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Market Competition in the Nuclear Industry

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The mission of the NEA is:

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- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

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In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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FOREWORD

The present and future owners of nuclear power plants require a wide variety of specialised equipment, materials and services to build, operate and fuel their plants. Low demand in many nuclear industry sectors since the 1980s has resulted in consolidation and retrenchment, with the emergence of some large global nuclear companies. Meanwhile, electricity market liberalisation in many OECD countries has changed the environment in which nuclear plants operate, putting them under competitive pressures.

These important structural changes in both the producer and consumer sides of the nuclear fuel and nuclear reactor design and engineering markets have had implications for the level of competition in the nuclear industry. This study examines market competition in the supply of goods, materials and services for the design, engineering and construction of new nuclear plants, for the entire nuclear fuel cycle, and for the maintenance and upgrading of existing plants. It does this by assessing a set of ten market characteristics selected to act as broad indicators of competitiveness, including the market shares of major participants.

With renewed expansion of nuclear power expected over the next decade and beyond, to the extent possible the study considers how the level of competition may change with a significant upturn in demand. It also looks at the potential implications for market competition of proposed multilateral fuel supply arrangements currently under discussion.

Acknowledgements

The study was carried out by an ad hoc group of experts nominated by NEA member countries, listed in the Appendix. The group was co-chaired by Dr. Koji Nagano of Japan and Mr. David Shropshire of the United States. The Secretariat would like to acknowledge the important contribution made by each member of the expert group. Thanks are also due to Professor Jan Horst Keppler of *Université Paris Dauphine*, who provided valuable advice on the methodology for assessing market competition.

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EXECUTIVE SUMMARY

The nuclear industry provides a wide variety of specialised nuclear equipment, materials and services to support the design, construction, operation and fuelling of nuclear power plants (NPPs). This includes the supply of NPPs themselves, the range of materials and services required in the nuclear fuel cycle, and the services and equipment needed for maintenance and upgrading. The markets to provide these have changed substantially as they have evolved from the government-led early stages of the nuclear industry, and most sectors now operate as competitive commercial markets.

There has been much consolidation and retrenchment in the nuclear industry since the 1980s in response to generally low demand, which has resulted in the emergence of a small number of large global players in some sectors. This partly reflects special factors in the nuclear industry, but also the more general trend towards globalisation of major industrial activities. Meanwhile, the liberalisation of electricity markets in many OECD countries has changed the business environment for NPP owners/operators. Electricity utilities have been exposed to increased competition, requiring them to improve their business performance and making them more cost-conscious.

There have thus been major structural changes on both the producer and consumer sides of the nuclear markets since the major expansion of nuclear power in the 1970s. The Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle of the OECD Nuclear Energy Agency (NEA) established the Ad hoc Expert Group on Market Competition in the Nuclear Industry to examine how the major market sectors are performing in present market conditions and, with renewed expansion of nuclear power expected over the coming years, how these markets can be expected to change with a significant upturn in demand. The study also considered the potential implications for market competition of the broad types of multilateral assured fuel supply arrangements which have been proposed by several governments.

In carrying out its study, the expert group kept in mind that there are some areas of nuclear activity where competition is necessarily limited or even absent. This includes many research and development activities, especially those with a longer term goal, where international co-operation and government support are necessary until new technologies are ready for commercialisation. Within existing commercial sectors, certain limitations also necessarily exist, notably non-proliferation controls on sensitive materials, equipment and technologies.

Furthermore, nuclear power involves very large investments in complex plant and equipment, and requires a high level of specialised expertise. This often results in long-term relationships between suppliers and customers, who work together to ensure that plants operate safely and efficiently, and that improvements and upgrades can be made effectively. The expert group noted that in nuclear markets, quality and reliability are often at least as important to customers as prices.

Assessing the competitiveness of markets

In the absence of detailed statistical information about each market sector, to assist the expert group in making objective assessments it was decided to consider a set of market characteristics which could act as indicators of competitiveness. Although the assessment of each indicator involved a degree of subjective judgement, taken together they provided a useful overall impression of the effectiveness of competition in each sector. These indicators were:

- Market shares of major participants.
- Degree of vertical integration.
- Proportion of long-term contracts.
- Barriers to entry.
- Transaction costs and market segmentation.
- Product differentiation.
- Balance of capacity and demand.
- Market alliances and supplier co-operation.
- Public goods aspects.
- Trade barriers and restrictions.

Where possible, market shares were used to calculate the Herfindahl-Hirschman Index (HHI) for the market sector, defined as the sum of the squares of the percentage market shares of all market participants. If the value of HHI is greater than 1 800 this is often taken as a sign that a market may be over-concentrated.

Main findings for each major market sector

Design, engineering and construction of NPPs

This sector appears poised for a major expansion in the coming decade and beyond. Despite the prolonged market depression since the 1980s and the consolidation which resulted, the remaining NPP vendors have continued to develop their designs and are now offering considerably improved products. At least in the major markets, where there is the potential for a series of orders, there is likely to be strong competition between four or five vendors. Despite some market distortions, notably where vendors dominate their home markets, a global market with several independent and competing vendors has emerged which provides a genuine choice of supplier to potential customers. However, different regulatory requirements for NPP designs between countries, which can lead to significant up-front costs for vendors, may effectively limit the choices available, particularly in smaller markets.

In the longer term, there is the prospect of the emergence of additional important NPP vendors. The most probable of these are those who have benefited from technology transfer deals with the existing vendors, and have gone on to develop the technology further themselves and eventually reach the status of independent vendors able to offer their distinct designs on the global market. In particular, such companies may well emerge in Korea and China. New vendors based on more innovative reactor designs developed independently of the existing vendors may also emerge, but this is less certain and is likely to take longer.

Uranium supply

A significant number of new uranium production facilities is expected to enter operation over the coming years in response to rising demand. Many of these will be owned by new entrants or smaller producers with growing production. Although some consolidation is likely to occur, the trend is expected to be towards reduced market concentration. However, the possibility of a merger of two of the major producers could be a cause for concern if it led to the merged company controlling a very large share of global production. Trade restrictions on uranium imports into the United States and the European Union since the early 1990s have affected market competition. However, increased demand and the reduced availability of supplies from existing stockpiles is likely to limit the practical impact of these restrictions on the market, even if the measures themselves remain in force.

UF_6 conversion services

There are effectively only three major suppliers of UF_6 conversion services to the global market, with a fourth supplier which is mainly limited to providing uranium, conversion and enrichment as a package. From a market competition perspective, this indicates that the market is more concentrated than would be desirable. However, the role of conversion plants as the main storage locations and clearing houses of the uranium market may mean that it is more convenient for market participants if there is a relatively limited number of sites. Together with the fact that conversion represents only a small fraction (around 5%) of the total cost of nuclear fuel, this means that new conversion facilities on new sites may have difficulty in establishing themselves. Present expansion plans indicate that the existing major suppliers will expand their capacity as required and little change can be expected in the degree of market concentration.

Uranium enrichment services

Enrichment technology is among the most sensitive in terms of non-proliferation, which means that it is possessed by a limited number of countries, and is entrusted by governments to only a small number of commercial operators; this inevitably limits market competition in this sector. However, the enrichment industry is undergoing major changes which will re-shape it over the next ten years and beyond. The remaining older gas diffusion plants in France and the United States will be replaced by new centrifuge plants, while there is also the prospect of laser enrichment technology being commercialised. There will be at least two and possibly as many as four new enrichment plants in the United States by 2015, each operated independently by competing suppliers. The large enrichment capacity in Russia is also expected to play a larger role in the international market. These developments are likely to lead to shifts in the market shares of the existing suppliers.

Fuel fabrication services

Unlike other fuel cycle services, fuel fabrication is essentially a bespoke service to prepare fuel assemblies to the exact requirements of each NPP. For a new NPP, fuel is initially supplied by the NPP vendor. Only later in the NPP's operating life does the possibility of choosing between competing suppliers open up. Furthermore, some NPP operators may not consider that the commercial risk involved in changing suppliers is justified by the potential savings on fuel costs. Nevertheless, significant competition does exist in the fuel fabrication market, and for NPPs of more common designs there may be a choice of up to three fabricators. However, the fuel fabrication market has consolidated over recent years, as the main NPP vendors have consolidated. It now appears that the market for fuel fabrication is more concentrated than would be desirable. For some market sub-sectors there is effectively no competition.

For new NPPs, initial fuel loads will inevitably be supplied by the plant vendors, who will add new capacity when and where necessary. Where a large nuclear programme is undertaken, additional capacity may be provided by licensing the fuel design to a local fabrication plant. However, the development of a competitive market for these new fuel designs will require alternative suppliers to emerge. This is a matter to which purchasers of NPPs will need to give due consideration when making their choice of reactor technology. Experience has shown that one way to ensure a choice of fuel supplier is to choose a NPP design which is being built in significant numbers, as in time such designs are likely to be better served by alternative fabricators.

Back-end of the nuclear fuel cycle

Much of the capacity of the limited number of spent fuel reprocessing plants is devoted to domestic arisings of spent fuel, but some also reprocess spent fuel from other countries under contracts with foreign utilities. Thus a limited international market does exist, but this has been declining in recent years. With the prospect of significant future expansion of nuclear power, the potential for spent fuel reprocessing and recycling is attracting renewed interest. However, reprocessing technology is highly sensitive from a non-proliferation perspective. Reprocessing is likely to be restricted to a small number of countries, or be subject to multilateral control. Its wider use is also likely to depend on the adoption of advanced reactor designs which allow full advantage to be taken of the recycled materials. The commercialisation of such designs is not expected to occur until well after 2020.

Plutonium separated in existing reprocessing plants can be used to fabricate mixed-oxide (MOX) fuel for use in some existing light water reactors (LWRs). There are presently two commercial plants in operation, in the United Kingdom and France. Fabricated fuel has been supplied to several European countries and to Japan. This has so far been a limited market, driven mainly by the desire of the utilities concerned to utilise their plutonium. MOX fuel fabrication is thus tied to the future of commercial reprocessing, and in the longer term to the deployment of advanced reactor types using fuel containing recycled materials.

