plants built in recent years is not covered by long-term contracts. These tankers will thus also be available to supply the spot market (IEA, 2004a). This trend may, however, further add to the perceived lack of security of supply.

Assumption 11 Energy concerns increasingly dominate foreign policy issues of most countries/blocs.

There are a number of reasons why it seems likely that security of energy supply concerns will increasingly dominate foreign policy agendas of several countries.

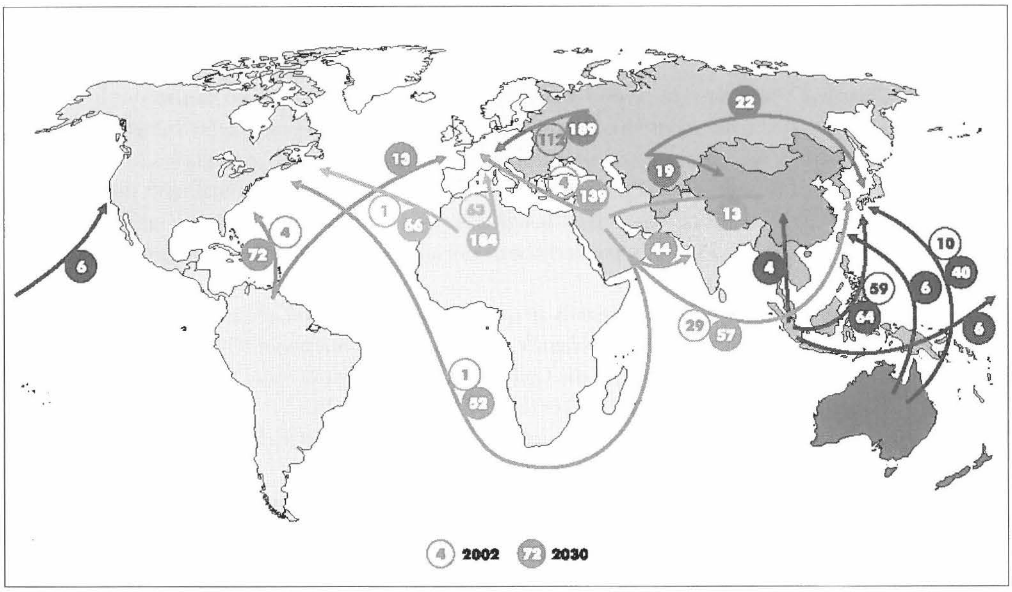
First, natural gas imports (as a percentage of total energy consumption) are projected to grow significantly in all industrialized regions: in the EU from 7% to 20% during 2000-20; in Japan from 9% to 16%; and in North East Asia from 1% to 3% (see Figure 4.16). This makes regions systematically more prone to disruptions which are beyond the control of their jurisdiction. This may add to security of supply concerns. Also the volume of internationally traded gas is likely to substantially increase during the next few decades (see Figure 4.17). Since international trade seems inherently more vulnerable to disruption than domestic transport, this may also increase concerns about future gas deliveries.

Figure 4.16 Gas Imports as percentage of total energy consumption (1970-2020)



Source: Shell, 2001.

Figure 4.17 Major net inter-regional natural gas trade flows, 2002 and 2030



Source: IEA, 2004a.

Second, as has already been argued before, the liberalization trend and the projected increasing role of LNG in traded volumes, spot market trading, short-term contracts, etc., all add to the transparency, liquidity and flexibility of the gas market, but may at the same time make actual deliveries less certain and contracts and contract terms less predictable. This changed contractual environment and structure of the market may be welcomed by some, but blamed by others because it lowers their sense of SoS. To that extent foreign policy may increasingly be used to restore the required SoS levels.

Third, SoS concerns will definitely increase if energy installations or LNG transport become the target of terrorist and other military attacks, or the subject of regional conflicts. Analysis of the main routes of international gas transport shows a number of risky spots in that regard as discerned in Table 6.1. In addition, to mention just a few other vulnerabilities, it can be pointed out that: 80 per cent of the Russian gas production comes from three fields only (Urengoi, Yamburg and Medvezhye); 90 per cent of Russian gas is transported via the Yamal-Nenets corridor; 80 per cent of Russian gas exports to Central and Western Europe transits through the Ukraine; 33 per cent of Italian gas consumption is transported via the Transmed pipeline linking Algeria and Italy; 30 per cent of Spanish consumption is transported via the Algeria/Spain GME pipeline; etc. In fact, there is evidence that natural gas companies are increasingly hedging themselves against possible terrorist attacks. Damage analyses show that the costs to society of a shortfall of gas, likely to occur after a terrorist attack, can be enormous. SoS concerns may further increase as major oil/gas producing regions, such as the Middle East, Russia and North Africa, would, for whatever reason, increasingly be perceived as politically unstable.

Another factor that may undermine the confidence in future international deliveries of natural gas is the increasing involvement of governments, instead of private companies, in the exploration and exploitation of energy resources.[36] For this reason, trade relations are expected to increasingly concern political trade-offs. This may also explain why energy issues will probably increasingly be linked with other major issues of foreign policy concern (e.g. international investment, transfers, economic operation, military assistance, etc.). Finally, accidents, especially with regard to LNG, may cause a disruption of supply on their own. A number of accidents and incidents have already taken place (see also assumption 6 for more details), which has shown that in actual practice the LNG route can be vulnerable.

In the meantime, a number of governments have addressed the security of supply situation. The Chinese Government, for instance, increasingly tries to secure its energy supply (most notably oil and gas) to fuel its economy. China's net oil imports are projected to rise on average by 8.3 per cent per year between 2002 and 2030, thereby increasing China's oil import dependency from about 30 per cent in 2004 to around 85 per cent in 2030. Presently, Chinese (state-owned) companies are buying oil from state-owned companies in Iran, not necessarily in exchange for money. Furthermore, China is extending its strategies to include Canada, comprehending plans for a pipeline and ports that would allow as much as one million barrels per day of oil from Alberta's tar sands to move to Canada's west coast for export to China. Furthermore, China has made a series of oil deals that extend its influence in Latin America. Russia's emerging relationship with China can be seen as another strategic alliance in the global run to secure the proper and timely availability of much needed energy resources.

Another example of increasing SoS attention is the recent study issued by the US Congress and carried out by the Congressional Research Service, which shows that LNG, due to its visibility and recognizable characteristics, may be vulnerable to terrorist attacks. However, possibly due to high security measures and heavy control, no terrorist attacks have been reported in the recent decades. The report signals that the costs involved in securing and protecting of LNG transports (ships), terminals and storage capacities rapidly increase with a rising demand for LNG and concludes that, although security has so far been guaranteed and incurring costs limited, US Congress may consider whether the LNG industry presently carries an appropriate share of the burden for future LNG security.

Another report by the Congressional Research Service presents an overview of attacks on oil and gas pipelines. For example:

- In Colombia rebels have bombed Occidental Petroleum's Caño Limón pipeline about 950 times since 1986, shutting it for months at a time and leading to lost revenues for the Colombian Government of some $ 2.5 billion.
- In 1998 one of these attacks caused a fire that killed or injured over 100 people.
- In the last 2 years, oil and gas pipelines have also been attacked in Nigeria, Pakistan, Sudan, Myanmar and, most recently Iraq.
- In 2001 a vandal's attack with a high-powered rifle, also on the trans-Alaska pipeline, forced a two-day shutdown and caused extensive economic and ecological damage.

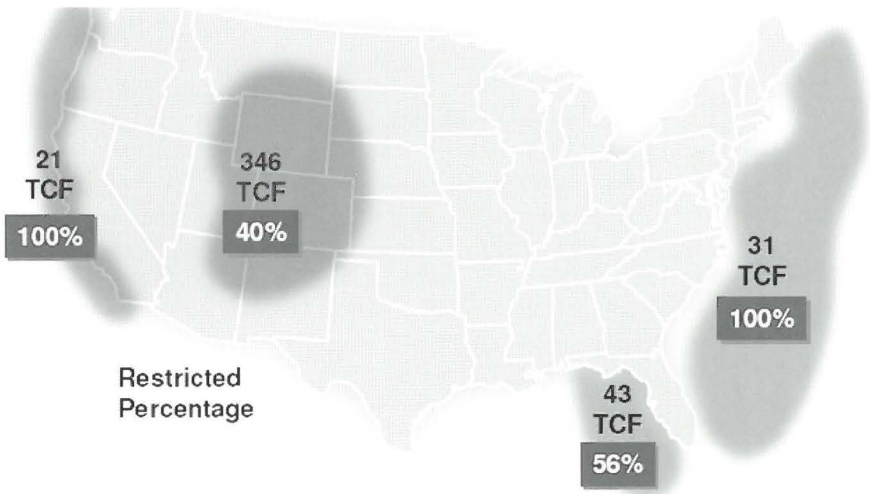
These examples suggest that SoS concerns are justified.

Assumption 12 **In the process of exploration and exploitation of natural gas, safety and environmental concerns play an increasingly important role, e.g. with regard to where and under what conditions gas exploration is allowed to be initiated.**

[36] An example is the claim the Russian government put on Yukos in 2003. Moreover, it is expected that soon a law will be passed making bidding by both foreign and Russian offshore companies (non-government) on Russia's natural resources impossible. Another example is state-owned Aramco, a Saudi state owned company about 20 times the size of BP or Exxon Mobil. Recent examples are the developments of increasing state control of energy resources in Venezuela and Bolivia.

Although legal restrictions on gas exploration differ strongly among countries, such restrictions can slow down exploration, or even prevent considerable gas resources/reserves from being explored at all. This puts further pressure on the increasing import dependency of a number of main industrial centers. An example is the USA, where – at least at present – according to the American Gas Association, a considerable amount of gas resources cannot be mined for various reasons. As far as the resources in the Rockies are concerned, approximately 29 trillion cubic feet (tcf) of it are closed for development and 108 tcf is only available with restrictions (see Figure 4.18).

Figure 4.18 US gas resources and restricted accessibility



Source: American Gas Association, 2004.

At the end of 2005, a plan to enable the drilling for oil in the Arctic National Wildlife Refuge in Alaska was rejected by the US Senate. As a rough estimate, this Wildlife reserve contains approximately 10 bn bbl of oil equivalent. This shows that resistance can be successfully mobilized by emphasizing environmental concerns, complicating efforts to exploit remaining reserves.

Another illustration of the increasing impact of environmental concerns is the recent announcement of the Russian President Putin that a new oil pipeline to the Far East will not be constructed just passing lake Bajkal (containing about 20 per cent of the world's fresh water reserves), but instead some 40 km to the north.

Assumption 13 **The structure of international gas contracting is increasingly dominated by security of supply concerns.**

In view of the expected increasing concern about security of energy supply, it seems fair to assume that there will be a continuous discussion on the issue whether the shift from the traditional, highly structured gas world of government-backed, bilateral, fixed-priced international contracts towards a world dominated by private, open market contracts, is desirable. Several countries of destination may increasingly try to secure their gas supplies via long-term bilateral contracts. In this process, new intermediary players will probably enter the market. Also governments could increasingly interfere with international gas contracting regimes, as shown by some examples under assumption 4.12.

For instance, it is expected that the EU will try to reach a compromise between spot-market transactions and long-term obligations, whereby long-term contracts will remain basic, and spot transactions will be of secondary importance. In 2010, about 90 per cent of demand is still expected to be served by long-term contracts.

A large number of further contractual implications can be foreseen if SoS concerns will increasingly prevail. Such changes could relate to the issues of: take-or-pay clauses, destination clauses, contract duration, coverage of swing factors, balancing conditions, Force Majeure, etc. It is difficult to project beforehand, due to different trends of liberalization and increasing concern about SoS, what the precise direction of international contract terms and conditions will most likely look like.

Finally, increased SoS attention may create new partnerships for exploration and exploitation of gas reserves and strengthen the role of public-private partnerships in this regard.

Chapter 5

Coal, Oil and Nuclear Storyline

5.1 General description

In this storyline economic growth in Asia and corresponding growth in energy demand remains high, whereas growth in the industrialized world remains modest, i.e. less than 2% per annum. Asia increasingly wants to use its large coal reserves to accommodate its strong economic growth. In addition, it considerably expands its nuclear power capacity (and some renewables) to be sure that energy shortages can be tackled. In terms of the components of energy supply, the USA shows a similar trend: in order to become less dependent of foreign supply, which is considered unreliable, extensive investments are made in in the exploitation of Canadian tar sands. Europe and Japan have a relatively strong focus on renewables and face no serious problems in meeting their energy demand by traditional imports of mainly oil, especially because oil reserves turn out to be larger than anticipated. In short, the energy strategies of the various countries are assumed to be increasingly targeted on self-reliance, i.e. to make sure that energy will be produced as much as possible through domestic primary energy resources or those of close allies.

In this storyline the commitments under the post-Kyoto regime gradually become tighter, but this process is very slow. There is quite some optimism that the combination of clean coal technologies, the nuclear option and renewables can solve the problem via technological breakthroughs.

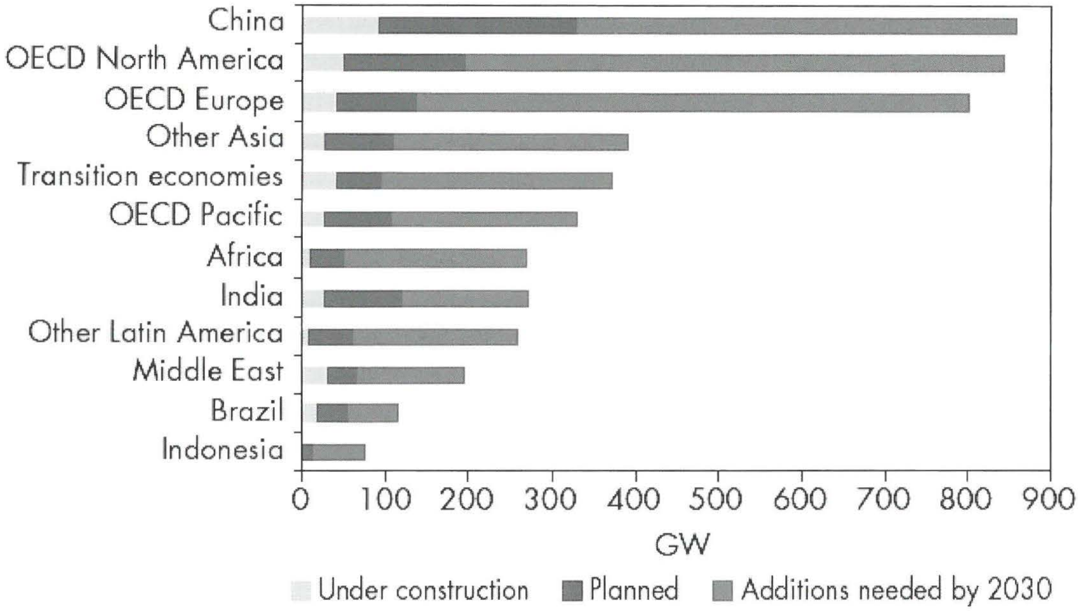
Thus, coal will make a considerable comeback, also because of new clean coal technologies, and the nuclear option gains considerable support, particularly in Asia. Because of the relative decline in oil demand and still large oil reserves, these developments combined lead to a much lower worldwide demand for gas than anticipated.

In such a world, both energy and carbon credit (-equivalent) prices do not rise much beyond present levels (i.e. about €70 per barrel for oil, and about €10-20 per barrel for the credit). As a consequence, the sense that energy is an urgent source of public concern will not emerge and incentives to invest in a large-scale expansion of gas infrastructure facilities remain subdued. Accordingly, natural gas will no longer be considered the transition fuel par excellence, and to the extent that governments feel committed to mitigation targets, also driven by green NGOs, they prefer, on average, to support the further development of specific renewables for particular purposes (e.g. hydrogen for transport; hydro for base-load power production, or solar for decentralized systems). In addition, the gas sector struggles with the new liberalization/regulatory regimes, which cause underinvestments in infrastructure development and exploration. Moreover, there may be concerns, especially regarding internationally traded LNG, that gas could be an unsafe form of energy. All this leads to a market share reduction of natural gas in overall energy supply.