In general, utilities remain responsible for the management of radioactive waste arising in their plants, at least until it is handed over to a national authority or agency responsible for its disposal. A similar situation exists for the decommissioning of disused facilities and the waste generated during such activities. Thus, commercial activity in these sectors is generally limited to the provision of services, technology and equipment. Many specialised companies are involved, as well as many of the main nuclear industry companies. Overall, there is considerable competition and innovation in the provision of services, technology and equipment for radioactive waste management and decommissioning.

Services for maintenance and upgrading of existing NPPs

With the lack of orders for new NPPs in recent years, reactor vendors and other nuclear engineering companies have been increasingly reliant on the business of maintaining, backfitting and upgrading the existing reactor fleets. With life extensions now planned for a large number of existing NPPs, the demand for major upgrading projects is likely to remain high. At present, there appears to be a good balance between capacity and demand in this sector with a good degree of competition in most sub-sectors of what is a multi-faceted market. However, if there is a significant increase in orders for new NPPs in the coming years this situation could change, as construction of new plants will often involve the same companies. It could potentially become more difficult to find competing suppliers able to undertake routine maintenance tasks and larger upgrading projects in a timely fashion.

Overall assessment of market competition

The expert group's analysis shows that the most concentrated nuclear industry market sectors are enrichment and fuel fabrication, with in each case one supplier having over 30% of the market and others in the 20% to 30% range. Reprocessing is also concentrated, although this is a smaller and less well-developed market. Overall, however, no sector in the front-end of the fuel cycle has a single company with an overwhelming dominance, with each having at least four competing suppliers. No indication was found from presently available information that market shares of leading suppliers are likely to increase significantly as the sectors expand over the next ten years. Indeed, in some sectors, notably uranium supply, it appears that the market may become less concentrated over the coming years.

In the market for new NPPs, it is difficult to assess future market shares as this will depend on the relative success of the vendors in winning orders. However, in most regions there is significant competition between at least three or four suppliers. In this, the NPP market compares favourably with certain other engineering-based industries with complex high-technology products, notably the aerospace industry. Early indications are that each major NPP vendor will win a significant share of new orders over the next decade. The future market for fuel fabrication services will to a large extent also be shaped by the market for new NPPs.

Several major nuclear companies have a significant share of more than one sector, i.e. there is a degree of vertical integration across several of the market sectors. Insofar as such companies supply nuclear equipment, services and materials as a package, this may lead to a reduction in competition in some sectors. In particular, some fuel cycle companies (which are not also NPP vendors) may be at a disadvantage, as might NPP vendors which cannot offer the full range of fuel cycle services. Such comprehensive arrangements are so far rare, but in future some customers may prefer the perceived security of receiving a complete package of services from a single large supplier. If comprehensive provision is preferred by some customers, it is likely that an increasing number of companies will try to position themselves to meet this requirement.

Implications of proposed multilateral fuel supply arrangements

With an increasing number of countries considering launching a nuclear power programme in the future, the issue of multilateral assured fuel supply arrangements is being discussed by governments in international forums, notably under an initiative launched by the International Atomic Energy Agency (IAEA). It is beyond the scope of this study to consider or take a view on the benefits of the proposed arrangements for addressing security of supply or proliferation concerns. However, the expert group did consider in a general way the potential implications for market competition of such arrangements, while keeping in mind that many of the details of the proposed arrangements have yet to be developed.

The study considered the proposed arrangements in three broad categories, which involve assurances being provided to consumers in the following ways:

- stockpiles or fuel banks controlled by an independent multilateral agency;
- fuel supply guarantees provided by multiple supplier countries;
- fuel cycle facilities under multilateral control.

Arrangements involving the establishment of one or more fuel banks would be expected to closely resemble current market conditions, and would not be expected to have a significant impact on international nuclear markets. However, they could potentially serve to protect the market shares of existing suppliers and to discourage new market entrants in some sectors. On the other hand, some existing trade restrictions could be removed, giving suppliers access to additional customers.

Where assurances would be provided by supplier countries or by the establishment of multilateral fuel cycle centres, this could result in nuclear infrastructure remaining concentrated in a limited number of countries, requiring consumers to enter long-term partnerships with suppliers or participate in multilateral centres. Such ties could reduce the ability to choose among competing suppliers in the market, and could also lead to more vertical integration, particularly if orders for new NPPs included the leasing of nuclear fuel. However, such arrangements could also be structured to encourage the establishment of additional fuel cycle facilities under independent commercial control, which could add to overall supply and increase competition.

Key findings and recommendations

- Competitive markets for the supply of goods and services for the construction, operation and fuelling of nuclear power plants are an important factor in ensuring the overall competitiveness of nuclear power, thus helping its benefits to be more widely spread. Governments should encourage and support competition in these markets, and actively seek to prevent concentration of market power where it unduly limits competition.
- An important policy aim of some national nuclear programmes is the development of a domestic nuclear capability. This may necessarily involve some protection of infant industries, with national investment focused on a single supplier to avoid duplication. However, care should be taken not to permanently exclude competitive pressures, which should be allowed to strengthen as market and industrial sectors mature.
- While longer term development and demonstration of new nuclear power technologies may require government support and funding, competition is a great spur to innovation and technological development, helping to improve the products and services available. As fledgling technologies mature and reach the stage of commercial deployment, they should be increasingly subject to the competitive pressures which will allow them to achieve their full potential.

- Strong non-proliferation controls on sensitive nuclear materials and technologies are vital for the existence of open and competitive global markets in the nuclear industry. Such controls will necessarily involve some market restrictions and limitations. Nevertheless, non-proliferation controls are consistent with the development of new capacities by competing suppliers to meet the growing requirements of nuclear programmes around the world.
- Other restrictions and tariffs on international trade in goods and services for nuclear power plants can unnecessarily add to the costs of nuclear power. Governments should aim to eliminate or reduce them to the extent possible.
- The best assurance of supply of nuclear fuel and other essential goods and services to NPPs worldwide is the existence of a geographically diverse range of independent suppliers competing on commercial terms in all market sectors. Governments should seek to create the necessary legal and regulatory frameworks in which such a situation can develop. Furthermore, the harmonisation of such frameworks between countries, especially for the approval of new NPP designs, would increase customer choice and enhance competition in nuclear markets.

1. INTRODUCTION

Designing, building, operating and fuelling nuclear power plants requires their owners/operators to procure a variety of specialised nuclear equipment, materials and services. The markets to provide these have changed substantially over their history as they have evolved from the government-led early stages of the nuclear industry.

Since the 1980s, there has been much consolidation and retrenchment in the nuclear industry, which has resulted in the emergence of a small number of large global players in some sectors. This partly reflects special factors in the nuclear industry, but also the more general trend towards globalisation of major industrial activities. Further consolidation and restructuring may take place in response to market changes.

Meanwhile, electricity market deregulation in many OECD countries has changed the business environment for NPP owners/operators. Utilities that were once state-owned or price-regulated monopolies have been exposed to competition, requiring them to improve their business performance at all levels. This has made them more cost-conscious, while freeing them from some government-imposed restraints.

Thus, there have been major structural changes in both the producer and consumer sides of the nuclear fuel and nuclear design and engineering markets since the major expansion of nuclear power in the 1970s. The Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle of the OECD Nuclear Energy Agency (NEA) decided to establish an ad hoc expert group to examine how the major market sectors are performing at present and, with renewed expansion of nuclear power expected over the coming years, how these markets can be expected to change with a significant upturn in demand.

This report presents the findings of this Ad hoc Expert Group on Market Competition in the Nuclear Industry. It covers market competition in the supply of goods, materials and services for the design, engineering and construction of new nuclear power plants (NPPs), for the front and back ends of the nuclear fuel cycle, and for the maintenance and upgrading of existing NPPs. These markets are analysed to determine if effective competition exists, and to identify the various constraints which may limit it. To provide context, some aspects of the historical development of these markets are also included. The study also considers the potential implications for market competition of the broad types of multilateral assured fuel supply arrangements which have been proposed by several governments.

In examining market competition in the nuclear industry, the expert group also kept in mind that there are some areas of nuclear activity where competition is necessarily limited or even absent. This includes many research and development activities, especially those with a longer term goal, where international co-operation and government support are necessary until new technologies are ready for commercialisation. Within existing commercial sectors, certain limitations also necessarily exist, notably non-proliferation controls on sensitive materials, equipment and technologies.

Building, operating and maintaining NPPs over their operating lifetimes of up to 60 years involves very large investments in complex plant and equipment, and requires a high level of specialised expertise. This often results in long-term relationships being developed between suppliers and customers, who work together to ensure that plants operate safely and efficiently, and that improvements and upgrades can be made effectively.

This can serve to limit competition, but may also be in the best interests of NPP owners, since the costs of lost production resulting from an unplanned outage could quickly outweigh any cost benefits from changing supplier. In some market sectors, such as maintenance and fuel fabrication, changing supplier may represent a significant risk to NPP owners. Thus, it is important to recognise that competition in the nuclear industry is not simply about price, but that quality and reliability are often at least as important.

2. ASSESSING THE COMPETITIVENESS OF MARKETS

In order to make objective judgements about the competitiveness of the various markets for nuclear energy related materials, goods and services, it is first necessary to define some criteria against which the market characteristics can be assessed.

In principle, the competitiveness of a given market can be assessed numerically by analysing the details of a large number of transactions. However, this requires a very high degree of market transparency, including knowledge of prices and costs. This can work well for markets where there is a large number of suppliers and consumers, and many transactions for which data are available.

In general, nuclear-related markets are characterised by relatively small numbers of both suppliers and consumers. Individual transactions are often very large, but few in number. Detailed cost and price information are rarely publicly available. Thus, it is unlikely that a numerical assessment of market competitiveness would be possible.

The approach adopted was to draw up a list of market characteristics which can act as indicators as to the degree of competition in a market. Each nuclear-related market was examined for the extent to which these indicators were influencing the market situation. Although the assessment of each of these indicators involves a degree of subjective judgement, taken together they provide a useful overall impression of the effectiveness of competition in the markets.

These indicators are:

1. Market shares

This can be measured numerically using the Herfindahl-Hirschman Index (HHI), defined as the sum of the squares of the percentage market shares of all market participants. If this value is >1 800, market regulators usually consider this a sign of over-concentrated market power. Several nuclear-related markets have HHI values above this level.

2. Degree of vertical integration

A high degree of vertical integration in a market can be a sign of market foreclosure, i.e. companies with a strong position in an upstream sector can use this to maintain or increase their share in downstream sectors.

3. Proportion of long-term contracts

Where a market is mainly conducted through long-term contracts, this can also be a sign of market foreclosure. Suppliers have sufficient market power to tie up their customers for long periods, limiting the opportunities for new market entrants.

4. Barriers to entry

There can be many different types of barriers to market entry. They may include the existence of patents and other restrictions on the required technology or know-how, the need for large capital investments, etc.

5. Transaction costs and market segmentation

This relates to the degree of market integration, i.e. do all suppliers have equal access to all potential consumers. Large differences in transaction costs (such as costs for transport and information) between suppliers can lead to market segmentation and reduced competition. Cultural and linguistic factors, as well as convenience of location for delivery and support services, can also play a role in market segmentation.

6. Product differentiation

In a perfect market, competing suppliers would supply products which were directly equivalent (or substitutable) for each other. In some nuclear-related markets, such as uranium supply, the products of different suppliers are directly equivalent, or "fungible". In others, such as fuel fabrication, there may be design differences and quality issues; these can affect the degree of competition.

7. Balance of capacity and demand

The existence of over-capacity in any market is generally a positive indicator for competition, as it increases consumer choice and tends to lower prices (a "buyers' market"). Conversely, a market with insufficient capacity (perhaps as a result of rapidly growing demand) can lead to reduced competition and higher prices (a "seller's market").

8. Market alliances and supplier co-operation

Market regulators normally have powers to prevent or punish clandestine collusion or cartel-like behaviour between different suppliers, such as price-fixing. However, other forms of publicly-announced co-operation or alliance between suppliers may be permitted where the impact on competition is deemed to be acceptable. Often such alliances will be limited to certain market sectors or geographic regions. In some circumstances the effect on competition can be positive, if it means that the allied companies can compete more effectively in a particular market with well-established incumbents. Nevertheless, there is the potential to limit competition, so the impact of such alliances needs to be monitored.

9. Public goods aspects

The concept of "public goods" covers protection of the environment and public health, which in the nuclear industry includes areas such as nuclear safety, radiation protection and non-proliferation. Governments seek to protect public goods through legal or administrative measures, often overseen by one or more regulatory agencies. Companies have to comply with regulations covering the construction and operation of industrial facilities, normally through a licensing process. Of course, governments have a clear responsibility to protect public goods in these areas, but if regulations are unnecessarily burdensome or inefficient, or vary widely between different jurisdictions, they can have a negative impact on market competition.

10. Trade barriers and restrictions

In addition to regulations designed to protect public goods, there may be additional legal or administrative barriers imposed by governmental agencies or by legal processes which (either unintentionally or by design) have the effect of limiting market competition. These include protectionist measures (such as import tariffs) designed to limit foreign competition, as well as restrictions imposed for other political reasons.

Of course, market competition may be limited as a consequence of barriers to entry and regulations which are obviously necessary or unavoidable. This may be particularly true for nuclear industry markets, many of which involve sensitive and hazardous materials and operations. However, while imposing such necessary restrictions, governments may also seek to limit their impact on market competition. For example, harmonisation of regulations between different countries can remove barriers to competition while still achieving the desired goal.

Not all of these indicators are relevant to all markets in the nuclear industry, and some may be difficult or impossible to assess accurately in particular cases. Nevertheless, where a number of these indicators point to market power being over-concentrated, this can be taken as demonstrating that market competition is being constrained. This indicates that there may be economic benefits to be gained by taking steps to increase competition in these markets, for example by removing certain restrictions or seeking to prevent anti-competitive behaviour.

3. COMPETITION IN THE DESIGN, ENGINEERING AND CONSTRUCTION OF NUCLEAR POWER PLANTS

The long period during which there have been very few new nuclear plant orders worldwide has led to considerable consolidation among NPP vendors, notably in Europe and the United States. This has led to the emergence of just three major global vendors for light water reactors: AREVA NP, GE Energy and Westinghouse. AREVA NP is a French-German company, GE Energy is a subsidiary of General Electric of the United States, while Westinghouse is a mainly US-based company which is now majority-owned by Toshiba of Japan.

This consolidation has to some extent been offset by the emergence of vendors from other regions (e.g. Japan and Russia) onto the international stage, with others having the potential to do so in the future (e.g. Korean and Chinese companies). Atomic Energy of Canada Ltd (AECL) also offers its pressurised heavy water reactors (PHWRs) on the international market.

It should be noted that the process of constructing a nuclear power plant is a complex one which will often involve several major contractors together with numerous sub-contractors. The contracting arrangements vary from plant to plant, from a turnkey approach whereby the vendor manages the entire process, through the appointment of an architect-engineering company to oversee the process, to in-house project management by the utility (see text box). Thus the main NPP vendors will normally be working with different partners for each project, especially in different global regions. In many countries, an important consideration is the extent to which national companies can be involved in the overall construction effort.

A distinction can be made, however, between the "nuclear island", incorporating the reactor itself and other systems and facilities specific to a nuclear power plant, and the "balance of plant". The latter comprises components and structures which are not specific to NPPs, being similar to those used in other types of power plant (including such major components as turbine generators). The analysis in this report will focus on the market for the supply of the nuclear island and the construction and engineering services which support this, which are normally the preserve of the specialist nuclear vendors.

Market shares

It is possible to examine historical market shares of the various NPP vendors. However, many reactors were supplied by vendors which no longer exist as independent companies, having been taken over or merged with other vendors. Major consolidations which have taken place include:

- Combustion Engineering (C-E) (which built several pressurised water reactors (PWRs) in the United States), was taken over by Swedish/Swiss engineering group ABB (constructor of boiling water reactors (BWRs) in Sweden and Finland) in 1990, resulting in the merger of the two companies' nuclear operations.
- The nuclear fuel and services activities of Babcock & Wilcox (B&W), constructor of several PWRs in the United States, were absorbed into Framatome of France (constructor of PWRs in France and other countries) in 1992.
- The nuclear divisions of Westinghouse Electric, the leading constructor of PWRs worldwide, were sold by their parent company to British Nuclear Fuels (BNFL) in 1999.
- ABB also sold its nuclear operations (including those formerly of C-E) to BNFL in 2000; these activities were subsequently integrated into Westinghouse.
- Framatome was merged with the nuclear activities of Siemens of Germany (which built NPPs in Germany and other countries) to form AREVA NP in 2001, owned 66% by AREVA and 34% by Siemens.
- Westinghouse was sold by BNFL in 2006 to Toshiba of Japan (itself a vendor of BWRs in Japan in partnership with GE). Toshiba presently holds 67% of Westinghouse, with Shaw Group of the United States (an architect-engineering company) holding 20%, Kazatomprom of Kazakhstan (a uranium producer) holding 10%, and IHI Heavy Industries of Japan holding 3%.

The net result is that AREVA NP is the successor to the nuclear activities of B&W (in part), Framatome and Siemens, while Toshiba (through its majority ownership of Westinghouse) is successor to ABB, Combustion Engineering and Westinghouse (although Westinghouse continues to operate independently of Toshiba). AREVA is presently constructing one NPP of its European Pressurised Reactor (EPR) design in Finland, and work has begun on a second EPR in France. The company is also constructing two units of an earlier design of PWR in China, in conjunction with local companies. (One heavy water reactor of a Siemens design remains under construction in Argentina, but AREVA does not have a major involvement in this project.)

Different approaches to NPP contracts

There is a spectrum of different approaches to contracting for the supply of a NPP, ranging from complete responsibility being taken by a single supplier to complete control being retained by the utility customer. However, the main approaches are normally classified into three main types of contracting model, each of which has a number of variations. These main classifications are:

Turnkey approach

A turnkey approach to NPP contracting involves a single large contract between the customer and a NPP vendor (or a consortium led by such a vendor), covering the supply of the entire plant. This will include design and licensing work, supply of all equipment and components (including at the first core of fuel and often several reloads), all on-site and off-site fabrication, assembly and construction work, and testing and commissioning of all systems and the entire plant. The vendor or consortium will sub-contract any elements of the project which it is not able to supply itself. Thus, the contractor takes on full responsibility for delivery of a complete and fully working plant to the customer.

There are several variations on this pure turnkey approach, which may still be described as turnkey. For example, the construction of some support facilities (often described as “owner’s scope”) may be excluded from the main turnkey contract, and customers with in-house nuclear expertise may wish to retain some involvement in design decisions during the construction process. Nevertheless, the overall responsibility for the construction and integration of all important plant systems remains with the main contractor.

Bidding for turnkey contracts normally involves a small number of competing nuclear vendors or vendor-led consortia, giving the customer a limited choice (each of which will normally involve a different reactor technology). The customer may be able to exert some control over the formation of the consortium by allowing separate bidding (either in parallel or sequentially) for different elements of the project, with a view to asking the successful bidders to form a consortium, which would then be awarded the contract.

Split-package approach

In the split-package approach the project is divided into a few major systems, each of which is the subject of a separate contract with a different supplier. At its simplest, this approach divides the plant into two packages: the nuclear island (essentially, the reactor containment building and all systems within it); and the conventional or turbine island (the turbine-generator and associated systems and buildings). More complex split-packages can separate the civil construction work on the whole plant from the contracts for the nuclear and turbine systems, and can also separate out other major electrical and mechanical systems into separate contracts. In each case, there may also be an owner’s scope part of the project.

(continued)

Different approaches to NPP contracts *(continued)*

In such an approach it is necessary to allocate overall responsibility for design and licensing, and for integrating the various packages to ensure that all the plant's systems work together correctly. Such overall responsibility could be taken by the plant's owner (where sufficient in-house expertise exists), or this role could be taken by one of the main contractors (usually the main nuclear island contractor).

Bidding for a split-package project can be carried out independently for each package, with the customer then free to choose the best option for each contract. This works best where the owner is retaining overall responsibility for the project. In other cases, bidding can be by rival groups of companies; this is similar to consortia bidding except that each member of the successful group has a separate contract directly with the customer. The lead contractor of the winning group (usually the nuclear system vendor) co-ordinates the overall project.

The customer can also choose a system of sequential bidding, allowing it first to choose a nuclear system vendor as lead contractor before choosing contractors for the remaining packages (in consultation with the lead contractor). Each contractor has a separate contract with the customer, but works under the overall co-ordination of the lead contractor.