5.2 Assumptions and rationale of the Coal, Oil and Nuclear Storyline

Assumption 1 **There is a general feeling that economic development will be vulnerable to the insecure imports of oil and gas. Such imports are not only costly because of the fairly high oil and gas prices in this storyline, but they are also increasingly considered unreliable and in conflict with the policy target of minimizing dependency from other countries, or even worse, from the inherently unpredictable world market energy supplies. This stimulates countries to actively develop an energy portfolio, which is compatible with such targets.**

Figure 5.2 Power generation capacity required by region (GW)



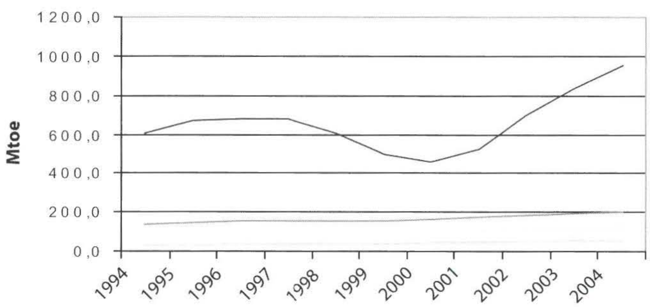
Source: IEA, 2004a: 209.

Assumption 2 **Growth in Asia remains high throughout the period; optimism about clean coal technology, relatively safe nuclear power production and some renewable options make Asia increasingly rely on their own coal reserves for their energy needs. Together with a noticeable expansion of their nuclear capacity and the introduction of some renewable energy sources, especially for decentralized systems, they succeed in considerably reducing their dependence on foreign energy supplies. Growth in the OECD region remains fairly limited: the USA actively tries to reduce its dependency on 'less reliable' energy sources and heavily invests in exploration and exploitation of Canadian tar sands for oil production and in its domestically widely available coal reserves. The European Union and Japan also show limited economic growth. With overall oil demand remaining low, these regions can maintain access to international oil supplies relatively easily, albeit at relatively high prices.**

There are a number of reasons to assume that countries like China and India will continue to rely on coal when satisfying their primary energy demand. The IEA projects, for example, that two-thirds of the increase in global coal use over the next thirty years will take place in India and China.

First, coal consumption clearly has already been on the rise (see Figure 5.3). During 2000-2004, for instance, coal consumption in China has doubled from about 500 Mtoe to about 1,000 Mtoe; substantially above the growth rate the underlying economy. This recent development may underline the clear intention of the Chinese authorities to maintain a strong focus on coal as one of the key energy drivers for the rapid economic progress.

Figure 5.3 Coal consumption (selected Asian economies)



Source: BP, 2004.

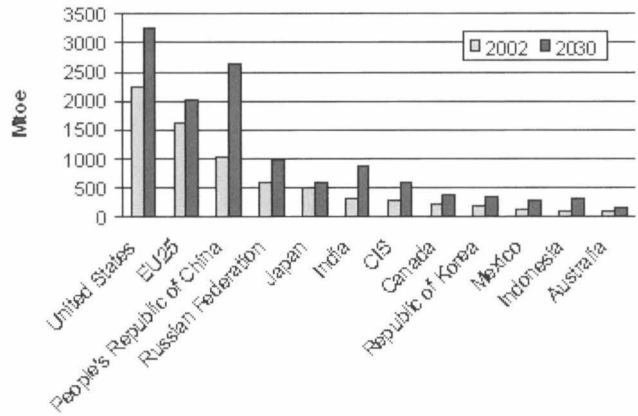
Without active diversification policies, most economic blocs are projected to become increasingly dependent from imported fossil energy, notably oil and gas (for the projected import dependency of gas, see Figure 4.16). As outlined in the former storyline, the assumed dominance of the security of supply (SoS) issue provides reasons why such an increased import dependency may give rise to major concerns in policy making circles and eventually also among the public at large: people will suffer from high and volatile energy prices, the development of which seems to be completely beyond control; there could be oil and gas shortages due to various interruptions during an earlier stage of the value chain; the feeling may grow that there is less control of its own economic progress and that one is left with vagaries of an anonymous world energy market; and one will actively try to refrain from the risks of serious international tension and conflict related to energy matters.

The obvious response to these concerns will be to strive for more self-reliance in terms of energy supply and therefore to look at options for energy production that would require less primary energy imports. The notion of increasing self-reliance, which is central in this storyline, substantially diminishes the attractiveness of oil and gas, and induces an active search for the main alternatives, which are: coal, at least typically in a number of strongly growing regions; nuclear energy; and some forms of renewables. Therefore, an important aspect in this storyline is, unlike the transition storyline outlined in Chapter 3, that natural gas is not a 'winning' but rather a 'losing' fuel, with a decreasing market share. In comparison to earlier expectations, the role of natural gas will remain disappointingly limited. This trend may be enhanced as more critical questions are posed concerning the very sizeable projected investments (about $ 6 trillion cumulative between 2003-2030) in gas and oil infrastructure, exploration capacity, pipelines, other transport infrastructure and terminals alike, and even larger projected investment in power generation capacity (about $ 10 trillion cumulative). It could be questioned whether investments would be needed for a continuing reliance on foreign, expensive and unreliable oil and gas as primary energy sources.

The implication of this increasing attention for the benefits of stronger energy self-reliance is that the shares of the several primary energy sources in 2030 will clearly differ from those projected in the IEA Reference Scenario. According to the IEA, the share of oil and gas in overall primary energy demand would increase from 57 per cent in 2002 to 60 per cent in 2030, which would be mainly due to a rising share of natural gas from 21 per cent to 25 per cent. This storyline, instead, assumes a drop in the combined market share of oil and gas to a level of about 50 per cent, whereas coal, nuclear and renewables jointly gain ground; their collective share rises from 43 per cent to 50 per cent. Which of the three sources in this 'alternative' mix (coal, nuclear or renewables) will become the main winner is typically region- or even country-specific. It seems fair to assume in this storyline that coal will gain market share in rapidly growing, resource-rich regions, whereas renewables will win in a number of industrialized countries; the position of nuclear energy will depend on national priorities which may easily differ, even among neighboring countries.

A specific point is that up to 2030 energy consumption (see Figure 5.1) and GHG emissions, as well as investment in the energy sector, are projected to expand most strongly in countries such as China,[37] India and South East Asia. This is mainly the result of a relatively strong economic growth. In fact, about half of the projected 16 trillion required cumulative investment in the energy sector during 2003-2030 is likely to take place in Asia (see Figure 5.2). It is conceivable that those countries will, with a view to such a tremendous investment activity, be careful not to make the mistake made earlier by other countries, to become economically too much dependent on foreign suppliers of products that are indispensable for economic progress. This is particularly likely since most of the important Asian countries in terms of projected growth have a long tradition of a certain political and economic self-reliance.

Figure 5.1 Energy consumption for selected economies, 2002 and 2030



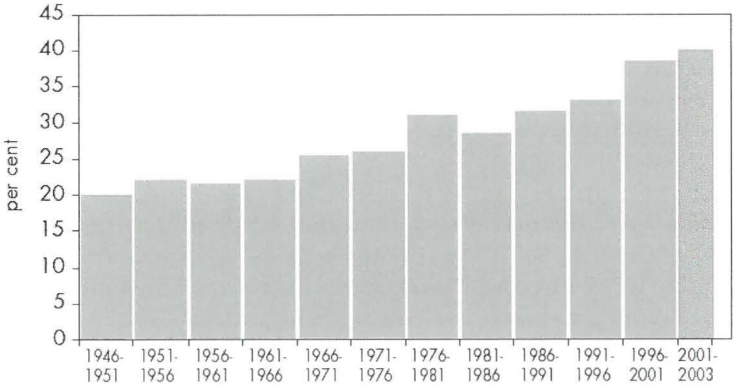
Source: Matysek et al., 2005.

[37] China's total energy consumption is projected to increase by approximately 250 per cent by 2030. According to IEA projections, China and India alone will be responsible for 68% of the increase in demand over the period 2002-2030.

Oil exploration technology and the use of new sources are now rapidly growing. There is no reason why the spectacular progress observed in the past could not be repeated in the foreseeable future. For instance, four decades ago oil wells were operated close to shore in relatively shallow water. Since then advances in exploration and production have enabled wells to reach reserves on the deeper continental shelf and beyond. According to Jim Emme, vice president for exploration at Anadarko, technology breakthroughs are the reason why exploration techniques have continuously improved: "If you had asked me in 1961 I'd have said that what we're doing now was impossible" (National Geographic, 2004: 105).

This justifies that one can indeed be fairly optimistic about the possible impact of a number of new developments, not only with regard to prospective drilling success showing a rising trend anyhow (see Figure 5.8), but also with regard to: heavy oils, tar sands and oil shales (National Geographic, 2004).

Figure 5.8 World oil exploration drilling success rate



IEA, 2004a: 100.

Heavy oils

Using current technology, about one-third of heavy oil reserves is potentially recoverable. Heavy oils can be pumped just like conventional petroleum, except that they are much thicker, more polluting, and require more extensive refining. About 90 per cent of estimated reserves are in the Orinoco 'heavy oil belt' of Venezuela, which contains an estimated 1.2 trillion barrels.

Tar sands

The development of oil sand deposits has become more important since the mid-1990s. Tar sands are found in sedimentary rocks and must be dug out and crushed in giant opencast mines. It takes about 5 to 10 times as much energy, area and water to mine, process and upgrade the tars as processing conventional oil. The Athabasca deposits in Alberta, Canada are the world's largest resource, with estimated reserves of about 1.8 trillion barrels, an amount that may exceed the world's remaining reserves of ordinary crude oil. Of this, only about 280-300 bn barrels may be recoverable, either because the tar sand lies too deep, or is located in deposits that are too sparse to be exploited. In Canada production accounts for about 20% of Canada's oil supply and it is growing by 7 per cent annually and is expected to have doubled by 2010 from earlier levels of some 1 m barrels per day. Venezuela has large documented deposits of oil sands as well.

The development of tar sands is stimulated by both technological improvements and Canada's cut in the royalties that companies had to pay during the first few years. In fact, due to this development, in terms of oil reserves Canada is now ranked second, right behind Saudi Arabia, and ahead of Iraq, Iran, and Kuwait. However, the development of tar sands requires much effort.[40] It takes three barrels of water to extract one barrel of bitumen, which draws heavily on the Athabasca River. Moreover, heating all that water takes vast amounts of natural gas. Worried about Canada's dwindling natural gas supplies, Alberta has even considered nuclear energy instead.

However, compared to world oil demand of over 80 m barrels per day (BP, 2005), Canada's production is rather small (or about 4% of world total). Nevertheless, one should take into account spin-offs emanating from recent efforts in this industry. If Canada showed

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[40] The sand has to be strip-mined, two tonnes of it for each barrel of oil. Trucks haul 400 tons in a single load, in beds heated during the subarctic winters so the sand does not freeze. Next to the mine, the sand goes into the equivalent of giant washing machines, where torrents of warm water and solvent rinse out the tar, or bitumen, leaving wet sand that is dumped in tailing ponds. Even then the bitumen is not ready to be piped off to a refinery like ordinary crude. To turn it back into crude oil, it is either cooked, or heated to lower temperatures and churned with hydrogen gas and a catalyst (National Geographic, 2004: 105).

the world (and Venezuela in particular) that it can economically develop these kinds of oil deposits (which are among the most costly in the world), there is a good chance that other countries will develop theirs at currently (2005) high oil prices.

Oil shales

Oil shales exist in large quantities in ecologically sensitive parts of Colorado, Wyoming and Utah at varying depths. However, the industrial process needed for oil extraction requires hot water, which makes it much more expensive and less energy-efficient than conventional oil. Currently, Shell, Exxon, Chevron Texaco and other oil companies are investing billions of dollars in this expensive oil production method.

All such new developments have led the US Geological Survey to conclude in a year-2000 study that oil availability is at least 50 per cent higher than pessimists believe, much of it is located the Middle East (National Geographic, 2004: 108).

An odd reason why oil reserves may turn out to be larger than presently anticipated is the perception of oil scarcity itself. Increasing doubts about timely and sufficient oil supply as well as price hikes stimulate both government and business investments in other energy sources. This holds especially for applications that increasingly compete with oil in the transport sector, which seems a key development simply because at present about 50 per cent of world oil demand is for transport purposes. This percentage may well increase further. With an expected increase in the role of natural gas, biofuels and even hydrogen in satisfying demand for transport fuels, this could considerably slow down overall oil demand. The same impact could come from progressive fuel efficiency standards, which would simply be imposed by governments, as it is already the case in a number of countries. Such trends may well save oil and therefore considerably prolong the oil era.

Finally, the low energy price period of the 1980s and 1990s has substantially reduced public energy research expenses in the Western world (except for Japan). For example, since the early 1980s, IEA Members have reduced their energy-related research and technology development budgets by half. In the 1979-1999 period US budgets fell by two-thirds. If, under the pressure of rising oil prices and concerns about long-term oil availability, governments would once again support public R&D expenditures, possibly in close collaboration with industry, new insights and breakthroughs on saving oil seem feasible.

Assumption 5 **Fall-out risks and the risks related to nuclear waste storage are reduced because of new technologies. This makes nuclear energy more fashionable and rapidly increases its market share in power production, especially in Asia; nuclear power production costs can take considerable advantage of economies of scale and learning effects.**

The main problem with nuclear power production is the disposal of nuclear waste. Basically, a nuclear plant produces two kinds of toxic waste: fission products and transuranics. When spent fuel rods from power production are removed from the reactor, they are temporarily placed in underwater storages, next to the plant. These rods are extremely radioactive because of the still active fission products, the so-called 90Sr and 137Cs, which, however, have only a relatively short half-life value: about 30 years. A much bigger problem is caused by the containment of transuranics, mostly 239Pu. The half-live value of this type of plutonium is much longer: about 24,000 years. The plutonium can also be used in a nuclear weapon program, which makes it even more dangerous. However, 239Pu can be reused and recycled, which diminishes the amount of nuclear waste produced.

Over the past decades, nuclear waste recovery and recycling techniques have improved and will continue to do so as the scientific community keeps searching for new ways of handling nuclear waste and reducing its half-life value. Current nuclear waste will remain very hazardous for approximately 100 years. After that period, it can be stored rather safely in underground storage facilities.

The technological and innovative advantages of nuclear power over e.g. wind and solar energy are obvious. Nuclear power has, for example, the potential to develop batteries that will last for over 10 years. Taking into account some other advantages, like low associated CO_2 emissions, it may well be that nuclear power will become a rather popular, if not standard, option for typically middle and high-income countries to meet ever increasing energy demand and to achieve technological innovation at the same time.

Table 5.2 clearly indicates that the 440 globally operational nuclear power plants can be found in 30 countries all over the world ranging from rather poor developing countries such as Argentina, Brazil and Pakistan to wealthy industrialized countries such as Sweden, the USA and Switzerland. Within a few years from now, the number of countries with nuclear power plants will probably increase to 37 countries. This expectation is based on the number of reactors that are under construction and have been proposed or planned and which would increase the number of nuclear reactors to 575 and raise installed capacity from about 368.000 MWe to about 485.000 MWe (a 32% increase).