Multi-contract approach

This approach gives the customer the maximum influence over the design and construction of the plant, but also the most responsibility for the success of the project. Only a few large nuclear utilities have this expertise in-house, so in most cases where this approach is adopted an external architect-engineering company will first be contracted to manage the overall project.

The architect-engineer (either an in-house team or external contractor) is responsible for the overall design and for licensing, for inviting bids and selecting contractors for each of the plant's systems [including the nuclear steam supply system (NSSS) and the turbine-generator system], for managing the actual construction work, and for plant testing and commissioning. It often directly employs many of the on-site construction, engineering and management staff. While some major contractors, such as the NSSS supplier, will also have a significant on-site presence, many other contractors supply pre-fabricated systems or components with little or no on-site presence.

Of course, there are many variations within this overall approach, in particular as to exactly how many separate contracts are issued. Breaking the project into a larger number of separately supplied components and systems can maximise the choice of supplier for each (thus increasing competition) or can allow increased local content, but is likely to make more onerous the architect-engineer's task of co-ordinating the project.

For the BWR market, GE Energy remains the dominant vendor worldwide. It has in the past licensed its technology to both Toshiba and Hitachi in Japan. However, following Toshiba's acquisition of Westinghouse, GE has announced the formation of a joint venture with Hitachi (known as GE-Hitachi) for the marketing of BWRs worldwide (except Japan), owned 60% by GE and 40% by Hitachi. A separate joint venture, owned 80% by Hitachi and 20% by GE, will operate in Japan only. Presently, GE is constructing two of its advanced BWRs for the Taiwan Power Company. Some co-operation on BWRs between GE and Toshiba is expected to continue under existing agreements, allowing Toshiba to offer advanced BWRs of a similar design to those offered by GE-Hitachi in some markets.

Licensing of NPP designs by the major vendors to companies in the countries where the plants are to be constructed has played a significant role in the NPP construction business for many years. Indeed, AREVA NP's forerunner Framatome was originally a Westinghouse licensee, although it acquired independent control of its technology in the 1980s. In Japan, Westinghouse PWR technology has been licensed by Mitsubishi Heavy Industries (MHI), which presently has one unit under construction. However, as with the link between GE and Toshiba for BWRs, the future of this arrangement may well be affected by Toshiba's takeover of Westinghouse. In 2007, MHI and AREVA NP announced a joint venture, dubbed ATMEA, to develop a new PWR design for certain markets in the 1 000 to 1 150 MWe range. Meanwhile, MHI has taken steps to offer its advanced PWR design (developed jointly with Westinghouse) in the US market.

Another significant long-term licensing and technology transfer deal was concluded between C-E (now part of Westinghouse) and Doosan Heavy Industries (and other Korean companies) for the development of an indigenous nuclear industry in Korea. This process has progressed to the point where Doosan is now the main vendor of NPPs in Korea, although Westinghouse retains a consultancy role and supplies components. Three NPPs are presently being constructed by Doosan and its partners in Korea.

A similar deal was concluded in 2007 between Westinghouse and China for the gradual transfer of technology to Chinese companies, initially though the supply of four NPPs. Although the China National Nuclear Corporation (CNNC) has developed its own PWR technology, this is less advanced than that available on the international market. CNNC has two units under construction in China, with another in Pakistan. To what extent CNNC will continue to develop its indigenous technology in future remains to be seen.

Also in 2007, the AREVA group signed contracts with Chinese organisations for the supply of two EPRs together with all the fuel and services required to operate them (including uranium supply). The scope of the agreement includes establishing an engineering joint venture which will acquire the EPR technology for the Chinese market (ensuring AREVA's participation in follow-on projects), as well as co-operation in the back-end of the fuel cycle which may lead to the construction of a reprocessing-recycling plant in China. A contract of this size and scope is unprecedented in the nuclear industry, and represent a significant success for AREVA's stated strategy of vertical integration across all sectors of the nuclear industry.

AECL has built its PHWR reactors, known as CANDUs, in Canada and several other countries. A new unit has recently been completed in Romania. An advantage of this type of reactor from the perspective of countries seeking self-sufficiency in energy supply is that it does not require enriched uranium fuel (although, of course, heavy water is required). This technology has been replicated for reactors built in India by the Nuclear Power Corporation of India Ltd (NPCIL), based on two CANDUs built in that country by AECL in the 1960s. NPCIL has three plants under construction in India at present.

The Russian nuclear industry, now consolidated under the state-owned holding company Atomenergoprom, has constructed all the NPPs in the former Soviet Union, most of those in Eastern and Central Europe, as well as other countries. All recent models have been of VVER (water-cooled and water-moderated reactor) designs, which are similar in concept to PWRs. Ten reactors are presently listed as under construction in Bulgaria (2 units), India (2), Iran (1), Russia (3) and Ukraine (2), while two units in China entered operation in 2006 and 2007. Under an agreement between the Soviet Union and the former Czechoslovakia, Škoda was the vendor for most VVERs in the Czech Republic and the Slovak Republic.

Taking into account the consolidations which have taken place, an assessment of the existing world fleet of large power reactors (excluding plants which are permanently shut down, but including those under construction), shows that the combined Toshiba/Westinghouse (including the former ABB and C-E nuclear operations) has built 120 of the total of 434 reactors, a share of 27.6% (see Table 1). AREVA NP (including former Framatome and Siemens operations) is not far behind, with 96 NPPs, or 22.1% of the total. Table 1 also shows that the Herfindahl-Hirschman Index (HHI) for these historical market shares is 1 666, which does not indicate an over-concentrated market. However, this historical data does not, of course, necessarily reflect the current status of the NPP market.

Table 1. **Nuclear power plant vendors with total number of reactors built worldwide still in operation (including consolidated companies), and percentage shares**

Company	No. of NPPs	Share (%)	HHI
Toshiba/Westinghouse (inc. ABB, C-E)	120	27.6	765
AREVA (inc. Framatome, Siemens)	96	22.1	489
General Electric (GE) Energy	54	12.4	155
Atomenergoprom	52	12.0	144
Atomic Energy of Canada Ltd (AECL)	34	7.8	61
Mitsubishi Heavy Industries (MHI)	19	4.4	19
Nuclear Power Corporation of India Ltd	16	3.7	14
Hitachi	10	2.3	5
Škoda Praha	10	2.3	5
Doosan Heavy Industries	9	2.1	4
Babcock & Wilcox (B&W)	7	1.6	3
China National Nuclear Corp. (CNNC)	7	1.6	3
Total	**434**	**100.0**	**1 666**

Table 2. **Nuclear power plant vendors with number of reactors completed in or after 2000 or under construction, and percentage shares**

Company	No. of NPPs	Share (%)	HHI
Atomenergoprom	14	25.0	625
Nuclear Power Corporation of India Ltd	9	16.1	258
AREVA (inc. Framatome, Siemens)	8	14.3	204
Doosan Heavy Industries	7	12.5	156
China National Nuclear Corp. (CNNC)	6	10.7	115
Atomic Energy of Canada Ltd (AECL)	3	5.4	29
Toshiba/Westinghouse (inc. C-E)	3	5.4	29
General Electric (GE) Energy	2	3.6	13
Škoda Praha	2	3.6	13
Hitachi	1	1.8	3
Mitsubishi Heavy Industries (MHI)	1	1.8	3
Total	**56**	**100.0**	**1 448**

Assessment of the recent market shares for the supply of NPPs gives a rather different picture, although this may well be misleading given the small number of new plants which are presently under construction, and their geographical concentration in a small number of countries (for example, there are presently no NPPs under construction in North America). An assessment of the 56 reactors worldwide which have entered into operation in 2000 or later, or which are presently under construction, gives the results shown in Table 2. The largest share of the market in recent years has been taken by the Russian nuclear industry, now consolidated under the Atomenergoprom holding company. However, this includes several long-delayed plants in Russia and Ukraine, as well as more recent orders for NPPs in Bulgaria, China, India and Iran.

Several organisations prepare periodic forecasts of future nuclear generating capacity, which provide an indication of the size of the future market for new NPPs. In general, expectations for new NPP construction have been increasing in recent years, as growing concerns about security of supply and climate change have led several countries to re-assess the nuclear option for the future. However, in practice nuclear growth during the period of primary interest for this study, up to 2020, is likely to be confined to countries where at least tentative plans already exist.

Forecasts prepared by the International Atomic Energy Agency (IAEA), the World Nuclear Association (WNA) and the NEA all show that by 2020, on all but the lowest scenarios, nuclear generating capacity will have risen from about 370 GWe in 2007 to somewhere in the range 450 to 500 GWe. Given that most new reactor designs have a power output of between 1.2 and 1.5 GWe, this implies that roughly between 60 and 100 new NPPs could be built by 2020. For them to be in operation by 2020, orders for these NPPs would have to be placed in the next few years, and no later than about 2015. Most of this growth is expected to be in Asia (notably China, India, Japan and Korea), Eastern Europe (including Russia), and the United States.

It is instructive to look in particular at the crucial US market, where tentative plans for over 30 new NPPs had been announced as of early 2008. Of these, for 27 units the reactor design and vendor had already been tentatively chosen and publicly announced. Westinghouse had 12 potential orders for its AP1000 design, GE had seven for its advanced boiling water reactor (ABWR) and economic simplified boiling water reactor (ESBWR) designs, AREVA had six for its EPR design, while Mitsubishi Heavy Industries (MHI) had two for its advanced pressurised water reactor (APWR) (see Table 3). This indicates that Westinghouse may a dominant share of the US market, but also that the other major vendors are likely to gain a significant number of orders. In addition, it appears that MHI may succeed in entering the US market for the first time.

Table 3. **Nuclear power plant vendors with number of potential orders announced in the United States as of early 2008, and percentage shares**

Company	No. of NPPs	Share (%)	HHI
Westinghouse	12	44.4	1 975
General Electric (GE)	7	25.9	672
AREVA	6	22.2	494
Mitsubishi Heavy Industries (MHI)	2	7.4	55
Total	**27**	**100.0**	**3 196**

Source: Nuclear Energy Institute.

An important aspect of the present US market is the licensing system, which has undergone significant reforms since existing NPPs were licensed. The current system allows NPP vendors to obtain design certification from the Nuclear Regulatory Commission (NRC) in advance of obtaining a firm order. Obtaining this certification, which is not site-specific, should mean that the subsequent licensing of individual NPP projects does not need to consider again the generic features of the design. As such, obtaining such certification is likely to offer a marketing advantage, and all vendors active in the US market have submitted one or more designs to the NRC. So far, Westinghouse and GE have designs which have received certification, but Westinghouse has submitted changes to its AP-1000 design and GE has yet to obtain approval for its latest design.

Degree of vertical integration

The complex nature of a nuclear power plant means that the owner/operator of the plant normally requires a considerable degree of "after sales" service from the vendor. In most cases, the vendor also supplies fuel fabrication services, as well as engineering and consultancy services. Replacement components and upgraded equipment and systems are often also supplied by the vendor during the plant's lifetime. Thus, all NPP vendors are also fuel fabrication suppliers and provide most of the necessary services and components to maintain the plant through its operating lifetime.

However, the supply of fuel and other services are distinct markets from that of NPP supply (as discussed in Chapters 3 and 4). While many utilities do favour the original NPP vendor for these products and services, many also look to competing suppliers. All the main NPP vendors are able to supply fuel and services to plants built by other vendors, and other competing companies are also active in these markets. Nevertheless, the original plant vendor may enjoy a considerable advantage in supplying fuel and other products and services to NPPs for which it is the original supplier.

As noted above, the recent series of contracts between AREVA and Chinese organisations represents a new level of vertical integration in the supply of NPPs, going well beyond fuel fabrication and engineering services. Whether this represents a special case which will not be widely replicated or the beginning of a major shift in the market for NPPs remains to be seen. It is likely, however, that other NPP vendors will increasingly try to position themselves to be able to offer similar deals, where customers require such a comprehensive package.

Proportion of long-term contracts

A contract to supply a nuclear power plant is by its nature relatively long term, and it will normally be part of a relationship between supplier and customer which is likely to continue well beyond the construction phase, often including fuel supply, maintenance and upgrading over the life of the plant. Where a utility is ordering a series of NPPs at more-or-less the same time, it may well be advantageous to negotiate an overall agreement with one vendor. Such multiple ordering may allow a more favourable financial arrangement to be negotiated, and should save on construction and licensing costs. Having several identical plants may also allow utilities to save on operating costs by, for example, sharing equipment and expertise between plants. The best example of such serial ordering is the series of deals between Électricité de France and Framatome (now AREVA NP) in the 1970s and 1980s. More recently, in 2006 Chinese companies reached agreement with Westinghouse for the supply of four units on two sites.

However, despite the possible advantages of such long term arrangement, historically in most cases contracts for the supply of NPPs have applied only to one unit, or to two (or occasionally more) units to be built on a single site simultaneously or in series. This may be because there are rather few utilities worldwide which have nuclear programmes large enough to benefit from such serial ordering from one vendor. In many cases, individual NPP orders have been a number of years apart, with significant design changes between successive NPPs (even where built by the same vendor). In the United States, utility mergers and acquisitions have brought NPPs of various designs under common ownership. Thus, some large nuclear utilities have a mix of plants supplied by more than one vendor (although, as noted above, these vendors may have subsequently merged).

Having learnt from past experience of licensing and construction delays, many utilities now considering ordering new NPPs are aware of the potential advantages of serial ordering. In the United States, for example, the present licensing process is likely to favour a small number of pre-licensed designs. Where utilities are ordering more than one unit, even on different sites, it seems likely that they will often enter into an exclusive arrangement with one NPP vendor.

Barriers to entry

The present NPP vendors have the benefit of many years of experience in the design, construction and maintenance of their NPPs, which has allowed them to develop ever more sophisticated designs. The consolidation that has taken place in the industry has concentrated this knowledge and experience in a small number of companies. Designing and constructing NPPs is a process which requires large multi-disciplinary teams working together over many years, building on past achievements and lessons learned. Overall, it takes many years to develop the skills and abilities to build the advanced NPPs which are now being offered in the market.

On the present outlook, therefore, it seems that the technology barriers to new entrants offering NPPs are formidable. The most likely source of new NPP vendors in the foreseeable future is companies which have developed an independent capability as a result of a licensing or technology transfer arrangement with an existing supplier, as has taken place with Japanese and Korean companies. In the longer term, Chinese organisations are also intending to follow this route. These new entrants may be limited by the terms of their licensing agreement, which may restrict them to certain countries or regions, or require them to act jointly with the original licensor of their technology. Eventually, however, they may develop the technology sufficiently to be considered independent NPP vendors.

Looking to the longer term (beyond 2020), when new and innovative reactor designs may become widely available in the market, there is the possibility that this will involve new actors. A range of companies and research centres from several countries is involved in the R&D activities for such advanced reactor designs. Some of these designs are for small and medium sized reactors (usually defined as 800 MWe or below), which may be more suitable for smaller countries or those with less developed electricity grids, for which existing designs (of up to 1 600 MWe per reactor) may be too large. For example, South African industry, with the encouragement of the government, is developing a pebble-bed modular reactor (PBMR). The initial aim is to construct a demonstration plant with an output of 165 MWe to enter operation by about 2013.

Although it is too early to foresee the shape of the market for NPPs in the longer term, it is clear that there is potential for new entrants to develop innovative reactor designs which will compete with the established NPP vendors. Particularly if the market for new NPPs expands strongly over the coming decades, it remains possible that some new entrants will become mainstream competitors, or will at least establish themselves in regional or niche markets.

Transaction costs and market segmentation

A utility ordering a NPP is purchasing the expertise and design capability of the vendor, more than its manufacturing capacity. While vendors will normally manufacture at least some critical components in their own facilities to integrate design and manufacture, in many cases much of the manufacturing is done under sub-contracts. Some sub-contractors may be local to the construction site, others may be from the same country as the vendor, while others may be from third countries. Thus, while it may be somewhat easier and cheaper for a vendor to build a plant in its home country, in most countries no particular vendor is likely to have a significant geographical advantage leading to lower construction costs.

However, in order to have a realistic chance of winning orders for new NPPs, potential vendors must first bear the significant costs of tailoring their designs to local regulatory requirements in each country where they wish to compete, and often of obtaining prior approval or certification for their designs from regulators. For larger markets, where there is potential for multiple orders and for more than one design to be selected, several vendors may be willing to risk such up-front investment with no guarantee of any return. However, for smaller countries where the number of NPP orders will be limited, some vendors may decide that such costs are unacceptable. This will effectively limit the choice of vendor available to potential customers in such countries. While some efforts to harmonise regulatory requirements for NPP designs between countries are being made, this remains an important factor preventing all NPP vendors competing on an equal basis across all markets.

Product differentiation

NPPs offered by different vendors differ considerably in their characteristics, even when they are of the same basic design type (PWR, BWR, etc.). This means that customer preferences can play a major role in the selection of a vendor. Indeed, the choice is often more a question of selecting a particular technology rather than the vendor *per se*.

There are many factors which can influence the choice of a particular vendor or technology for a new plant. Of course, cost will play an important role, with most potential customers requesting tenders from several competing suppliers in order to achieve the best prices. However, there are other important factors which may sway a decision.

NPP vendors are traditionally strong in their home countries, so preference for a domestic supplier clearly plays a role in some cases. Other reasons to select a particular technology may include: existing ownership by a utility of a plant supplied by the same vendor; how well the generating capacity of the competing designs matches the requirement for new capacity; the ability to meet regulatory requirements and the relative ease of licensing each design in the country concerned; and the existence of similar plants which are already in operation elsewhere, giving confidence that the design is reliable and well-established.

Balance of capacity and demand

Despite the consolidation which has taken place, there appears to be no shortage of competition to supply NPPs. In recent years, any utility announcing that it intended to build a new NPP was likely to have several design options to choose from, from several different vendors. Given the small number of orders in recent years, and the importance to vendors of demonstrating their new designs, it has been a “buyers’ market”, with vendors showing a considerable degree of flexibility in structuring deals (including technology transfer).

However, with the prospect of a significant number of new orders from utilities in North America and Europe, i.e. developed countries with established nuclear programmes, the market may be changing into a “vendors’ market”. In response, some vendors may concentrate their resources on these markets, and pay less attention to developing countries without existing nuclear programmes. Thus, for utilities in these countries it may be that supply options become more limited, and they may find the vendors driving a harder bargain. On the other hand, this could provide new opportunities for regional vendors (such as Japanese and Korean companies) to enter new markets.

Furthermore, the availability of competing designs from a variety of vendors may disguise some constraints in the supply chains for new reactors. Significant parts of these supply chains are not under the direct control of the vendors themselves, but are sub-contracted to other industrial operators. In particular, almost all reactor designs require large speciality steel forgings for the manufacture of pressure vessels and steam generators. There are only one or two facilities worldwide which can prepare the forgings needed for some large reactor designs. In practice, this means that for some projects the only supplier at present for certain large forgings is Japan Steel Works Ltd. Although AREVA is expanding its own facilities in France to enable it to produce such forgings, the prospect of a significant number of new orders in the United States and elsewhere is calling into question the adequacy of the capacity for large forgings.

If there is indeed a resurgence of orders for NPPs, there will need to be a substantial increase in the relevant industrial capacities to prepare the necessary structures, systems and components. Some of this expansion will need to be carried out by the plant vendors themselves in their own facilities, but some (such as large steel components and concrete) may require additional capacity to be provided by other construction-related industries. In such areas, the demand for use of such capacities from other major construction projects will impact their availability for nuclear projects (and their costs).

In addition to industrial facilities, there also needs to be an adequate skilled workforce to design and build new NPPs, while continuing to maintain and upgrade existing plants. At the same time, skilled personnel will increasingly be in demand by regulatory authorities and plant owners/operators. In some sectors, the availability of the necessary skilled labour may limit the rate at which capacity can be increased to meet rising demand. The present age distribution of the workforce in NPP engineering is skewed towards older workers approaching retirement, and it will take time for their experience and knowledge to be passed on to new generations.

Market alliances and supplier co-operation

Co-operation between the main NPP vendors and local companies in the country of construction is a normal part of the NPP market, from the initial marketing process through to construction itself, and extending into the after-market for fuel and services. In many countries, this is a necessity for both practical reasons and to satisfy the requirements of the purchasing utility or the government concerned. Such alliances can also help vendors overcome cultural and technical barriers in different markets (including differing regulatory requirements). In some cases this is done on a project-by-project basis, in others it is a longer term arrangement which may cover the development of an entire nuclear programme.