Table 5.2 World nuclear power reactors 2004-05

	Nuclear electricity generation 2004		Reactors operable		Reactors under construction		Reactors panned		Reactors proposed	
			July 2005		July 2005		July 2005		July 2005	
	billion kWh	% e	No.	MWe	No.	MWe	No.	MWe	No.	MWe
Argentina	7.3	8.2	2	935	1	692	0	0	0	0
Armenia	2.2	39	1	376	0	0	0	0	0	0
Belgium	44.9	55	7	5728	0	0	0	0	0	0
Brazil	11.5	3.0	2	1901	0	0	1	1245	0	0
Bulgaria	15.6	42	4	2722	0	0	0	0	1	1000
Canada	85.3	15	17	12080	1	515	4	2570	0	0
China	47.8	2.2	9	6587	2	1900	8	8000	19	15000
Czech Republic	26.3	31	6	3472	0	0	0	0	2	1900
Egypt	0	0	0	0	0	0	0	0	1	600
Finland	21.8	27	4	2656	0	0	1	1600	0	0
France	426.8	78	59	63473	0	0	0	0	1	1600
Germany	158.4	32	17	20303	0	0	0	0	0	0
Hungary	11.2	34	4	1755	0	0	0	0	0	0
India	15.0	2.8	15	2993	8	3638	0	0	24	13160
Indonesia	0	0	0	0	0	0	0	0	2	2000
Iran	0	0	0	0	1	950	1	950	3	2850
Israel	0	0	0	0	0	0	0	0	1	1200
Japan	273.8	29	55	47700	1	866	12	14782	0	0
Korea DPR (North)	0	0	0	0	1	950	1	950	0	0
Korea RO (South)	124.0	38	20	16840	0	0	8	9200	0	0
Lithuania	13.9	72	1	1185	0	0	0	0	0	0
Mexico	10.6	5.2	2	1310	0	0	0	0	0	0
Netherlands	3.6	3.8	1	452	0	0	0	0	0	0
Pakistan	1.9	2.4	2	425	0	0	1	300	0	0
Romania	5.1	10	1	655	1	655	0	0	3	1995
Russia	133.0	16	31	21743	4	3600	1	925	8	9375
Slovakia	15.6	55	6	2472	0	0	0	0	2	840
Slovenia	5.2	38	1	676	0	0	0	0	0	0
South Africa	14.3	6.6	2	1842	0	0	0	0	1	125
Spain	60.9	23	9	7584	0	0	0	0	0	0
Sweden	75.0	52	10	8857	0	0	0	0	0	0
Switzerland	25.4	40	5	3220	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	3	4500
Ukraine	81.1	51	15	13168	0	0	1	950	0	0
UK	73.7	19	23	11852	0	0	0	0	0	0
USA	788.6	20	103	97838	1	1065	0	0	0	0
Vietnam	0	0	0	0	0	0	0	0	2	2000
WORLD	**2618.6**	**16**	**440**	**367,684**	**23**	**17,431**	**39**	**41,472**	**73**	**58,145**

Note: Building/Construction = first concrete for reactor poured, or major refurbishment underway
Planned = first concrete for reactor poured, or major refurbishment underway
Proposed = clear intention but still without funding and/or approvals
The world total includes 6 reactors on Taiwan with a combined capacity of 4884 MWe, which generated a total of 37.9 billion kWh in 2004 Source: World Nuclear Association, 2005.

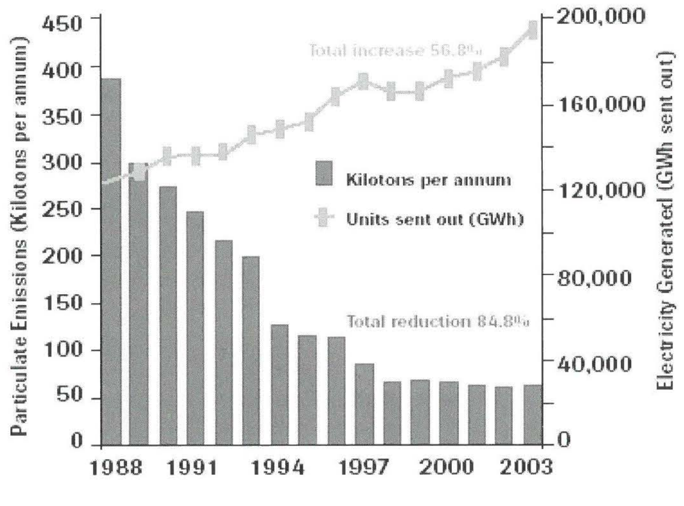
Assumption 6 **Clean coal technologies will take a giant leap forward. Gasification of coal, modern pulverized coal combustion, electrostatic precipitators and other forms of Clean Coal Technologies (CCT) make the use of coal nearly as clean as natural gas, while still being price competitive. CCTs are widely implemented in energy production.**

Current conventional coal-fired power generation normally takes place via pulverized coal combustion (PCC): coal is pulverized into a powder and burnt in a high temperature furnace to heat water and drive a steam turbine. 90 per cent of present coal-fired capacity uses this technology. Circulating fluidized bed combustion (CFBC) makes up for the remaining share.

Except for the CO_2 pollution associated with the use of coal, other environmental concerns are emissions of particulates, SO_2 and NOx. Also for these emissions there is clear evidence of improvement through technologies which deal with particulate emissions (such as ash from coal combustion, electrostatic precipitators, fabric filers, wet particulate scrubbers and hot gas filtration systems) and which reduce and in some cases eliminate SOx emissions (the most widely used technology being wet scrubbers). These technologies are now being applied in both industrialized and developing countries. The same holds for technologies to cut NOx emissions, although these are less prevalent in developing countries.

As far as particulates are concerned, Figure 5.9 shows improvements achieved at a power station in South Africa by means of electrostatic precipitators (ESPs). ESPs use an electrical field to create a charge on particles in the flue gas, so that the particles are attracted to collecting plates. This technology can reduce over 99 per cent of particulate emissions. In the case of the Lethabo Power Station, the precipitators remove 99.8% of fly ash, part of which is sold on to the cement industry.

Figure 5.9 Particulate emission reductions at Lethabo Power Station, South Africa

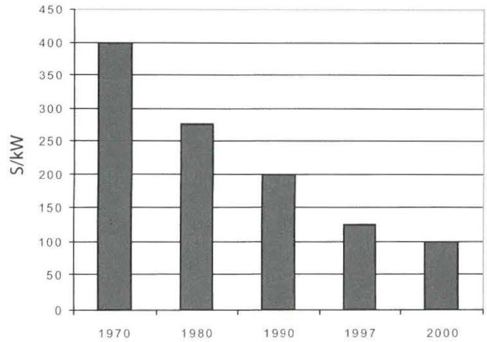


Source: WCI, 2004.

With respect to SO_2 emission reduction, the flue gas desulphurization (FGD) technology can be effectively employed. This technology uses a sorbent, usually lime or limestone, to remove SO_2 from the flue gas. In 2003 FGD systems were installed in 27 countries and resulted in enormous SO_2 emission reductions (WCI, 2004: 7). As it is shown by Figure 5.10, the cost of FGD units has significantly been reduced, at least in the USA. This, together with global concerns about the effects of acid rain, has led to the widespread utilization of these kinds of technologies. Major US utilities have announced their intention to install FGD systems in a number of their coal-fired power stations.

NOx reduction technologies include the use of low NOx burners, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). The latter two technologies reduce NOx emissions by treating the NOx post-combustion in the flue gas, whereas the former technology, together with burner optimization techniques, is used to minimize the formation of NOx during combustion. The SCR technology has achieved 80-90 per cent of NOx reduction and has been applied commercially in Japan since 1980 and in Germany since 1986 (WCI, 2004). Nowadays, about 15 GWe of coal-fired SCR capacity is operational in Japan and nearly 30 GWe in Germany, out of a total of approximately 53 GWe worldwide (WCI, 2004).

Figure 5.10 Reductions in FGD costs in the US

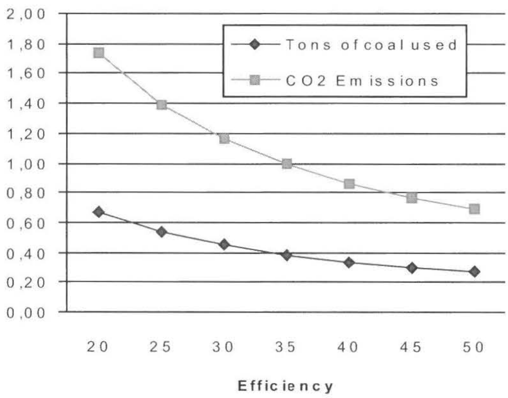


Source: IEA Clean Coal Centre in: WCI, 2004.

The deployment and continuous enhancement of a range of advanced technologies allow for further reductions in the emissions of pollutants and improves efficiencies of coal power plants. These technologies include: fluidized bed combustion (FBC), supercritical and ultra supercritical (USC) power plant technology [41] and Integrated Gasification Combined Cycle (IGCC). Circulating fluidized bed combustion (CFBC) is of particular value for low grade, high ash coals that are difficult to pulverize and which may have variable combustion characteristics, while still ensuring low emissions of NOx and SOx. Presently, the first supercritical CFBC plant is being established in southern Poland; it is scheduled to become operational in 2006 with projected efficiency levels of around 43 per cent, which is about 7 per cent higher than the current OECD average of 36 per cent. According to the World Coal Institute, CFBC is likely to be the most attractive form of FBC technology and could thus achieve a serious share of the global market for power generation. Generally, supercritical power plants can achieve overall thermal efficiencies of about 45 per cent, compared to a mere 30 per cent of traditional plants. Improvements in coal combustion efficiency dramatically reduce emissions as Figure 5.11 highlights. When comparing energy efficiency rates of supercritical power plants with traditional ones, CO_2 emissions are reduced by about 0.4 per MWh of electricity produced, which comes down to 35 per cent. Generally speaking, a one percentage-point increase in efficiency reduces emissions by around 2 per cent (WCI, 2004: 6).

In most countries supercritical plants are now commercial, with capital costs only slightly higher than those of conventional plant and with significantly lower unit fuel costs. In 2003 more than 400 supercritical power plants were operating globally, with a focus on the USA, Europe, the Russian Federation, and Japan (Paul, 1999: 1). China, the world's largest producer of coal, now applies supercritical plants as a standard for new plants. Currently, nine supercritical plants are in operation in China, with 16 under construction and a further eight planned, altogether amounting to over 21 GW of coal-fired capacity (WCI, 2004: 9).

Figure 5.11 CO_2 emissions per MWh of electricity produced from coal at various efficiency levels



Source: WCI.

[41] Supercritical is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase (that is, they are a homogenous fluid). Water reaches this state at a pressure above 22,1 megapascals (MPa). Supercritical coal fired power plants with efficiencies of 45% have much lower emissions than subcritical plants for a given power output. Options to increase the efficiency above 50% in ultra-supercritical power plants rely on elevated steam conditions as well as on improved process and component quality (WCI).

The further development and support of IGCC offers the prospect of net efficiencies of 56 per cent and therefore its widening deployment will have an increasingly favorable impact on the environmental performance of coal (WCI, 2004: 9). Currently, around 160 IGCC plants are in operation worldwide. According to the National Mining Association, around 16,500 MWe of IGCC is expected to be in operation in the USA by 2020 (NMA, 2003). IGCC is deemed particularly important for the future as this technology may be the chosen pathway for the ultra low emissions system of the future, using carbon capture and storage (see assumption 7), and as part of a future hydrogen economy. In IGCC systems coal is not combusted directly but it reacts with oxygen and steam to produce a 'syngas' composed mainly of hydrogen and carbon monoxide. The syngas can be 'shifted' to produce CO_2 and H_2, which can then be separated so that the hydrogen is available as a clean fuel product for use in power generation via gas turbines and fuel cells. The CO2 is then available in a concentrated form for capture and storage.
Finally, operational synergies can be achieved in using renewable energy resources (biomass-based options) in coal-fired power plants. Existing conventional coal-fired power stations can generally use between 10 and 20 per cent of biomass without modification. Furthermore, purpose-built coal and biomass co-fired plants can also be constructed.

The World Coal Institute, the IEA Clean Coal Centre and other institutions are widely promoting CCTs. Although these technologies are presently still rather expensive, many research and marketing efforts are dedicated to support their development (see Box 5.1). The coal industry realizes that it has to invest in these technologies in order to survive in the long run.

Box 5.1 R&D projects

Ultra-clean coal
Engineers in Nottingham are developing ultra-clean coal that could make power generation 50% more efficient and reduce carbon dioxide emissions by a third. When coal is dug from the ground, it contains about 15% mineral matter, including sulphates, oxides, clays, quartz and carbonates, which greatly restricts its use. The chemical leaching process being developed promises to reduce this figure to less than 0.1%, meaning much greater efficiency per metric ton of coal and up to 33% less CO_2 pollution from the power station. The main advantage of ultra-clean coal is that it can be burned directly in gas turbines, reaching efficiency levels of around 55%. This is a much better result when compared with traditional efficiency levels of about 37% (the OECD average).

AD 700 Power Project, Europe
The AD 700 Power Plant involves collaboration between the European Commission and industry and is one of the projects financed by the EU's Fifth Framework R&D Programme. The project aims to raise efficiencies to 55% through ultra supercritical technology, resulting in lower fuel consumption and a reduction in CO_2 emissions of almost 15%.

CANMET Energy Technology Centre, Canada
At the CANMET Energy Technology Centre, clean coal R&D focuses on a number of areas. These include research into oxy-fuel combustion, so that flue gases from power stations might be made CO_2 rich (rather than diluted with nitrogen form the air) to eliminate the capture step prior to storage; fluidized bed combustion of steam coals for reduction of acid precursors; and mercury emission reductions from coal-fired power stations.

COAL21, Australia
COAL21 is a major initiative of the Australian Coal Industry aiming at "fully realizing the potential of advanced technologies to reduce or eliminate greenhouse gas emissions associated with the use of coal." Furthermore, the program is also to explore coal's role as a primary source of hydrogen to power the hydrogen-based economy of the future.

EAGLE (Energy Application for Gas, Liquid and Electricity) Project, Japan
The New Energy and Industrial Technology Development Organization (NEDO) is undertaking a major project to develop coal gasification for use in fuel cells. A pilot plant has been constructed, with a coal processing capacity of 150 ton / day, which aims to develop a coal gasifier suitable for IGFC. Deployment of IGCC-fuel cells in Japan in expected to begin in 2010, with the introduction of 50 MWe distributed power generation installations, followed by the introduction of a 600 MWe system for utility use by 2020.

ZECA, USA/Canada
ZECA is researching the development of the hydro-gasification process, whilst also cooperating with researchers who are looking into mineral carbonation as a route to CO_2 disposal.

The future improvement of coal extraction technologies in terms of lower material use and fewer environmental impacts will play a key role in determining whether coal can be the fuel of choice, especially in developing countries where coal is largely available. For example, extraction of methane from coal deposits instead of from coal would reduce both the material requirements and the overall environmental impacts (Nakicenovic et al., 2000: 29). Extracted methane is another abundant category of 'unconventional' gas to be exploited in the future and which may support the attractiveness of coal as a fuel. It is interesting to note in this regard that the US government recently released a policy paper in which the use of coal is promoted, albeit under the condition that the technologies used will be consistently cleaned up.

Assumption 7 **Similar breakthroughs are realized in the process of capture and disposal of CO_2. Economies of scale and learning effects make this technology increasingly cost effective and contribute to the acceptability of using coal, especially for power generation, for meeting primary energy demand.**

Until a few years ago, CO_2 capture and underground storage (CCS) as a technology to save time in the transition towards low-carbon energy systems has acquired little attention. Until recently, a relatively small group of experts discussed CCS technologies, with little public awareness and support.