In addition to the full mergers and consolidations noted above, there are also some joint venture and co-operation agreements between the various vendors and potential vendors. The acquisition of Westinghouse by Toshiba has led to a re-alignment some of these agreements. As noted above, GE and

Hitachi have strengthened their relationship by establishing joint subsidiaries for the Japanese and global markets, while AREVA and MHI have agreed to a more limited form of co-operation. Previously, MHI had been working with Westinghouse, while GE had been co-operating with both Toshiba and Hitachi in the Japanese market.

While Électricité de France is a major customer of AREVA in France, the two companies also co-operate on the marketing and/or construction of NPPs in some markets. EDF offers its architect engineering expertise for construction of AREVA NPPs where customers prefer this contracting model.

Public goods aspects

In all countries, the design and construction of NPPs is subject to detailed licensing and approvals processes, which are required by legislation. These are necessary to ensure that safety standards are met and that public health and safety are protected. However, even if the aim is identical, regulatory processes differ significantly between countries. This may mean that a NPP design which can be licensed in one country cannot be licensed without significant modifications in another.

Despite efforts, both past and ongoing, to reduce these differences, they often remain significant. This can cause difficulties (and additional costs) for vendors if they have to introduce substantial modifications to their designs for different countries. As noted above, for larger countries where there may be a significant number of orders, the cost is likely to be considered worth bearing. However, for smaller countries with a limited and uncertain market for NPPs, the costs of preparing a custom design to meet local licensing requirements (where they differ significantly from other markets) may be considered an unacceptable risk by some vendors. This may limit the choices available to utilities in such countries.

The transfer of sensitive nuclear technology is restricted under non-proliferation controls. The international supply of technology and materials which are considered "dual use" (i.e. which could have non-peaceful applications), which includes reactor technology and nuclear fuel, will generally require a special export licence.

Trade barriers and restrictions

There are no trade barriers which specifically target the supply of nuclear power plants across borders. However, in general the supply of a NPP to a particular country will require there to be an inter-governmental agreement on nuclear co-operation between the supplier country and the recipient country. Although a network of such agreements exists among most countries with existing nuclear programmes, there are exceptions. A notable exception until recently was the United States and Russia; however, an agreement on nuclear co-operation between these countries was signed in May 2008.

For countries embarking on a nuclear programme for the first time, it may be necessary to establish such agreements before a plant can be ordered. The lack of such an agreement, or refusal to enter into one, may have a public good aspect (i.e. it may be due to non-proliferation concerns). However, such agreements may also depend on other political factors which are not connected with the protection of public goods. In practice, therefore, this may limit the available choice of NPP vendor for utilities in some countries.

Under the provisions of the Euratom Treaty, all investments in NPPs or nuclear fuel facilities in EU member states have to be notified to and approved by the European Commission. The Commission has to determine that the investment is consistent with established guidelines for energy and environmental policy.

4. COMPETITION IN THE FRONT-END OF THE NUCLEAR FUEL CYCLE

The front-end of the nuclear fuel cycle includes all the activities which precede the loading of fuel elements into the core of the nuclear power plant. These activities are divided into several discrete steps, each of which is carried out on a separate site and usually by different companies. Thus, each step forms a distinct market sector.

In the fuel cycle for light water reactors (LWRs), by far the most common type of reactor, the following discrete activities can be distinguished:

- Mining of uranium ore (either by conventional or *in situ* leaching techniques), followed by production of uranium ore concentrate (U_3O_8, sometimes known as yellowcake).
- Conversion of U_3O_8 into uranium hexafluoride (UF_6).
- Enrichment of this natural UF_6 to increase the proportion of the ^{235}U isotope from the 0.71% present in natural uranium to the level required for nuclear fuel (usually in the range of 3.5%-5%). Enrichment is measured in separative work units (SWUs).
- Fabrication of fuel assemblies, including the conversion of enriched UF_6 into uranium dioxide (UO_2), the sintering of UO_2 into ceramic pellets, the sealing of these pellets into metal tubes (usually a zirconium alloy) to form fuel elements, and the placing of these elements into a larger fuel assembly ready for loading into the reactor core.

There are also secondary activities, including the handling of tailings arising from mining and enrichment activities, management of other types of wastes, and transport of the materials between separate steps.

The contribution of each of these steps to the overall cost of nuclear fuel will vary according to conditions in each market sector at a given time and the portfolio of contracts held by each individual NPP owner. However, as a general guide, enrichment costs are likely to amount to around half of total costs, with uranium and fabrication costs each accounting for 20%-25% of the total; UF_6 conversion and other costs (including transport) comprise about 5% of the total.

Although these steps form discrete market sectors, and are discussed separately below, there is an important interconnection between the uranium supply and conversion sectors on the one hand and the enrichment sector on the other. To a certain extent, it is possible to substitute enrichment for uranium (and UF_6 conversion), and vice versa. This is because performing additional enrichment work on a quantity of natural UF_6 will extract more ^{235}U (leaving a lower ^{235}U assay in the tailings). Hence, the same quantity of uranium enriched to the desired level can be obtained from a smaller quantity of natural UF_6 feed.

For any given combination of prices for natural UF_6 and enrichment, there is an optimum balance between the amount of UF_6 used and the amount of enrichment performed. Thus, if the price of uranium rises it may become attractive to use less uranium and more enrichment (provided the cost of enrichment does not also rise by an equivalent amount), and vice versa. In practice, the ability to take full advantage of such substitution may be limited by the availability of capacity and limited flexibilities within existing contracts. Nevertheless, the effects of this substitution on the uranium and enrichment markets can be significant. At times of high uranium prices, it can effectively become an additional source of uranium supply.

For example, to produce one kilogram of uranium enriched to 4.95% ^{235}U requires 12.74 kg of natural UF_6 and 6.52 SWUs if produced with a tailings assay of 0.35%. If the tailings assay is reduced to 0.25% by performing additional enrichment work, only 10.2 kg UF_6 are required, with the enrichment required increasing to 7.82 SWU. Thus, a reduction of about 20% in the requirement for uranium feed can be achieved, at the cost of an increase of about 20% in the requirement for enrichment services.

For NPPs which use natural uranium fuel, the front-end is simpler because of the absence of the enrichment step. U_3O_8 is converted directly into UO_2 before going for fuel fabrication. Only the uranium supply sector is common between LWRs and other reactor types, with other steps of the fuel cycle generally carried out in separate facilities (although some heavy water reactors may use slightly enriched uranium, this is very uncommon). The analysis below will concentrate on the standard LWR cycle, which accounts for over 88% of presently operating NPPs worldwide.

4.1. Uranium supply

The present situation in the uranium supply industry is the result of considerable contraction and consolidation which took place during the 1980s and 1990s. A long period of low uranium prices saw numerous producers close down or be taken over. The availability of large amounts of uranium from stockpiles of various types (known as "secondary supplies") throughout this period depressed prices and caused the production of newly mined uranium to fall to only half of current consumption. In recent years, newly mined uranium has accounted for only about 60% to 65% of the requirements of operating NPPs, or around 40 000 to 42 000 tonnes of uranium (tU) of requirements of approximately 65 000 tU.

Market shares

Uranium is presently being produced in significant quantities (>1 000 tU/year) in eight countries, while a further ten countries have limited uranium production facilities. However, some companies have interests in more than one country. In 2006, only eight companies had annual production of at least 1 000 tU (or about 2.5% of the total). Between them, these eight controlled about 86% of global production (see Table 4), with over 52% controlled by the three largest producers. Beyond these eight, there were a further five companies which each control between 1% and 2% of world production, and about nine minor producers with less than 1% of production each.

While most uranium is mined as a primary product, some producers in Australia and South Africa produce uranium as a by-product or co-product along with gold, copper and other metals. Hence, conditions in the markets for these other products can also affect uranium production levels. There are also prospects for uranium as a by-product from phosphates and coal ash in the future.

Taking the total size of the market as equal to the amount of newly produced uranium gives a value for the HHI of 1 208 for 2006. This is well below the level of 1 800 which normally causes concerns about over-concentration of markets. However, this gives only part of the picture since, as noted above, newly mined uranium only accounts for about 60% to 65% of annual reactor requirements, which represents the total market for uranium.

The remaining 35% to 40% of the market has been supplied from so-called secondary sources, i.e. the stockpiles or inventories of various market participants and governments, including nuclear materials recycled from reprocessed spent fuel, uranium produced by the re-enrichment of tailings (depleted uranium) left from earlier enrichment operations, and former military materials released to the commercial markets. Precise information about the market shares of some of these sources is often not publicly available. However, sufficient detail is known about the size of most of them to enable a reasonable estimation to be made for the present purpose.

Table 4. **Major uranium producing companies with 2006 production under marketing control** (tU per year) **and percentage global shares**

Company	**Production**	**Share** (%)	**HHI**
Cameco	8 249	20.9	438
Rio Tinto	7 094	18.0	324
AREVA	5 272	13.4	179
Kazatomprom	3 699	9.4	88
TVEL (Atomenergoprom)	3 262	8.3	68
BHP Billiton	2 868	7.3	53
Navoi	2 260	5.7	33
Uranium One	1 000	2.5	6
Major producers total	**33 704**	**85.5**	**1 189**
Other producers	5 726	14.5	19
Total	**39 430**	**100.0**	**1 208**

Source: World Nuclear Association.

Inventories of uranium may be held by all the various participants in the uranium market, including nuclear utilities, uranium producers, other nuclear fuel cycle companies (such as enrichment companies), and by traders and investors. Although the reduction of inventories which has taken place over recent years may come to an end in the near future, it remains for the present a major source of supply.

Insofar as this supply is from inventories held by nuclear utilities for their own use it effectively serves to reduce market demand and dilutes the market power of the major producers. Most other inventories, with the exception of those held by major uranium producers, also serve to diversify the market. While uranium producers do hold inventories in order to balance short term differences between production and contractual deliveries, these are not thought to have a significant market impact. Some material from the inventories held by the US Government has also been sold in the uranium market in recent years, and uranium from stockpiles held in Russia (including recycled uranium) is also thought to be meeting a proportion of domestic and foreign demand. In all, inventories are thought to have supplied in the region of 10 000 to 12 000 tU per year in recent years.