Why has attention for CCS, also during climate negotiations, been so little? In comparing CCS with the 'competing' storage technologies of land use, land-use change and forestry (LULUCF), which have received much attention in the Kyoto discussions, discussions have made clear that the LULUCF option has problems with respect to permanence and measurement. CCS, instead, seems to suffer less from these problems because:

1 stored CO_2 can remain underground forever; and
2 the monitoring of the storage is relatively easy, among others because, on the whole, the proven leakage seems rather limited if not negligible (certainly < 0.1% p.a.).[42]

Moreover, unlike LULUCF, CCS does not require scarce land, the use of which may compete with other socially desirable uses (e.g. food production). Therefore, CCS has no opportunity costs (except for the few cases where storage capacity could be used to store other gases). In fact, insofar as CCS enhances oil, coal bed methane or even gas recoveries, its opportunity costs can be negative!

Tentative IEA-data suggest that deep saline aquifers offer storage capacity of at least 1,000 Gt (but probably ten times more) and depleted oil and gas fields and unmineable coal seams offer another approximately 1,000 Gt storage capacity. According to the IEA, storage potential in depleted gas fields is much larger than in depleted oil fields. The reservoirs tend to be bigger, and there are more of them. Total capacity is estimated at about 1,000 Gt of CO_2, equivalent to almost 50 years of current global CO_2 emissions (see Table 5.3). Theoretically, underground storage capacity is therefore sufficiently large to capture all likely anthropogenic CO_2 emissions projected for the next 50-100 years even if fairly pessimistic assumptions about future emissions are used (CCS also compares favorably with LULUCF in this regard).

Table 5.3 Natural reservoirs suitable for storage of CO_2 [43]

Storage option	Global capacity	
	Gt CO_2	% of emissions to 2050
Depleted oil and gas fields	1000	50
Deep saline reservoirs	400 – 10.000	20-500
Unmineable coal measures	>15	>1

Source: IEA, 2001; IEA, 2004b.

IEA scenarios, based on the Energy Technology Perspectives (ETP) model, suggest that in the scenario-specifications where a $50/ tCO_2 penalty is introduced (during 2005-15 and 2020-30 in the industrialized and developing countries respectively), the introduction of the CCS option in the model lowers cumulative emissions until 2050 by about a quarter as compared to those without-CCS

42 It should be mentioned though that safety concerns are not completely absent. Concerns about the safety of underground storage still have to be dealt with. The same goes for solvents used to capture CO2. These gradually degrade in use and consequently suitable procedures for destruction/disposal need to be in place.

43 Actual storage potential may be reduced as the pressure cannot be brought back to the original pressure and parts of the reservoir may be water-flooded.

scenario. The IEA further argues (2004a: 120) that if the same cumulative emission reduction (as achieved in the scenario with CCS) were to be achieved without CCS, "the undiscounted cumulative systems cost [...] increases by $11 trillion, or 63%". Although such outcomes are very sensitive for a wide range of assumptions and should be taken with a grain of salt, it is altogether clear that CCS deserves active public support.
CCS technology development may also have a wider application. Successful CCS requires further technology development and application regime information of CO2 capture, transport and storage. Such information can also enhance knowledge of capture, transport and storage of other GHGs, such as methane, nitrogen or hydrogen. But probably more importantly, CCS could assist rapidly developing countries with a large coal basis, such as China and India, in achieving benefits in terms of GDP growth, contributing positively to mitigation, 'saving time', and having to rely less on foreign energy sources (and/or nuclear energy). This could be helpful in mitigating pending worldwide concerns about the security of energy supply and add to world stability.

On the whole, the costs of capture and pressurization are typically responsible for the bulk of the costs whereas CO_2 transport and storage costs are modest (although this can obviously differ from one case to another). Whether or not there is enhanced fossil-fuel recovery involved in the CCS activity (although this will be the exception rather than the rule) also makes a large difference. Keeping all this in mind, the present costs of the full CCS chain per metric ton CO_2 (if no-regrets options are disregarded) probably range from very little for a number of options, such as transporting and storing pure CO_2 residues from industrial processes, to € 40-80 for most other cases. Such costs are indeed considerable, but not insurmountable if serious public support would enable progress with the CCS technology. It seems fair to assume that such costs could probably be halved over approximately the next 25 years (IEA, 2004b:17). In other words, investing now in learning about CCS application in combination with CO_2 penalties could bring large-scale commercially feasible CCS within reach within a decade, especially if coal prices remain low in comparison to other energy sources.

Along that track, it seems logical to start with developing low per tCO_2 CCS options first, e.g. enhanced recovery projects or projects where pure CO_2 is released from industrial processes. The present problem, however, is to get such activities off the ground in the absence of clear incentives for potential private investors to do so. First, stable and predictable long-term public investment support for such technology development has thus far remained very modest internationally, if not virtually absent. Second, it is even still unclear how underground CO_2 storage can be dealt with in the Kyoto–regime. Indeed, insofar as the KP provides incentives for mitigation, it is as yet unclear how this would apply to CCS, irrespective of whether CCS would be set up as domestic action (i.e. how CCS should be accounted for in national inventories), or as an element of any of the KP flexibility mechanisms. Even in the EU ETS the role of CCS is still unclear, because its inclusion in the scheme would require national storage monitoring and verification guidelines, which are not (yet) in place. It seems feasible, however, that incentives become more concrete and certain as time progresses.

Nowadays, about one million metric tons of CO_2 per year is being injected into a deep saline reservoir under the Norwegian sector of the North Sea in conjunction with gas production from the offshore gas field Sleipner West. This project started in 1996 and marked the first instance of CO_2 being stored in a geological formation because of climate change considerations. In 2000 the saline aquifer carbon dioxide storage (Sacs) project demonstrated that the injected gas remains in place instead of leaking out.

Given its early experience on CCS, Norway might become a recipient of CO_2 from European countries as the North Sea provides ample space to store its emissions over the following centuries. The formation can store 600 billion metric tons of CO_2. To allow for such far-going cooperation, the Norwegian government established a national fund of €240 million (US $ 307 million) to stimulate the development of technologies for CO_2 capture and storage related to the use of natural gas.
With CO_2 taxes levied as it is the case in Norway, this option could become commercially interesting. The Sleipner West licensees would have had to pay about the same amount of money in taxes as they pay now for injecting the CO_2 and being more environmentally friendly.

Another potential storage medium is unmineable coal. Despite a substantial amount of coal-bed methane (CBM) already being produced in the USA and elsewhere, so far there is only one CO_2-enhanced CBM project, which is the Allison Unit in New Mexico, USA. Over 100,000 metric tons of CO_2 have been injected at this unit over a three-year period.

Globally, resources have been dedicated to study the possibilities of this promising technique; the 'Carbon Sequestration Leadership Forum' being the most extensive.[44] Europe's Energy commissioner Andris Piebalgs has dedicated €100 million to sequestration and storage of CO_2 from coal and stimulates both European countries and utilities to invest in clean coal technology, hoping to establish a large, Europe-wide research project in the field. In the beginning of April 2005, the European Commission adopted the Seventh

[44] Participating countries are: Australia, Brazil, Canada, Colombia, Italy, India, Japan, Mexico, Norway, the People's Republic of China, Russia, the United Kingdom and the US.

available in a large number of countries, will regain prestige, especially supported by the introduction of CCTs and CCS. Also the prestige of nuclear energy as a modern, fossil free, domestic power production technology may grow considerably. If using renewables becomes fashionable, especially in industrialized countries with governments that consider renewables as a typical way to express their willingness to innovate, the overall result could be that massive oil and gas imports are increasingly perceived as something from the past.

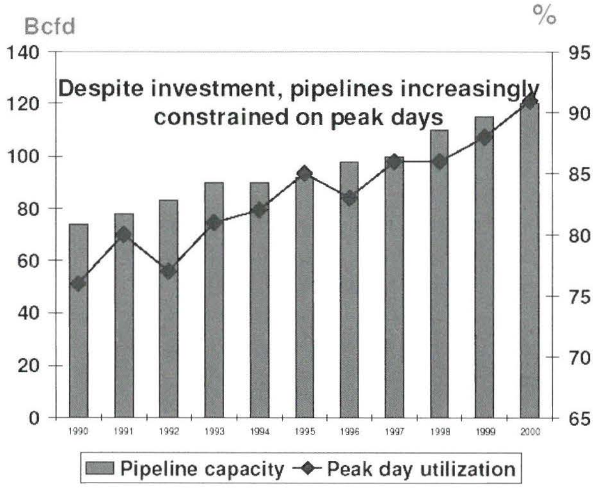
Obviously, also in this storyline oil and gas will remain important primary energy sources, but the perception would change with a declining share in the use of oil and gas altogether. In fact, oil use is projected to be increasingly confined to petrochemical industries and transport use only, which is in line with the historic trend. To illustrate, whereas in 1973 oil still accounted for about 20 per cent of US power production, it has now declined to less than 1 percent. Domestic heating by oil has declined from one out of four houses to one out of ten nowadays. A likewise trend – although slower – can be discerned in the case of transportation. To an increasing extent, the oil industry faces competition from newly developed techniques, the fuel cell being the ultimate aim of many. The road hereto remains unclear, but the trend seems CNG/GTL.

Assumption 10 **The gas sector increasingly faces problems in dealing with the challenges that result from liberalization, internationalization, and re-regulation of the sector. As a consequence, the sector increasingly faces problems of meeting demand conditions, including those with regard to the growing demand for flexibility.**

In this storyline, the gas sector performs in fact rather badly, which is also detrimental to its image and adds to the perception that gas must be considered a fuel from the past, rather than of the future.
The first argument has already been outlined and boils down to the point that an increasing tendency towards self-reliance leads to a domination of coal and nuclear energy in global power production. Oil will defend its market share and increasingly focus on transport. Governments will primarily focus on the environment/innovation nexus, which may also benefit renewables. In that storyline, natural gas may only achieve a modest market share in transport, heating and power production, and will basically be the losing fuel in the big battle of the primary energy carriers.

Second, it should not be ruled out that the liberalization trend will lead to increasing security of supply concerns (SoS) among the public which further undermines the role and reputation of natural gas. Not only have liberalized markets been characterized by more price volatility so far, but also, and probably more importantly, by increasingly less SoS. Some examples of incidents in liberalized energy markets may serve as an illustration. The transitional policy regime in the European Union and the USA has already caused a number of incidents, especially in the electricity sector, the most notable example being shortages and blackouts in Italy (UCTE) and in Northeast America, both in 2003. The liberalization trend on the gas market puts a similar pressure on the gas market players to be as competitive as possible, which has already resulted in a number of crises in the gas sector as well (e.g. the 2001 California crises and the 2003 London crisis).

Figure 5.13 More efficient use of assets: North American pipeline capacity



Source: IEA, 2004a.

One of the underlying reasons why the SoS situation would get worse through market liberalization, is the decreasing availability of information for market players about future market developments, so that traders will increasingly tend to focus on short-term profit making and increasingly act in an unpredictable manner. In fact, gas infrastructure planners may obtain fussy information from the market, because of active speculation and arbitrage next to 'normal' trading. This could lead to wrong investment decisions, i.e. investing too much or too little, in the wrong manner, and/or with a wrong timing. Such decision making by TSOs can be further complicated if regulators have their own targets, for instance, to discipline the TSOs. A fundamental problem with market liberalization is that the resulting loss of information available to investment planners makes that theoretically past SoS levels can only be maintained with more investment capacity and therefore higher levels of investment in infrastructure. It is questionable whether such higher investment levels will materialize in actual practice in liberalizing markets. As Figure 5.11 shows, investment in the US liberalized market seems to be dangerously low, which could lead to transport capacity bottlenecks and therefore SoS problems.

Finally, the role of natural gas may also be affected by an increasing concern about depletion of gas reserves during the next few decades. Such concerns do not necessarily have to relate to global reserves, but instead to reserves which are considered to be under control, i.e. domestic reserves or reserves within allied nations. Data for gas reserves presented by the industry, unlike public data, do not show that reported reserves have increased since the early 1980s (about 600 Tcf). Shell presented similar data in its 2001 report 'Energy Needs, Choices and Possibilities – Scenarios to 2050', which estimates ultimately recoverable conventional gas resources at 15,000 – 20,000 EJ and unconventional gas resources at another 13,000 EJ. These resources could support 3% annual growth for some 25 years only. In addition, earlier optimistic estimates regarding unconventional gas, e.g. from hydrates and clathrates, have substantially been adjusted downwards. Also the recovery rates of most gas fields do not allow for much further improvement.

Assumption 11 **Governments are increasingly influenced by public opinion and green NGOs and particularly try to specify and achieve mitigation targets and targets with regard to the share of renewables in energy production and consumption. In this world, there is increasing pressure not to use gas as a transition fuel, but rather to aim at a mix of renewable technologies along with clean or zero-emission power plants, irrespective of the underlying fossil fuels. Consequently, gas will not succeed in acquiring an accepted status as the transition fuel of the future.**

To an increasing extent, the public focus on the environment and innovation reduces the acceptability of incurring high costs related to changing the current fossil fuel dependency by switching from one fossil fuel to another, especially in the Western world. Green NGOs and other pressure groups point out that replacing coal and oil with gas is just 'a trick' to postpone action and that fuel-switch actually slows down innovation towards sustainable energy systems. The past resistance from the same green NGOs against the Kyoto flexibility mechanisms was in fact largely based on the same argument, namely that the use of these mechanisms would eventually postpone the need for domestic adjustments and reduce the focus on domestic efficiency improvement and introduction of renewables. Such pressure could, in combination with a concern about energy import dependence, increase governments' receptiveness of this argument.

A recent Eurobarometer survey, the first survey of public attitudes to the environment across the enlarged EU-25 region, revealed Europeans' stance towards the environment in relation to both economic and social policies. In fact, the respondents want policy makers to consider the environment an equally important issue as economic and social policies (EC, 2005). Climate change and air pollution are among the environmental issues that citizens worry about most. Environment commissioner Stavros Dimas: "...This survey is proof that European citizens care greatly about their environment, and believe that it is intrinsically linked to working to deliver a high level of environmental protection..."

Assumption 12 **There is a growing perception that natural gas poses serious security risks, which is particularly related to the international transport and storage of gas. Terrorist attacks or other means of violence, e.g. based on national conflicts, turn out to pose a major threat to LNG ships and terminals. Also major gas pipelines are vulnerable. Compared to almost all other forms of energy, gas is perceived by far as the least safe and therefore less suitable for international transport, especially in off-grid systems. This seriously limits the volumes of international gas transport and therefore trade.**

As will be outlined in Chapter 6 (see for instance Figure 6.8 and Table 6.1) international LNG trade is perceived by some as surrounded by a serious security risk.

Chapter 6

Underinvestment Storyline

6.1 General description

In this storyline it is assumed that for the period up to 2040 there are no clear trends with regard to: economic growth in the var regions, energy efficiency, the use, availability, acceptability, and accessibility of particular energy sources, energy prices, or even direction of climate and other environmental policies. Consequently, there is a serious lack of certainty and conviction as to wl where, and how much investment would be required to secure a reliable and sufficient energy supply. Taking into consideration huge amount of resources and finance, as well as long lead times involved with most energy production and transport projects, lasting uncertainty about energy world development paralyzes investment both in exploration/exploitation and international en transport capacity.

This uncertainty is further increased due to limited information about the size and direction of internationally traded energy fl (and LNG in particular), which is caused by the liberalization trends that increasingly characterize the various national and regi energy markets. For instance, the unpredictability of gas supply conditions is enlarged by the replacement on the international market of allocation based on long-term, well-defined, government-controlled contracts with allocation via an anonymous o market system. This development also increases the risks related to potential investments. Also other uncertainties, such as the r for flexibility services, the relevant regulatory regimes, the possibility of producer cartels, security risks due to international con or terrorism, bilateral contracts with other destinations, etc., add to the overall picture of a world where confusion about the en system is significant, thereby making market parties reluctant to invest.

The main result of the above will be underinvestment, which creates security of supply problems for end-users. Even if potential en supply remains available at acceptable conditions, it will quite often not be able to satisfy demand because of a lack of infrastruct Since a reliable infrastructure requires that all links in the chain are equally strong, the fact that some links are controlled by gov ments/regulators and others by private sector entities only without a clear coordination mechanism between the various actors, cre a considerable risk that the overall chain is too weak to serve the market properly.

6.2 Assumptions and rationale of the Underinvestment Storyline

Assumption 1 **There are no clear trends with regard to regional economic growth. Just as in the 1980s and 1990s, internati financial crises occur at irregular intervals due to major economic disequilibria; in addition as time progre the supply of particular commodities and environmental concerns may impose sudden limits to economic gro in particular industries/regions. As a consequence, there is continuous confusion as to whether form perceived growth trends of particular regions can be sustained in the future. The related boom-bust cycles ir investment generally feed into the energy sector, as well.**

Because of the clear link between the overall demand for energy and overall economic growth, economic growth projections are sources of information for investors in the energy sector. A number of organizations generate long-term economic growth projecti such as the World Bank, OECD and IMF. On the whole, base-case projections do not deviate much from extrapolations of trends. However, long-term investors, next to necessary knowledge of the most likely authoritative economic development projecti to know the likelihood that the picture will be much different due to unforeseen events, such as: political instability/conflicts, eseen policy action, sudden market instability, technology breakthroughs, etc. Although it is beyond the scope of this report to sively deal with the stability of long-term growth projections, it may be worthwhile to just briefly discuss a number of past events ı seems to have had a severe overall growth impact and which show that, unexpectedly, things can easily turn out differently.

ıples of events which had a pervasive economic impact during the last few decades are: the 1973/79 oil crises; the 1982 Latin ican financial crisis; the 1989 fall of the Berlin wall; the 1990/91 Gulf War; the 1997 Asian crisis; the 2001 9/11 terrorist at- and the subsequent war in Iraq in 2003/04. In other words, past experience suggests that each decade shows a number of large ›ected disruptions which have a potential impact on economic growth perspectives in at least parts of the world.

ıg the most risky factors for economic growth are significant macro-economic disequilibria, which eventually lead to abrupt tments. Financial crises are probably the clearest examples of the latter: according to the IMF, from 1975 to 1997, 158 currency [45] and 54 banking crises [46] occurred, of which the 1982 Latin American debt crisis and the Asian currency crisis of 1997 were ıbly the most severe ones. The first one resulted in a lasting economic setback in a number of developing and industrialized :ries, and threatened to undermine the stability of the international banking system. The latter crisis eventually had a less severe ›mic impact, but nonetheless caused dramatic economic disturbances throughout Asia and nervous responses on worldwide cial markets, as well as a temporary reduction in economic activities in some industrialized countries. Because the underlying 's leading to financial crises are still intact, it seems likely that financial crises will occur again in the future. The risks that such escalate into worldwide economic shocks therefore still exist. Moreover, according to the IMF, crises during the last two decades different nature than those in earlier decades because of financial innovations and the increased integration of global financial ets during the last two decades. The latter leads to more pronounced and far-reaching spillover effects and a contagious spread ses (IMF, 1998: 74).

rience shows that the trend of economic progress can change so suddenly that the relevant stakeholders are insufficiently prepared nay even carry out counterproductive policies. An example of this is the post-WWII development of the Japanese economy a significant growth during forty years: during the period 1951-1973, Japanese GDP growth reached about 9 per cent per year; : 1980s annual growth was about 5 per cent. Then, after the stock market collapse and banking crisis in 1990, the economy ated and came to a factual standstill during more than a decade. Only recently authorities stem to have succeeded in reversing to ingful positive economic growth figures.

her, opposite, example is the USA, where trend growth has accelerated from levels of around 3 per cent per year during the 1960s- s to levels close to 4 per cent since then. This acceleration has come at the cost of a current account deficit that accumulated to 5 per cent of GDP in 2005-06. Without changes in growth rates, patterns of demand, or relative prices of different countries' ıt, projections show an increasing trade deficit, which may even culminate to over 10 per cent in 2010. The unprecedented high t is by many considered a non-sustainable situation that may require future correction and which could affect the long-term :h trend of the country.
her example is Germany where average economic growth figures of around 3 per cent per year during the 1960-80s reduced to a ı lower growth trend of about 1 per cent for a considerable number of years after the German reunification.

mption 2 **The debate on the anthropogenic factor in the climate change issue continues during the post-Kyoto period. Also the question what the overall cost of climate policy and climate change damages to society amount to, given the adaptation potential and costs, remains on the agenda. Consequently, a clear direction of the international climate policy regime concerning the period up to the year 2040 and a clear direction of the carbon credit prices and national policies and measures are lacking.**

ı fact that the average global temperature rose with about 1oC during the 20th century. A large number of scientists argue that ncrease in temperature has contributed to the thawing of the permafrost, the rise of ocean levels and extreme weather events. In ion, many experts argue that further increases could seriously disrupt ecosystems, agriculture and human lifestyles (IPCC TAR I-III, 2001; Millennium Ecosystem Assessment Report, 2005). A number of disputes remain, however. First, some experts keep

currency crisis occurs when a speculative attack on the exchange value of a currency results in a devaluation (or sharp depreciation) of the currency, or forces : authorities to defend the currency by expending large volumes of international reserves or by sharply raising interest rates (IMF, 1998).
›anking crisis refers to a situation in which actual or potential bank- runs or -failures induce banks to suspend the internal convertability of their liabilities or ich compels the government to intervene to prevent this by extending assistance on a large scale (IMF, 1998).

questioning to what extent the actual climate change can be attributed to anthropogenic, as opposed to natural factors. Second, t is no clear picture of the expected net damages due to climate change, because, depending on the region, there may also be signifi gains, and the regional impacts of climate change are less certain. Third, as there is no consensus on the method for valuation overall assessment of a number of potential damages (e.g., ecosystem loss, increased frequency of diseases, casualties) is diffi Fourth, there is no clear picture of the risks of system instability and consequent chances of climate change acceleration. Fifth, not yet clear what the overall economic costs of mitigation regimes amount to and how such costs relate to adaptation action. Si there is no consensus on the priority that should be given to climate change in comparison with other targets when allocating resou (these other targets may turn out to be more cost effective, at least on the short run). Finally, in the absence of clear and internatior accepted and enforceable incentive systems, there is no generally accepted solution to the free-riding problem of any internati climate policy regime, i.e. countries may use a range of arguments why they should commit less or not at all to policy action.

The above explains why the creation of a first climate policy regime has been a fairly lengthy and cumbersome process. Since it se unlikely that the disputes mentioned above will be solved in a generally accepted manner in the foreseeable future, significant s forward beyond the Kyoto Protocol regime may be equally time-consuming and difficult, especially if different economic circ stances and public perceptions apply. The various official and unofficial discussions about a potential post-Kyoto regime have provided a clear picture of the future system so far (i.e. by early 2006); ideas range from much stricter and enforceable targets base cap-and-trade systems with a broader country coverage and effective anti-free rider regime, to systems based on weaker commitm and (voluntary) action on particular policies and measures instead. Surprisingly, whereas the EU originally preferred a regime base policies and measures but later embraced a cap and trade scheme, the USA, instead, seems to follow precisely the reverse route.

Irrespective of the future climate policy developments, the strictness of the climate regime will ultimately determine market incen for mitigation and innovation towards greener energy systems. Thus, the absence of a clear trend on the strictness of an evol post-Kyoto regime would automatically lead to uncertainties about incentives for accomplishing a transition towards a carbon- energy system.

Uncertainty may further increase due to the fact that experiences on a smaller scale have so far demonstrated that small shifts climate policy regime may have far-reaching implications for the resulting incentives. For instance, when in the framework of EU ETS during 2004 the subsequent national allocation plans (NAPs) of the several EU members were submitted to the Euro Commission, the credit prices on the forward market responded strongly as soon as a particular NAP was perceived as strict or leni Also, when in the summer of 2005 droughts in Spain halved hydro capacity and increased reliance on fossil fuel energy product the country was expected to face difficulties with complying with its EU ETS target, which caused EU-wide credit prices to resp very heavily and to increase from about €10,-/tCO_2 to levels of about €30,-/tCO_2 in July and slightly above €30,-/t CO_2 hal April 2006. At the end of April, however, prices fell again considerably for various reasons (see assumption 3.5 and Figure 3.4). S examples illustrate that small, sometimes unforeseen market changes can easily lead to rather volatile emission penalties.

Assumption 3 **In the absence of a clear and convincing climate policy direction, energy efficiency trends remain on averag they were in the past.**

First, the long-term past trend of energy efficiency improvement seems to be rather robust. Data for countries with long-term tistical records show improvements in total energy intensities by more than a factor of 5 since 1800, which corresponds wit average decline of total energy intensities of about 1 per cent per year (Nakicenovic et al., 1998). In most Western countries this t changed to annual averages of about 2 per cent between the mid-1970s and 1990s, which was most likely due to the probably f unique, unexpected about 5-10-fold increase in oil and energy prices during that period. After that, however, oil prices came d considerably without major rapid changes. Only during 2004-2006, oil prices quadrupled again, which makes the present oil p hike comparable to what happened during the 1970s.

Historic evidence therefore suggests that without any other considerable incentives, a development towards an energy effici improvement which is significantly higher than the approximately 1 per cent historical trend, seems unlikely. With a view to Nakicenovic et al. conclude, based on three global energy future cases, that (until 2050) "the overall global average energy inte reductions vary between about 0.8 and 1.4% per year. These figures bracket the historical rate of approximately 1% per year expe ced by the more industrialized countries during the past hundred years" (1998: 40).

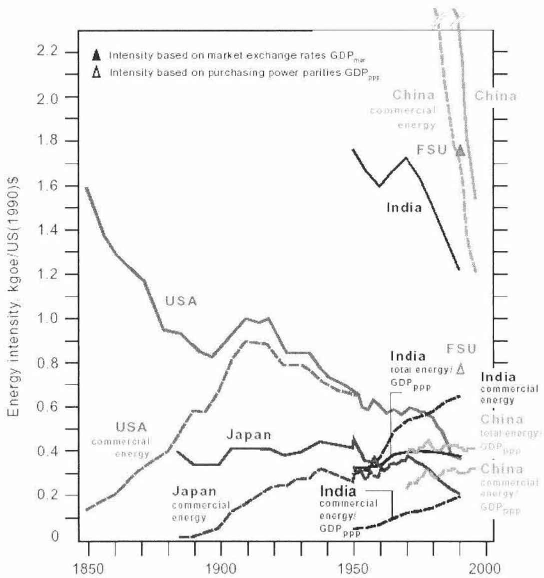
The question remains whether even a quite well determined international climate policy regime may be capable of seriously alte this past trend. Assuming that much of the new incentives based on concern for climate change will boil down to credits, ca ions penalties, or equivalent incentives, it should be born in mind that a credit of about \$10,-/tCO_2, adds only about US \$5,- per to the market oil prices (assumed carbon content of oil: 85%; conversion factor CO_2 to C: x3.6; 1 barrel: 159 liter). Thus, even lit prices would rise to \$50,-/tCO_2 levels, this would add merely about \$25,- to the oil per barrel price. This impact would, in rms, still be much smaller than the price development observed in the 1970s, and also clearly less than the 'spontaneous' market 1 price hike since 2004.

ıd, the largest potential for progress in energy efficiency improvement seems to exist in the formerly centrally planned economies ral and Eastern Europe). Total energy intensities in China, the Former Soviet Union (FSU) and Central Europe range on average en 1 and 2 kgoe per US (1990)\$. In comparison, average energy intensity levels in Western regions are well below 0.4 kgoe. It fair to conclude that the relatively high energy intensity levels in the formerly centrally planned economies are linked to the ion of low and subsidized energy prices for the own population in these countries. Such practices are gradually being removed s region, although the speed of abandoning such traditional policies is severely limited by political acceptance factors or even cal system stability. Progress towards more market-based energy prices with incentives to improve energy efficiency may therefore atively slow.

, the potential to adjust the energy mix in poor countries must not be overstated. Traditionally, non-commercial energy repre- about half of the primary energy use in such countries (with an even larger share in final energy use). Past statistics suggest a elation between modern energy forms and technologies and GDP per capita levels. On average, only at income levels well above 0 - \$6,000 per capita modern energy systems can be found, which is significantly higher than the present income levels of the ity of the world population and which will most likely not be reached during the time frame considered in this study.

h, it may be more difficult and costly to further increase energy efficiency once relatively high levels of efficiency have been ed. A clear example in this respect is that of Japan where energy intensity has been historically low in the absence of significant nous energy resources (as early as 1900, the Japanese total energy intensity already amounted to about 40 per cent of the cor- nding level in the USA!). This may explain why in the course of time the reduction in energy intensity in Japan has been smaller in the USA, and in countries with a tradition of energy subsidies rather than energy efficiency improvement (see Figure 6.1). projections suggest a rather limited scope for energy efficiency improvement in the foreseeable future in countries that have typical energy efficiency frontrunners. Moreover, insofar as energy efficiency improvement can be attributed to a shift towards a e-based economy, also this factor may run out of steam, simply because the services share in GDP already amounts to 60-80 per n much of the OECD, and will therefore not grow much further.

6.1 Energy intensity reduction in four selected countries and FSU, historical development from 1850 to 1990, as a ratio of primary energy to lomestic product (MJ/\$)



total (solid lines) and commercial energy (dashed lines), in kgoe, per GDP, in \$ (1990). Unless otherwise specified, GDP refers)Pmer. For China, India, and FSU intensities based on GDPppp are also given.

e: Nakicenovic, Grübler and McDonald, 1998: 38.

Finally, the scope for energy efficiency improvement is sometimes overstated through data manipulation. In literature on the re tionship between energy intensity of production and GDP per capita levels, international comparisons are often made by focusi on energy use without including non-commercial energy and without correcting for international differences in purchasing pov (PPP-correction). Based on that analysis, it was suggested that energy intensity would increase in the low GDP per capita range a substantially decline with increasing GDP per capita levels. Such data may have led to the impression that further economic progr would almost automatically lead to very significant energy efficiency improvements.

Should the focus be on total energy use and international differences in purchasing power be corrected for, energy intensity differen between countries with different welfare levels would turn out to be much smaller. The following figures illustrate what the data lo like when using this more correct comparison: the total primary energy use in the main regions with below US $ 3,000,- per cap income levels lies between 0.35 and 0.45 toe/1,000 $ (1990) GDPppp, whereas the corresponding figures in the Western regions between 0.25 and 0.4 (Nakicenovic, Grübler and McDonald, 1998: 19). The main exception to this overall picture is Central a Eastern Europe where this figure ranges from 0.45 to 0.75. The above suggests that, although there is considerable scope for ener efficiency improvements (in kgoe/value added) with increasing welfare levels in considerable parts of the world, this scope should r be overestimated.