Nuclear utilities in Europe recycle relatively small quantities of uranium and plutonium extracted from the reprocessing of their spent fuel, and Japanese utilities also plan to recycle reprocessed materials. However, this is material which is already owned by these utilities and thus can be considered to form part of their inventories. It is estimated that such recycling presently displaces the equivalent of about 3 000 tU per year. This may rise somewhat in coming years, but the need for special fuel cycle facilities, as well as licensing and other issues, means it is likely to increase only gradually.

A further secondary supply is uranium produced by re-enriching the tailings from earlier enrichment operations, to produce the equivalent of natural uranium. This has been carried out in recent years in Russia, due to the existence of substantial surplus enrichment capacity (which has been excluded from international markets, as discussed later in this report). This has involved some Russian tailings, and also tailings exported to Russia from European enrichers Urenco and AREVA. This uranium has been used to meet a proportion of world demand, either in Russia or in Europe. This can be conservatively estimated as amounting to around 2 000 to 3 000 tU per year.

One of the largest secondary sources is former military high enriched uranium (HEU) being delivered from Russia to the United States under a 1993 intergovernmental agreement, which continues in force until 2013. The equivalent of approximately 9 000 tU per year in the form of low enriched uranium (LEU) derived from HEU is presently being delivered. A marketing agreement between the parties involved divides control of the uranium between four companies (in the proportions shown in brackets): AREVA (30%), Cameco (30%), TENEX (30%) and NUKEM (10%). The first two are also major uranium producers, while TENEX is (like TVEL) wholly owned by Atomenergoprom, the Russian state-owned nuclear holding company. NUKEM is a nuclear fuel trading company based in Germany.

As this agreement for the uranium derived from HEU gives control of additional uranium in the market to some of the major producers, it is worth examining its effect on market concentration and the HHI. If we exclude the approximately 15 000 to 18 000 tU estimated to be supplied from inventories, recycled materials and re-enriched tails (the majority of which is controlled by a diverse mixture of companies other than the main uranium producers), this leaves a market size of a little less than 50 000 tU. Adding the shares of the HEU material to the mined production of AREVA, Cameco and TVEL (considering TENEX and TVEL together, as both are owned by Atomenergoprom), gives control of about 66% of uranium to the top four companies (see Table 5). This translates into a value for the HHI of 1 283 for 2006. In other words, the effect of the HEU material marketing agreement is to somewhat concentrate the market, but its overall impact is only slight.

Looking ahead, uranium demand is expected to rise slowly over the next few years, on the basis of demand from existing nuclear plants and those already under construction. By 2015, it is presently expected that a significant number of additional nuclear plants will be under construction. As the uranium for the first cores of new plants is normally contracted several years before the plant enters operation, with delivery at least one year in advance, this will result in increased uranium demand even before 2015. Thus, uranium demand by that date could exceed 80 000 tU, i.e. an increase of 20% to 25% on present levels.

Table 5. **Major uranium producing companies with 2006 supply under marketing control, including HEU material,** (tU per year) **and percentage global shares**

Company	Supply	Share (%)	HHI
Cameco	10 949	22.6	511
AREVA	7 972	16.5	271
Rio Tinto	7 094	14.6	215
Atomenergoprom	5 962	12.3	152
Kazatomprom	3 699	7.6	58
BHP Billiton	2 868	5.9	35
Navoi	2 260	4.7	22
Uranium One	1 000	2.1	4
Major producers total	**41 804**	**86.3**	**1 268**
Other supply	6 626	13.7	16
Total	**48 430**	**100.0**	**1 283**

Source: World Nuclear Association.

In addition to increased demand, it is expected that the availability in the international market of supplies from secondary sources will become more limited than it has been in recent years. Thus, a higher proportion of demand is likely to be met from primary production. In particular, the delivery from Russia to the United States of material derived from former military HEU is expected to end when the present agreement expires in 2013. However, remaining stocks of Russian HEU could continue to be used to meet a proportion of domestic demand, which would reduce global demand for newly mined uranium. Furthermore, as discussed above, to some extent the expected increase in demand may be offset by the use of lower ^{235}U assays in the tailings from enrichment plants, provided sufficient enrichment capacity remains available (see Section 4.3 below).

Responding to this market outlook, there are numerous plans for new uranium production capacity around the world, and also for increases in output from existing facilities. A survey of publicly announced expansion plans from existing uranium companies and potential new market entrants shows that primary production could grow to about 70 000 tU by 2010, and to perhaps 88 000 tU by 2015. Of course, it is likely that some of these potential projects may not proceed, and others may be delayed. There may also be additional projects which have not been publicly announced. Nevertheless, this projection shows that the potential is there for uranium mining to expand sufficiently to meet demand from new reactors in this timeframe.

Although all the present major producers are expected to increase their production by 2010, with the same eight companies continuing to be the leading producers, their joint market share is likely to be diluted to about 81% of the total (including the HEU material) as some new entrants become significant producers. An analysis of publicly announced plans for new mines and expansions shows that by 2010 there could be around 14 companies with production of 1 000 tU or more, with the HHI having dropped to 1 085 (including the HEU material).

It should be noted that it typically takes many years for a uranium mining project to move from discovery to production, a process which often involves lengthy licensing and regulatory processes. Thus, most projects likely to enter production in the next few years are based on deposits discovered some years ago. Exploration activity has increased over the last few years, but this may not lead to significant new production for a considerable time. However, much new production is expected to use *in situ* leaching techniques (rather than conventional mining), which can potentially be brought into operation more quickly, albeit on a more gradual basis than a conventional mine.

Looking further ahead to 2015 (see Table 6) involves considerably more uncertainty about both future demand and plans for uranium mining. However, as noted above, it can be assumed that the supply of HEU material from Russia to the international market will have ended by that date. Indications are that the HHI will show a further slight fall to 1 003. While some of this fall results from the growth of smaller scale producers, much is due to falling market shares of the largest producers as additional medium-scale producers emerge.

Table 6. **Major uranium producing companies with projected 2015 production under marketing control** (tU per year) **and percentage global shares**

Company	Production	Share (%)	HHI
Cameco	13 200	14.9	223
BHP Billiton	12 700	14.4	206
Atomenergoprom	11 000	12.4	155
AREVA	10 900	12.3	152
Kazatomprom	9 700	11.0	120
Rio Tinto	7 900	8.9	80
Uranium One	4 800	5.4	29
Navoi	3 000	3.4	12
Paladin	2 260	2.6	7
Denison	2 100	2.4	6
Major producers total	**77 600**	**87.8**	**990**
Other producers	10 800	12.2	13
Total	**88 400**	**100.0**	**1 003**

Sources: World Nuclear Association and individual company statements.

Of course, mergers and acquisitions could change this picture. Uranium One has emerged as a significant producer as a result of acquisitions and a merger with another smaller producer, and other companies could emerge in the same way. However, the emergence of new medium-sized producers should serve to strengthen competition in the market. On the other hand, a merger between two of the largest producers could result in over-concentration.

It is unlikely that any of the state-owned nuclear companies would merge, and shares in Cameco are subject to restrictions on foreign (non-Canadian) ownership. However, the potential merger of the two general mining companies, BHP Billiton and Rio Tinto, remains a possibility. In 2007, BHP Billiton proposed a takeover of Rio Tinto, which was rejected by the latter. A fresh offer and rejection took place early in 2008. The potential merger of these two mining giants has raised concerns about over-concentration in several mining sectors, including uranium supply. Merging the production of these two companies in the projection in Table 6 would create the world's largest uranium producer with over 23% of the market, and would raise the HHI to 1 260. However, this would still be considerably less than 1 800, the normal level of concern.

Degree of vertical integration

In many industries, companies with a significant market share in one sector may look to expand into related sectors, upstream or downstream from their existing activities. The nuclear fuel cycle, which comprises several discrete activities in a supply chain, clearly provides opportunities for this. Beyond the fuel cycle, vertical integration could include the construction of NPPs, allowing a company to supply customers with NPPs and all the uranium and fuel cycle services required by those plants. It could also extend to directly owning and operating the NPPs.

Among the major producers, Rio Tinto and BHP Billiton are large global mining companies, whose uranium interests form a small part of their diversified mining assets. They do not have any other interests in the nuclear fuel markets. Navoi of Uzbekistan also confines its activities to mining and related activities. Cameco is a major operator in the UF_6 conversion market, and also owns a 31.6% share of the Bruce nuclear power plant in Canada. It also has a strong position in the market for supply of natural UO_2 and fabricated fuel to CANDU type reactors.

AREVA, which is controlled by the French Government, can be considered fully vertically integrated, with activities spanning the entire fuel cycle; it is also a major vendor of nuclear power plants. In addition, the various Russian fuel cycle companies are all owned by the Russian Government. They are being reorganised under a new holding company known as Atomenergoprom, which will also offer the full range of nuclear fuel cycle products and services, as well as being a vendor of nuclear power plants and the owner/operator of NPPs in Russia. Kazatomprom, owned by the Government of Kazakhstan, operates the Ulba plant which manufactures fuel pellets for Russian-design reactors.

Despite the existence of some vertical integration, the various steps in the cycle have traditionally been the subject of separate contracts between the supplier and the utility end-user. Thus, even where companies are present in more than one market sector their products and services are normally contracted for separately, rather than as a "bundle". However, such bundling could potentially become more common in future, particularly if suppliers were able to offer "take-back" or "leasing" arrangements for the management of spent fuel.

To date, the main example of bundling has been the supply of complete fabricated fuel (incorporating uranium, UF_6 conversion, enrichment and fabrication) by Atomenergoprom and its predecessors to operators of Russian-designed nuclear plants. In addition, some enriched uranium (incorporating the uranium, UF_6 conversion and enrichment steps) is being supplied from Russia to operators of other (non-Russian) reactors.

Another type of vertical integration can occur when utilities, as the end users of uranium and normally customers in the uranium market, themselves become investors in the uranium production sector. By creating what is essentially tied production, this could have the effect of limiting competition if it accounted for a significant proportion of production. Such direct investment by consumers was not uncommon in the early stages of the development of the commercial nuclear industry, but has been rare in recent years while low prices have prevailed. However, there are some indications that there may be more investment by utilities in expanding uranium production in the coming years, as they seek to secure reliable supplies of uranium.