Assumption 4 **In the international energy policy arena, the official authorities fail to adopt a consistent long-term view on t key issues of concern, whether this would be security of supply, energy market instability, insuffici investment, or climate change and other environmental concerns. Moreover, the debate on whether ener supply shifts will favor coal, oil, natural gas, renewables, or nuclear energy, lacks a clear and internationa common strategic position. Private investors suffer from this absence of a uniform vision, which on the wh will make them reluctant to invest in various elements of the energy value chain.**

Over the past few decades the focus of public concern regarding energy has varied greatly. In the 1970s, due to the oil crises, over helming attention was paid to the availability of energy and to the issue of how energy price volatility could affect overall econo progress. This awareness led among others to the creation of strategic energy reserves, OPEC counterforce, and diversification exploration. In the 1980s policy makers became gradually aware of the climate change risks of using fossil fuel. This resulted activities to set up an international climate policy regime and to promote the development and use of renewables, which culmina in the creation of the UNFCCC/KP/Marrakech Accords policy framework since then. In the 1990s market liberalization became buzzword in several parts of the world, which led to significant regulatory, market, and structural adjustment in the energy sector the 2000-2006 period, awareness increased that the world may be running out of oil within an overseeable number of decades and t this could lead to serious security of supply issues, which may increasingly dominate international foreign relations. This notion reinforced by the sudden and unexpected energy price rise during 2004-2006, which also contributed to awareness in various capi that successful access to the international energy market may require new initiatives and new forms of diplomacy.
In short, over the last 30-40 years, as far as the energy issue is concerned, both the dominant topic of concern as well as the po agenda has frequently shifted back and forth and it is hard to see why something similar would not be the case during the next 30 years.

Many political systems, especially those with a democratic tradition, face the problem that a long time horizon for strategic vi and subsequent policy action is hard to incorporate in the generally much shorter political time horizons. This explains why poli and measures are rarely guaranteed as applicable for decades: policies and measures taken by one administration can be reversec the subsequent administration. This creates a natural problem for long-term private sector investments which are sensitive to policy regime. The same applies to regulatory regimes that may even be adjusted overnight, and can therefore easily undermine investment climate. Also the strong tradition of command-and-control policies in the area of environment/energy is not helpfu that regard, because it may more easily lead to unpredictable adjustments than under market-based regimes.
The following examples illustrate the above.

- Whereas, during the second half of the 1990s, the European Commission tried very hard to introduce a Euro carbon/energy tax in the spirit of greening the tax regime (amongst others to deal with the climate and other environme issues), the initiative was dropped as soon as it turned out to be politically not (yet) acceptable and was replaced l cap-and-trade regime, which was successfully introduced in 2005 (the EU ETS).
- The Chernobyl accident of 1986 led to the decision in a considerable number of (Western) countries not to start investments in nuclear energy capacity, and to close down the existing capacity in due time. Only a few decades l concerns about the availability of energy have resulted in the fact that some of these countries reconsider this position.
- With the PROAlCOOL program Brazil successfully introduced the use of sugarcane alcohol as a commercial fuel a

end of the 1970s. Within some years, due to this program even 2/3 of the domestically produced cars ran on ethanol. However, international price oscillations led the program to slow down in the 1990s, to only regain strength once again after 2000 as soon as ethanol and gasoline prices were on the rise again and car manufacturers introduced so-called 'flexible-fuel' cars, which can operate on either pure ethanol or ethanol/gasoline blends.

umption 5 **Investments are held back, because the various countries in the world have no universal system to organize the market. Country-specific conditions, along with political considerations, determine what is locally perceived as the best market regime. Some regions opt for a far-going process of energy market liberalization combined with a privatization of all chains in the sector, whereas other regions prefer to maintain a significant government control and even ownership on exploration, exploitation, transport and trade, or elements thereof. Due to the mixed experiences with the gas market liberalization, earlier policy initiatives into this direction may occasionally be reversed, and vice versa.**

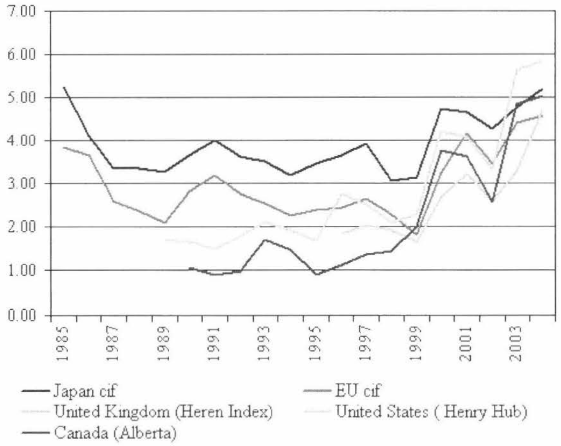
pite the clear recent trend towards liberalization of the gas market, especially in the Western world, there is not yet worldwide sensus as to the overall gains of liberalizing the gas market under all circumstances.

·ket liberalization and regulation typically focus on just a part of the value chain. Although the mix varies widely depending on -specific circumstances, as a ballpark picture for the broad, average situation, one could say that the end-use gas price is for about determined by the commodity itself, for 10-20 per cent by transmission to the gas company and storage, and for 30-40 per cent listribution to consumers. Traditionally, the liberalization and regulation regime of national governments only focuses on the - and downstream part of the value chain: it tries to reduce transmission and storage costs by regulatory measures, and to reduce ribution and commodity costs by supporting as much competition, market transparency and liquidity as possible.

overall expectation is that regulatory measures can reduce the transmission tariffs, and that the various liberalization measures ıbundling of TSO and traders, TPA, entry-exit, fair balancing rules, etc. – will enhance competition at the international gas market thus lower distribution and commodity prices. It is expected that the overall result implies more market transparency, more ket liquidity, more internationalized markets, and eventually lower prices for end-users. An additional expectation of such market ralization is that competition in trading may reduce price volatility because of profit-seeking activities of traders: as soon as prices perceived to be low, traders act as net buyers and vice versa, thus stabilizing the market.

he meantime, however, a number of experiences and insights have created some doubts about whether this liberalization optimism be completely justified.
t, there is no convincing evidence that prices at liberalized markets have been systematically and significantly lower and/or more le than in the non- or less liberalized markets (see Figure 6.2). In fact, precisely those markets where liberalization was introdu- first (i.e. the Anglo-Saxon world), experienced serious disruptions during the last few years (the California power/gas crisis in 0/2001 and the London gas crisis in mid-2003), or significant price volatility (early 2006).

·e 6.2 *International gas prices ($ per million BTU), 1985-2004*



e: Japan cif is for LNG.
rce: BP, 2005.

Second, one has become aware that in practice regulation may eventually undermine investment in infrastructure. On the one har regulated TSOs, usually state-owned or state-controlled entities, are capable, using their strong market position, of adopting t long-run perspective required for appropriate investment decisions. On the other hand, regulators may be tempted – based on t perception, whether or not justified, that TSOs should be viewed as least efficient monopolies – to put pressure on the TSOs so tl the optimal investment levels cannot be reached (for more arguments see also: assumption 6). This risk manifests itself even strong as TSO revenues are often used by the State for general budgetary purposes, which hampers the TSO in spending sufficiently long-term capital projects.

Third, experience has shown that free access to the gas trading market may also attract increased arbitrage and speculative behavi to the market. Although such action could stabilize markets, it can also have a destabilizing impact, especially if traders try to bene from specific infrastructural bottlenecks. Some experts attribute some of the recent market volatility or even security of supply pr blems to specific behavior of traders.

Fourth, the unbundling of the ownership of the infrastructure from the trading activity systematically reduces the TSOs' marl information. Because infrastructure investment will eventually be based on insight in the most likely future market needs, TSOs a less certain about the future use of their transport systems. This problem applies not only to the long term, but may also apply in t short run, because the TSOs do not know the nomination plans of the shippers. As market integration causes gas flows to switch mu more easily depending on the best returns, TSOs may have insufficient insight to clearly assess optimal investment levels.

Finally, the market stabilization impact of liberalization may well be much less than in markets with relatively high supply and dema elasticities. First, most empirical studies suggest that gas demand elasticities are fairly low because gas is rather inevitable in terms production and/or comfort. Second, supply elasticities may also be low among others because of the long investment lead times tl gas market supply typically face.

In short, the original optimism about the benefits of gas market liberalization seems to have been replaced in some circles with a mo cautious assessment, based on the concern that market liberalization may, under some circumstances, deteriorate security of supp reduce market stability, and prevent appropriate infrastructure investment levels from being activated.

The ongoing debate on the pros and cons of gas market liberalization makes it hard to see why markets would develop in a clear dir tion based on a broadly accepted view on optimal market conditions. This is the more so because national gas market conditions, well as the quality of the institutional frameworks, widely differ so that optimal market regimes would differ from country to coun anyhow.

Assumption 6 **The regulatory regimes in the various countries will differ accordingly. A typical problem is that regulators actual practice typically act on the basis of trial and error, which is caused by one of the fundamen characteristics of regulation, i.e. information asymmetry between the regulator and the subject of regulati This may create conflict and uncertainty, add to the uncertainty that market players already face, and may itself act as a disincentive to invest in regulated assets.**

The essential role of regulators is to serve the public interest and keep transport tariffs low. They can do so by putting regulatory pı sure on the 'natural monopoly', which they generally believe is represented by the TSO. If the TSO is independent from the regula the latter may suffer from information asymmetry, which may be reduced by transparency and information requirements imposed the TSO, but cannot be removed completely. This disadvantageous position of the TSO may cause the regulatory body to use t and error strategies to achieve the maximum result. The outcome of the information-regulation game is unpredictable, but may l to situations of over-regulation, i.e. the set of restrictions may become so binding that the TSO will in fact refrain from making investment which is required for an acceptable SoS situation.[47] This may not only apply to the use of the grid, but also to the of underground storage. With regard to the latter, a prescribed TPA regime with low rates may, for instance, prevent investment storage capacity from taking place, even if such capacity could provide an essential element in enhancing SoS.

Alternatively, the regulator may – in the absence of appropriate and reliable market information – aim at cost-plus based strategie far as the tariff for infrastructure use is concerned. Such a regime may act as an open invitation for the TSO to overinvest, i.e. in beyond the level required from a SoS point of view. In the end, the costs due to this over-investment will be born by the end-u via increasing transport tariffs. All this will eventually have an upward impact on the end-use price of gas. In theory, the tariff-rais impact of over-investments could reverse any possible downward impact on end-use gas prices caused by increased competition to market liberalization.

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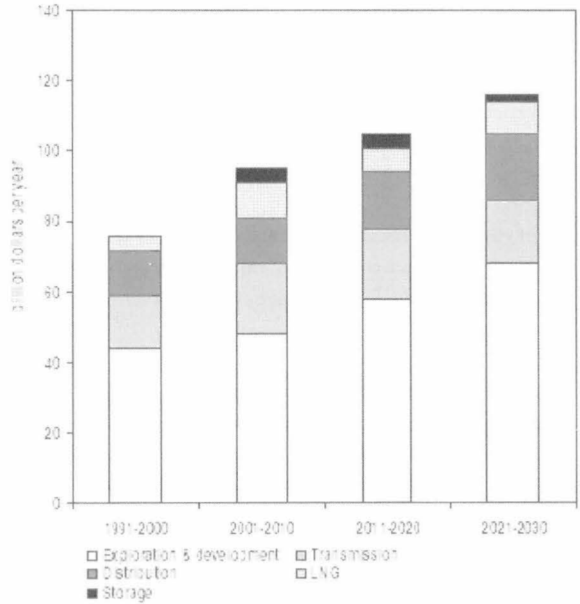
[47] For the difficulties historically facing regulatory decisions in e.g. the US, see http://www.naturalgas.org/regulation/history.asp.

umption 7 **For a number of reasons, the complexity of the investment decisions on major infrastructural projects will further increase in the future. This may in itself slow down the speed of investment decision-making, because the investment amounts, the international interests at stake, and the uncertainties and investment risks are becoming so large that it will be increasingly difficult to organize sufficient support for actual investment decisions.**

: future project investment needs in the worldwide gas sector are enormous. According to the IEA Reference Scenario (2003), ıual amounts will probably increase from the present levels of about $90 billion to about $120 billion during the 2020s (see Figure).

:se substantial investment needs in the gas sector are evidently linked to the projected large increase in demand for gas. The In- ıational Energy Outlook 2004 projects 1.8 per cent growth per year in the demand for gas in the industrialized countries during)1-2025 and 3 per cent growth in the developing countries. In the Asian region, growth is projected to reach 3.9 per cent in Korea, per cent in India and 6.9 per cent in China. During the same period, gas production is expected to increase in Russia/FSU from 6 tcm to 45 tcm; in the Middle East from 8.3 tcm to 18.8 tcm; in Africa from 4.6 tcm to 14.1 tcm; and in Central and South ıerica from 3.6 tcm to 10.6 tcm.

re 6.3 Global gas investment (billion $ per year)



ırce: IEA, 2003.

the Figure indicates, most of the investment needs mentioned above will be in exploration, but such investment will only be ef- ive if transmission infrastructure is developed simultaneously. The Figures below, representing the existing and possible future gas astructure for Europe, China, and India, may serve to illustrate the enormous challenges that investors in gas infrastructure are ng in view of servicing the future gas market.

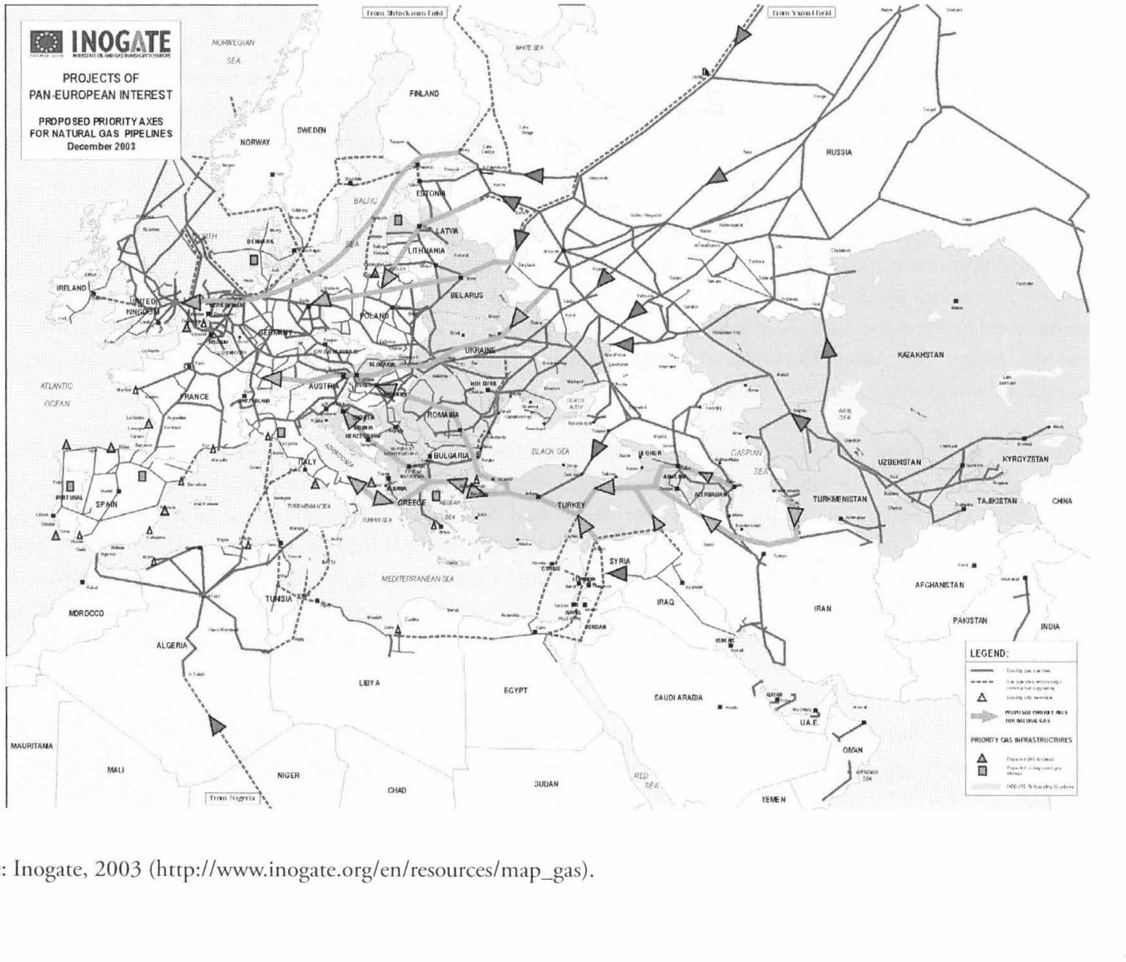
a number of reasons, decisions on such future infrastructure investment are extremely cumbersome and complex.
t, the amount of resources and organizational capacity involved in such projects is very large. For instance, the costs per km of ısnational gas pipelines range from about €2.5 m under easy conditions to about €5 m under more difficult conditions. Pipelines ı a length of several hundreds of kilometers, including the additional compression equipment, therefore will cost hundreds of lions, if not billions of Euros.
ond, in the absence of any long-term clarity with regard to the position of the regulators involved in the TPA and tariffication me, it will be difficult to make long-term projections of expected internal rates of return. The same lack of clarity applies to the t-Kyoto regime and the direction of the liberalization process.
rd, if, e.g. in the spirit of liberalization, long-term contracts, which usually provide certainty about transported volumes of gas, not effectively be implemented, it would become more difficult to establish long-term IRR estimates.

Fourth, in addition to uncertainty about future demand for gas, it is also uncertain what the dominating transportation modes a going to be. Expectations of which part of international gas flows will be transported via the LNG route and which part through t pipeline system differ widely: for more details on LNG projections, see assumption 6.10 next. Finally, and probably most important any future competition in demand from the major industrial centers will create dilemmas, and therefore uncertainty, for investors gas infrastructure on the direction in which the infrastructure would need to be developed to obtain maximum expected returns. T main future gas exporters are expected to be Russia, the Middle East, the Caspian Gulf area and Northern Africa (see Figure 4.15 a 4.17). These areas may require foreign direct investment (FDI) in order to finance the necessary infrastructure investment. All the regions may either way face the question, next to how much investment is needed for domestic purposes, to what extent infrastructu for gas deliveries will primarily focus on e.g. the northern American, the European, or the Asian market.

Consequently, with a view to the uncertainties which typically characterize the future international gas market, it is quite understa dable why investors on average are reluctant to take firm investment decisions on new gas infrastructure. However, because grids on work when connected, the slowing down of a particular investment can block a much longer transportation route and therefore ha serious security of supply complications.

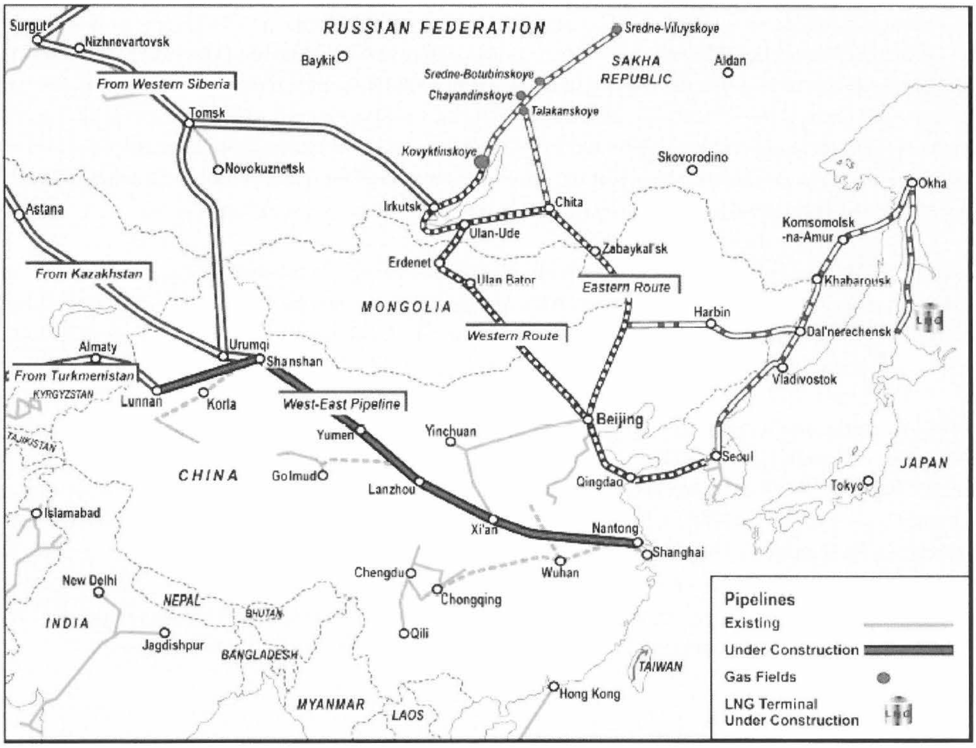
During the last few years, the world's private oil majors do not seem to use all feasible resources for investment in new energy su ply systems. Oil companies, such as Shell, ExxonMobil, Chevron and BP are all very actively involved in share buy back schem ExxonMobil for $24 bn since the 1999 merger thereby reducing the number of shares outstanding by over 8 per cent; Shell cancel 62.5 mln shares since the beginning of 2001; BP bought back shares for an amount of $13.5 bn since 2000; Chevron will emba on a common stock buy back program of up to $5 bn by 2007, and repurchased for more than $2 bn at the end of 2004; and To bought back shares representing 17 per cent of its capital during 2000-2004. So, in total, during the last few years, approximately $ bn value of shares was bought back by these companies. Just to illustrate, if one assumes a debt/equity ratio of 1/3, such an amou could have financed an additional production capacity of 4.7 mln bbl/d oil or 160 bn m3/year natural gas.

Figure 6.4 Natural gas pipelines



Source: Inogate, 2003 (http://www.inogate.org/en/resources/map_gas).

ıre 6.5 *Natural gas infrastructure development in Asia and FSU*



umption 8 **Given the mere absolute and relative size of the energy investments projected for the next couple of decades, the funding of such investment programmes will be increasingly difficult because of the increasing investment risks, the location of the investments, and the reduced involvement of public authorities in the financing of these investments.**

:ording to the reference scenario of the World Energy Outlook (2002), the total gross investment requirement for energy-supply astructure worldwide over 2001-30 is about $16.000 bn, assuming an average annual energy demand growth of 1.7 per cent ıghly half of this amount would be required for maintaining the present system, the other half for serving the increasing demand). average this would correspond with about 1 per cent of world GDP, but for some regions this percentage can be even much higher ;. Russia: 5%, Africa: 4%). About $3,100 bn of the above amount relates to investment in the gas sector, excluding investments ıired to meet rapidly growing power station fuel requirements.

otentially complicating factor in financing this investment is that about 60 per cent of the overall investment amount for energy ıtioned (about $9,500 out of the US $16,000 bn) is expected to be needed in the non-Western world, including: China ($2,300 ; the rest of Asia (about $2,500 bn); Africa ($1,200 bn); Middle East ($1,000 bn); Russia and other transition economies ($1,600 ; and Latin America (about $1,000 bn). Moreover, about US $5,500-$6,000 bn of the non-Western world investment (about one d of the future global energy investment requirement) will have to be made to serve the local market, which may typically face ding problems because: future finance will probably be provided by less-predictable private instead of public sources; domestic ca-l markets may be unable to handle the financing of such massive domestic projects (to illustrate, Africa's investment requirements ɔunt to about half of total domestic savings!); and foreign investors may be reluctant to step in.

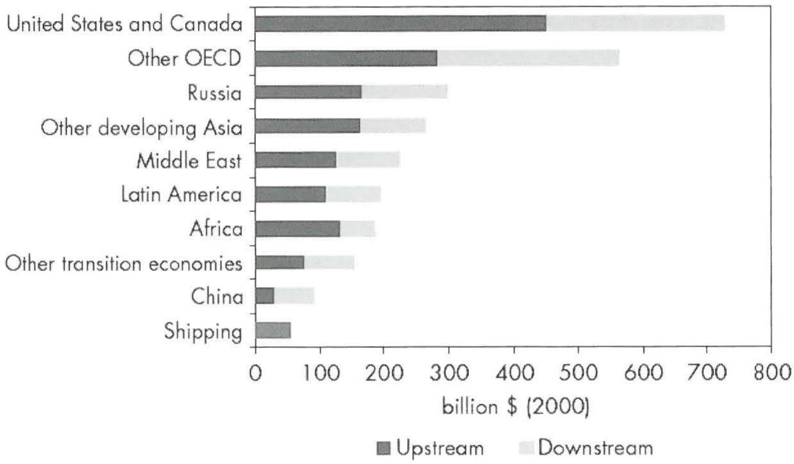
; hard to see how governments of poor countries, whose domestic capital availability for such massive investments is insufficient, where much energy is now provided at low or even negative returns on capital, would be politically able to change conditions iciently on time with returns (taking the high risks into account) at levels to successfully compete for financing on the international ital market. This could create serious future problems in allocating investments where they are needed most. Moreover, it could siderably weaken the overall energy supply chain, and worldwide market stability.
ar as natural gas is concerned, potential problems of financing the about $3,100 bn investment requirement may become equally

acute, for the following reasons:

- Since the average annual demand for gas and gas infrastructure investment is projected to grow faster than overall ener demand (2.4% vs 1.7%), an annual increase of some 300 bcm of gas production capacity would be required;
- A similar, relatively strong, growth expectation applies to projected power demand, while the share of gas in pow production is expected to rise to a level of about 40-45 per cent (associated cumulative investment requirements for t period 2001-2030: US $4,000 bn);
- 55 per cent of gas-related investment requirement is needed for exploration, mainly in countries where risks are perceived above-average in terms of the predictability of exchange rates, political regime, economic policy, institutional syst characteristics, etc. (see Figure 6.6);
- Gas exploration will shift to offshore fields, which is more capital intensive and requires additional investment;
- In the gas sector there will probably be a massive shift towards market internationalization with a larger role for LN (which could potentially represent about half of interregional gas trade by 2030), which requires very substantial investme in new infrastructural capacity;
- Also in the gas sector, market liberalization and regulatory adjustment have typically increased uncertainties about investm requirements in transmission networks, whereas in many countries this has not yet led to higher investments in su systems;
- The introduction of renewables and decentralized systems, as well as the tendency for past investment in infrastructure remain below required levels, increases uncertainty and enlarges investment requirements in transmission networks.

So, should such financing bottlenecks appear in some parts of the gas chain in some regions, this could not only have socially und rable consequences, but could also affect worldwide gas prices and price volatility.

Figure 6.6 Cumulative Investment in Natural Gas, 2003-2030



Source: IEA, 2004a.

Assumption 9 **A number of factors cause the attention on the gas market to shift from servicing base load to servicing flexibi demand. This may require considerable adjustments in gas infrastructure investment and may require m rapid investment action to service the market, the planning of which is relatively difficult.**

First, less predictable market conditions due to market liberalization will lead to an increasing demand for flexibility (seasonal, day day, etc.), which is increasingly difficult to meet.

Second, the liberalization of the gas market increases the competition for peak load, so that, possibly also due to the market beha of traders, prices on the flexibility market become more volatile.

Third, flexibility by production slows down in a number of regions and is increasingly taken over by flexibility from storage possibly by flexibility provided via imports of LNG or otherwise. This will require considerable adjustment in gas infrastruc investment.

Fourth, decentralized energy systems are gradually gaining ground throughout the world, although experts have different opinion the extent to which and how quickly this trend will continue in the future (see also Box 6.1). With decentralized systems becon increasingly important, the demand for flexibility through the grid or otherwise may increase substantially because decentral systems usually provide little flexibility. Demand for flexibility services in gas supply will further increase when gas will be used bling power companies to provide additional flexibility. Although the scope of this development is still unclear, it seems obvious : this will also require investment in new infrastructure.

3ox 6.1 On the scope of Decentralized Energy systems

)ecentralized energy (DE) systems show a long-term rising trend. During the last few years, however, its world market share has ıot increased much further and amounted to 7.2 per cent in 2004. Global installed decentralized energy (DE) capacity stood at round 280 GWe at the end of 2004, the great proportion of this consisting of high efficiency cogeneration systems (combined ıeat and power, CHP) in the industrial and district heating sectors, fuelled by coal and gas and, to a lesser extent, biomass-based uels. Some 32 GWe of this was added during 2002-04, most of this being 'non-renewable'-based cogeneration. Unlike the ogeneration market, PV industry growth rates remain very high during the same period; from about 700 MWe produced in :003 to almost 1000 MWe produced and installed in 2004, an approximate forty per cent increase.

n the US, DE cogeneration development has been slowed down recently by high gas prices and regulatory barriers; in the :U the EU ETS and the 2003 Cogeneration Directive may somewhat reverse the standstill in DE capacity development; and ı some developing countries, notably Brazil based on new gas discoveries and India based on biomass, the expansion of DE ystems seems promising.
)n the whole, future DE market prospects depend critically on the removal of electricity market regulatory barriers and of ɔng-standing incentives/subsidies for central generation. Still, electricity market regulatory frameworks stimulate this central ıodel of generation and supply.

ource: Based on WADE, 2005.

flexibility on the international gas market will probably be strongly affected by the projected increasing role of LNG. While ;-term contracts will continue to dominate the LNG business in the foreseeable future due to investment requirements, spot sales ırt-term or single-cargo sales) are expected to become more important. Between the late 1990s and 2003, the share of spot trading lobal LNG trade grew from 2% to almost 11% (IEA, 2004a: 142). Several ships that are presently being built are not earmarked ɔarticular projects, and will thus be available for spot-trading opportunities. Moreover, part of the capacity of some liquefaction ıts built in recent years, which is not covered by long-term contracts, will be available to supply the spot market.

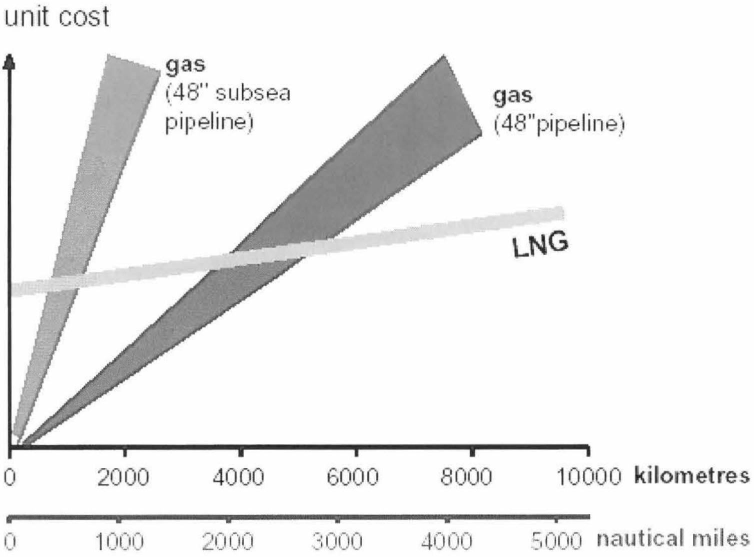
ems likely that more flexible pricing mechanisms and shorter-term contracts will become more common in liberalized markets. ; suppliers are already adapting their pricing policies to the needs of individual buyers, including power generators who have ın to contract for their LNG purchases directly.

ers may increasingly push for less take-or-pay obligations, because assessing their future needs will be harder in competitive kets. More contractual flexibility and more LNG trade will increase the scope for buyers in different countries to swap supplies for :rent time periods, to take advantage of differences in peak load, and to minimize purchase costs.

ımption 10 **The share of LNG in the internationally traded volumes of natural gas will increase substantially. This will require significant and coordinated capacity investment in the several elements of LNG infrastructure.**

projections suggest that more than half of the growth in gas trade will be in the form of Liquefied Natural Gas (LNG). One ıe reasons for this is that competition on gas markets will encourage short-term trading, which may stimulate the use of LNG. :ther with declining unit transport costs (see Figure 6.7 for a comparison of modes of transport), LNG may become increasingly ılar. LNG may also enhance the ability of buyers to deal with a supply shortfall by seeking alternative sources. The development of mon operating standards covering safety, gas quality and other technical factors will further help foster international LNG trade.

Figure 6.7 Cost comparisons among modes of gas transport



Source: Cook, 2005: 3.

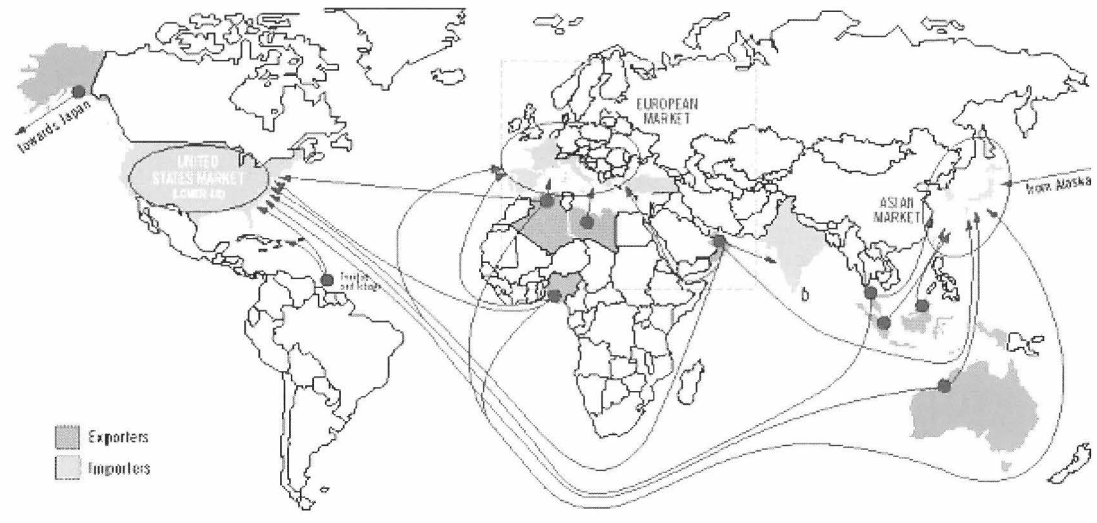
In 2002, interregional LNG trade amounted to 150 bcm (about 6 per cent of world consumption and some 25-30 per cent of interregional gas trade; for an illustration of the LNG flows in 2004, see Figure 6.8). IEA expects this amount to increase to 250 bc in 2010 and 680 bcm in 2030. In case this would happen by 2030, more than 50 per cent of all interregional gas trade will be in t form of LNG.

During the last decade, the overall LNG infrastructure investment has already grown to substantial levels: at the beginning of 20 there were 15 LNG export terminals, 43 import terminals and 154 tankers operating worldwide. In addition, 8 liquefaction termin were expanded, 5 new ones under construction, 8 new import terminals built in the OECD region, 54 new LNG ships on order a some 30 new LNG supply projects planned (IEA, 2004a: 141). Global LNG liquefaction capacity is expected to increase to 9.4 per year in 2007, based on facilities currently under construction.

In terms of volumes, LNG trade has so far quite heavily been concentrated in the Asia-Pacific region. Japan, for example, was r ponsible for 66 per cent of world LNG imports in 1990. In that year, LNG was only a marginal source of supply to US markets. however, all these investment plans will be materialized, LNG trade will become a truly international phenomenon (for an overvi of possible future LNG routes in 2010, see Figure 6.9).

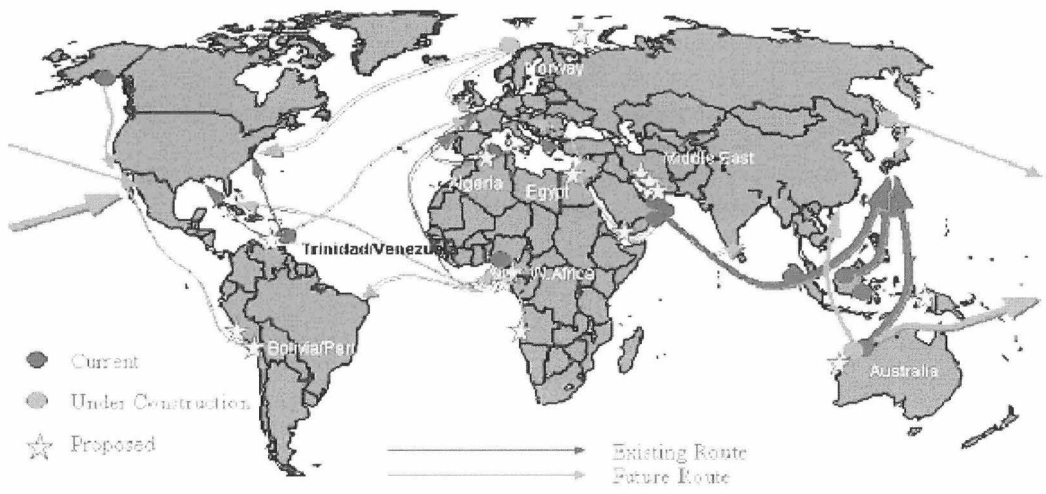
It should be mentioned though that the optimality of LNG may be restricted by particular physical, market and regulatory conditic at various destinations. In actual practice, this may require gas suppliers to be sufficiently flexible by offering a variety of deliv modes and contract terms.

re 6.8 *LNG export flows, 2004*



rce: Eni, 2005.

re 6.9 *Possible future LNG trade routes (2010)*



rce: BP, 2004.

umption 11 **Security issues with regard to internationally traded gas are increasingly incorporated in investment decisions. Since, on average, the security situation has become worse, also in the main natural gas producing countries, security becomes a serious issue that may block, or at least retard particular investments, especially in LNG capacity, but also in pipelines for gas and related infrastructure.**

nost all future gas flow projections suggest that natural gas will increasingly flow through politically unstable regions, irrespective whether transport will take place via LNG ships or via pipelines (see Figure 6.9, 4.14 and 4.17). With time this will probably rease attention for security issues and create reluctance within the international investment community to invest in international transportation infrastructure.

Table 6.1 shows that, presently, a considerable volume of gas (over 70 bcm in 2002) is already transported with LNG carriers v specific strategic seaways which seem vulnerable for terrorist action. Projections show that this amount could show a five-fold increa to levels of over 350 bcm in 2030. Such frequent international shipment via strategic maritime channels may therefore create considerable future safety risk, not only with a view to potential terrorist attacks, but also because it increases the chances of any oth accident with severe damage and casualty potential. These concerns may hamper investment decision-making - it seems likely tha serious disaster with LNG infrastructure leads to a setback in investments, at least temporarily.

Table 6.1 Oil and LNG tanker traffic through strategic maritime channels

		2002		2030	
		Volume oil (mb/d) gas (bcm)	**Share of global inter-regional net trade (%)**	**Volume** oil (mb/d) gas (bcm)	**Share of global inter-regional net trade (%)**
Straits of Hormuz	Oil tankers	15	44	43	66
	LNG carriers	28	18	230	34
Straits of Malacca	Oil tankers	11	32	24	37
	LNG carriers	40	27	94	14
Suez Canal	Oil tankers	1	4	3	4
	LNG carriers	4	3	60	9

Source: DOE/EIA, 2004; IEA analysis in: IEA, 2004a: 119.

In fact, a number of accidents and incidents (Arun Indonesia, 2001; Bintulu Malaysia, 2003; Skikda Algeria, 2004; Bontang Indoı sia, 2004) have already taken place, which has shown that in actual practice the LNG route can be vulnerable.

Assumption 12 **As the actual and contractual gas flows will increasingly differ, TSOs will at some stage no longer be able properly serve the market.**

In the modern internationalized gas market, the use of gas swaps, hubs and trading derivatives is expected to increase significantly. a consequence, however, contractual and actual flows will increasingly deviate from each other. At the same time, it may become creasingly difficult in an internationalized market, e.g. due to the use of entry-exit, to differentiate between transit flows and flows domestic destinations. Moreover, increasing international arbitrage activities, by choosing the optimum from different internatio transportation routes, possibly supported by some speculative positions, could increasingly complicate TSOs' efforts to simultaneou satisfy all contracts and the various rules and regulations set by the regulatory authorities. This may eventually lead to security of sı ply problems that are, just like security of supply problems due to too little investment in gas infrastructure, not related to proble with the availability of international gas supply.

Assumption 13 **In a liberalizing gas sector the traditionally integrated multinationals are increasingly being replaced wit wider range of, to some extent, new enterprises which operate on the (international) gas market, including n market players in the rapidly growing developing regions. This restructuring of the gas sector requires mı attention and energy, which may cause reduced attention to investments in new initiatives.**

Globally, a process can be observed of natural gas market liberalization together with unbundling of gas infrastructure and gas tra which will result in a fully competitive internationalized market. For gas market players this process has caused a lower predictabi of the market in which they operate, with regard to the roles and responsibilities of all parties involved in transportation and trad natural gas.

At the same time, there seems to be a clear restructuring process going on in the energy industry, characterized by the creation of ı players based on a process of mergers and acquisitions.

s combination of, on the one hand, unbundling of activities and, on the other hand, combinations of new entities absorbs much rgy in the business, which may crowd out the required attention for investment in new infrastructure projects. The restructuring / also affect competition in such a manner that it becomes increasingly difficult to coordinate massive international investments. It ld also lead to the forming of the international consortia that are typically needed for the substantial investments in the sector.

Summary

For the next few decades, the gas industry appears to have a fairly strong card to be among the winners in terms of its share of t market of primary energy carriers. A number of factors provide strong opportunities: natural gas is the cleanest of all hydrocarb energy sources; it has very low emissions of pollutants such as particulate matter, sulphur and nitrogen oxides, and the carbon dioxi emissions of burning gas are less than half of the carbon dioxide emitted by burning coal. New technologies for conversion of natu gas into electricity and other energy forms reduce and virtually eliminate most of the adverse environmental impacts.

These advantages of natural gas as a source and energy carrier have six important implications. First, gas has a relatively favoral position when compared to other fossil fuels in contributing to the ongoing decarbonization of global energy, simply because t carbon emissions per unit of energy are relatively low. Second, based on the same characteristics, gas can be seen as one of the m suitable candidates for being the transition fuel par excellence in the transition towards more sustainable energy futures. The fa that natural gas also fares well in terms of other emissions than carbon dioxide further contributes to its relatively environmenta friendly image. Third, unlike oil, gas seems to face much less serious reserve and resource constraints, which may lower its relati price. Fourth, efficiency levels of gas combustion technology are among the highest, and in addition natural gas is rather flexible its various applications. Fifth, compared to most other primary energy sources including renewables, gas is relatively easy to sto and finally natural gas can be seen as a precursor to hydrogen and therefore as a way to prepare for a long-term development towa alternative energy systems.

Thus, natural gas has a good card to play. However, one will not win the game automatically. First of all, other fuels also have so strong cards to play, which may unexpectedly alter the way the game evolves. Furthermore, the gas sector typically also faces so threats that, if not tackled well, may disturb the game substantially, the most severe threat probably being increasing concerns ab international security of supply, and finally it should not be taken for granted that the gas industry will automatically take the measu and investment decisions that are needed to substantiate its prospective increasing role.

As far as the first threat, security of supply problems, is concerned, it needs to be acknowledged that the natural gas import depe dence of many regions and countries is projected to increase substantially, while supply is likely to be increasingly concentrated i limited number of countries and coming typically from regions with vulnerable political systems. Also, the international gas transp infrastructure, particularly as far as LNG is concerned, seems to be increasingly susceptible to risks of accidents or even attacks transport bottlenecks and other supply interruptions. Also the fact that international pipeline systems will connect a number of d ferent countries adds to the infrastructure vulnerability.

The second threat to the prospective stronger role of natural gas stems from the fact that competing energy sources such as for insta coal, nuclear and renewables will not remain passive. Clean coal technologies are for instance rapidly evolving, possibly jointly w CO2 capture and storage; the image in some regions of nuclear energy as being unsafe may well gradually shift towards the image being clean, flexible and efficient, and a number of renewable technologies may well develop towards large-scale commercial appli tion much more rapidly than anticipated. In other words, competing energy sources may well gain strength and crowd out natural g especially if at the same time natural gas would increasingly be perceived as a problematic fuel from the geopolitical perspective.

The third threat that could alter the picture substantially is that investments by the major players in the gas industry in the vari stages of the chain will stay behind levels that would sustain a larger role for gas in the energy system. The gas industry is typic facing a large number of uncertainties such as: the climate and other environmental policy regimes, the liberalization and regulat regimes, the link between gas and oil prices, the public versus the private role with regard to investment, or the role of LNG and G In addition, the gas sector structure may face changes that will absorb attention and energy away from investment decisions. T substantial lack of clarity of many factors may cause the sector to postpone significant investments, which may weaken the ove chain. Given the long lead times and significant resources typically required for gas infrastructure development, this may underm the potential role of gas during the next decades.

hallenges for the gas industry

:h storyline carries its own implications for the gas sector.

nsition Storyline

transition storyline capitalizes on the perception that gas is green, safe, reliable, efficient and flexible in application. The industry have to invest in order to make sure that this image lasts and is covered by facts. This may require clear marketing activity and ful image building. Another implication could be that the sector tries to demonstrate more clearly that gas is the transition fuel excellence and will bring us towards more sustainable fossil free energy systems: examples could be demonstrations of green gas ects, decentralized gas fuelled systems combined with renewables, virtual power plants, increasing attention for flexibility services, igh safety standards. The image of gas as a reliable energy source could be further improved by investment in underground storage a stable contracting regime. Substantial innovative activity should be developed to further improve efficiency levels of gas-fired er plants.

ernational Security of Supply storyline

his storyline, the industry and governments have to work together to establish and maintain good commercial and diplomatic tions with the major supplier countries and regions. Such international cooperation may require international technology trans- more attention for international joint ventures, and a larger focus in foreign policy (including development or international iate policy) on international energy security of supply. To add to the security of supply situation, countries could consider forming tegic coalitions to serve their energy needs, and to set up new schemes of strategic gas reserves to overcome unexpected shortages ipply.

al, Oil and Nuclear Storyline

he coal, oil and nuclear storyline it is important for the gas sector to defend its market share by looking for coalitions with other ns of energy. For instance, decentralized energy systems may get off the ground more easily if gas and renewables can be combined. ould also seem perceivable that the combination of oil and gas may turn out to be attractive for a number of applications. In ition, the sector could try to penetrate some new markets, such as the mobility sector and in some rapidly growing developing ntries in order to improve its presence on quickly growing markets. This may require the sector to prepare for long-term predictable tracts and to offer integrated systems of both infrastructure for transport, training and implementation.

derinvestment Storyline

ie investment level is the major concern, it would be helpful to improve the quality of information about developments with regard ther energy sources, overall energy technology development and possible patterns of demand and supply. The better the informa- , the better the scope for investment. Various measures would need to be taken to make sure that governments will not frustrate stment decision-making via cumbersome bureaucratic procedures or unpredictability. This will require good cooperation with the lic authorities and possibly more public-private-partnerships. Also, strategic coalitions, possibly with financial institutions, that ild be required for substantial investment programs would need to be prepared well in advance.

erall

rder for the sector to be prepared for a wide range of different futures, it is extremely important not only to be well organized, so one can have a serious economic and political impact, but also have and demonstrate a clear vision as to what position should be n and what direction one wants to go.

he same time, the information in the sector about the most likely developments needs to be updated continuously, so that one as clear a picture as possible of where the trends go and what that would mean for the gas industry. This also requires continuous ibility and preparedness to adjust, simply because the future will most likely be different than one anticipates now.

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