Proportion of long-term contracts

Uranium is a product which has essentially only one use, and thus the market for it depends on demand from utilities which own nuclear power plants. On the other hand, these utilities have made very large investments in their NPPs and require a reliable supply of uranium for uninterrupted operation. Thus both sides often see long-term relationships as being in their interests. For the producers, this underpins their investment in mining facilities, while for utilities it provides surety of fuel supply.

As a result, it is estimated that around 90% of uranium is sold on long-term contracts directly between producers and the utility end-users. The length of these contracts varies, but they will typically last for five-six years, often with some flexibility on the timing of deliveries.

However, not many utilities will wish to have an exclusive relationship with a single producer. Large utilities especially will aim for a diverse portfolio of contracts with different companies, normally with a geographical spread of production facilities. There is sufficient turnover of contracts that there are always potential customers willing to negotiate long term contracts with new entrants.

Barriers to entry

The barriers to entry in the uranium mining business are not insurmountable even for start-up companies. With the sharp increase in uranium market prices since 2003, there has been a flurry of interest in developing uranium deposits in several countries, including Australia, Kazakhstan, Malawi, Mongolia, Namibia, South Africa and the United States. There are a number of known but undeveloped or abandoned uranium deposits in these countries which could be mined profitably under the right market conditions.

The recent price increases have also led to significant investor interest in uranium production. This has led to an increase in speculation in uranium-related companies, many of which are unlikely to bring deposits into actual production. However, this does mean that companies with rights to attractive deposits and the necessary mining expertise are increasingly able to attract the capital needed to move towards production. Over the next few years it is expected that several new mines in the countries mentioned above will enter operation. As at least some of these will be owned by new companies entering the market, this should lead to a reduction in market concentration.

Technological advances in the use of *in situ* mining techniques for uranium extraction may also have helped to lower barriers to entry in the uranium industry. In principle, such technology makes possible smaller scale uranium production facilities with lower capital costs and shorter development times, allowing smaller mining companies to enter the market more easily.

Transaction costs and market segmentation

Much uranium production takes place far from the fuel cycle facilities where it has to be taken for further processing. The shipping costs are normally borne by the producer, with delivery to the customer taking place at a conversion facility. Major conversion facilities exist in Canada, France, Russia, the United Kingdom and the United States, which means that the great majority of uranium has to be shipped to one of these countries. The preference of a consumer for a particular delivery location is likely to depend on the intended location of the enrichment step. A European utility with an enrichment contract in the United States would normally prefer delivery of the uranium in North America, and vice versa, to avoid additional transport costs between the conversion and enrichment steps. However, in some cases this can be overcome by two utilities holding uranium in different locations to swap their holdings to avoid transport costs.

In general, the uranium market does not exhibit significant regional segmentation as a result of transport costs, which comprise only a very small fraction of total nuclear fuel costs. However, in addition to costs, shipping nuclear materials can cause logistical problems and delays, given the limited number of available ports and shipping lines which are able and willing to handle nuclear cargoes.

Product differentiation

Uranium is a fungible commodity, subject only to meeting internationally accepted standards for purity and isotopic composition. Thus there are no physical product differentiation issues which constrain the market. However, as noted under Public Goods Aspects below, the origin of each batch of uranium (normally the country where it was mined) may place on the owner certain permanent legal constraints governing its use and re-sale (including the handling of spent fuel). If such constraints are perceived by some customers to be too onerous, they can serve to differentiate one batch of uranium from another.

Balance of capacity and demand

As has been noted above, the present capacity for uranium production is significantly lower than demand (as represented by reactor requirements). On the face of it, this under-capacity would appear to give producers a large degree of market power. However, the existence of large secondary supplies (essentially, inventories of one kind or another) has meant that producers have endured a long period of low prices, which only came to an end in 2003.

Recent price rises have stimulated considerably increased activity in uranium mine development and in uranium exploration, as would be expected from normal market behaviour. This is likely to result in significant capacity additions in uranium production over coming years, especially if uranium demand looks set to increase (i.e. if construction of planned and prospective new reactors does in fact begin). These capacity increases are expected to result from existing producers expanding capacity at their operating mines as well as by opening new mines, and also by the entry into the market of new producers.

Although it remains possible that new mining capacity will turn out to be too little and/or too late to keep up with demand, potentially giving increased market power to existing producers, there does remain a large amount of already mined uranium in various forms which could enter the market (as discussed above under *Market shares*). It is the availability of these sources of supply which will determine the course of events in the uranium market as much as the efforts of primary producers. Given that a significant part of these inventories is under government control, the policies of the governments concerned will play an important role here.

Market alliances and supplier co-operation

There are several uranium mines which are joint ventures between more than one producer, including several of the major companies in the market. In some cases, the mine output is shared for marketing purposes between the partners in accordance with their joint venture agreement, while in others one of the partners may be responsible for selling all the uranium produced. This situation is likely to continue, as some uranium deposits in Canada and elsewhere are being or are expected to be jointly developed, including the Cigar Lake deposit in Saskatchewan.

Public goods aspects

As with other parts of the fuel cycle, the international trade in uranium is governed by a complex web of bilateral agreements, the main aim of which is to ensure non-proliferation. These involve the legal concept of the "origin" of uranium and the associated "obligations" which usually apply to the material in perpetuity, even after further processing and irradiation in a NPP. In many cases, supplier nations retain rights of prior consent for future use of the uranium supplied. For example, the supplier nation would have to approve the reprocessing of spent fuel containing the uranium supplied.

Usually these agreements do not overly restrict trade, although in some cases those suppliers with less onerous requirements may be preferred by consumers. However, the absence of such an agreement between two countries clearly can serve to limit uranium trade. The lack of an agreement until recently between the United States and Russia, for example, did not prevent the delivery of enriched uranium from Russia to the United States, but it did mean that this material, or any material containing it or derived from it, could not be subsequently returned to Russia. After a long negotiation, a bilateral agreement between the US and Russia was signed in May 2008.

To ensure common minimum requirements for non-proliferation controls on nuclear trade, the main nuclear supplier countries co-ordinate their policies through the Nuclear Suppliers' Group (NSG). Nuclear trade is also subject to the multilateral framework of safeguards established by the International Atomic Energy Agency (IAEA) within the scope of the Nuclear Non-Proliferation Treaty (NPT), to which almost all countries with nuclear activities subscribe. However, many countries require their bilateral agreements to contain more stringent requirements applying to the nuclear materials which they supply.

Nuclear trade with India is generally not permitted at present, as it is not a signatory to the NPT and is not subject to IAEA safeguards. However, the United States and India have agreed to negotiate a bilateral agreement, which will also require India to reach agreement with the IAEA and other supplier nations in the NSG, in order to open nuclear trade between India and other countries. This process is proving controversial in both countries and still has some way to go before such trade can begin.

Trade barriers and restrictions

In addition to these non-proliferation controls, there are also trade restrictions imposed by governments for other purposes. These include measures designed to ensure security of supply by maintaining a diversity of suppliers, and those designed to protect domestic industries. Each of the two largest markets for uranium, the United States and the European Union, has some import restrictions. Although these take rather different forms, the effect in both cases has been to limit imports of uranium (and enrichment) from Russia. Previously, imports from Kazakhstan and Uzbekistan were also affected.

In the European Union, all uranium purchase contracts by EU end-users (i.e. nuclear utilities) have to be approved by the Euratom Supply Agency (ESA), an agency attached to the European Commission, established in 1960 under the Euratom Treaty. In approving such contracts, the ESA seeks to maintain what it judges to be a sufficient diversity of supply sources, with the aim of enhancing security of supply. The main effect of this policy in recent years has been to limit the market share taken by supplies from Russia. The results of the application of the policy are set out in the ESA's annual reports, which showed that in 2006 the total supply from Russia (including re-enriched tailings and a proportion of the material derived from ex-military HEU) was 26% of the EU market. In practice, imports of natural uranium from Russia are not presently restricted, as most material available for import is in the form of LEU.

In the United States, import restrictions on uranium are the end result of actions taken by domestic uranium producers under "anti-dumping" legislation. This legislation requires the Department of Commerce and other government agencies regulating international trade to determine if domestic producers are being hurt by unfair competition, and if this is found to be the case, to take measures to prevent this. In the case of uranium, this process was halted by a so-called "suspension agreement" between the United States and Russia which effectively prevents the import of Russian uranium beyond a certain quota (which amounts to a proportion of the uranium being delivered under the HEU agreement discussed above).

In February 2008, an amendment was agreed to this suspension agreement which sets out quotas from 2011 for the supply from Russia directly to US utilities of low enriched uranium (LEU), i.e. of uranium, UF_6 conversion and enrichment. For the first three years, during which time deliveries of HEU material will continue, the quotas are very limited. However, from 2014 to 2020 the LEU quota will represent about 5 000 tU per year (about 20% of US demand). In addition, Russian LEU may be supplied for the first cores of new NPPs in the United States. From 2021 it is expected that restrictions will be removed.

4.2. UF_6 conversion services

Competition in the UF_6 conversion sector is limited, with only four major operators worldwide. However, much of the uranium supply which has come in recent years from secondary sources (including former military material) has been in the form of UF_6, thus displacing demand for conversion services as well as newly mined uranium. This has meant that, like the uranium mining industry, the conversion sector has also experienced a long period of low demand and low market prices.

Market shares

There are two large conversion plants in North America, with two in Western Europe. Russia also has a large conversion capacity, and a small plant is in operation in China to feed the enrichment plant there. The largest conversion company is Cameco, which has its own plant in Canada and presently has marketing control of the output from an additional plant in the United Kingdom (which is owned by the UK Government through its Nuclear Decommissioning Authority, NDA). AREVA subsidiary Comurhex operates a large facility in France, while a US plant is operated by ConverDyn (jointly owned by Honeywell and General Atomics).

As discussed above for uranium, under a United States/Russia agreement low-enriched UF_6 derived from former Russian military HEU is presently being delivered to the United States. This contains a conversion component, as well as uranium and enrichment, shares of which (together with the uranium component) are under the marketing control of Cameco, AREVA, NUKEM and Atomenergoprom. Taking present conversion plant capacities and the HEU material into account, the 2007 supply capacities are as shown in Table 7. This shows that the HHI for the global UF_6 conversion market is 2 286. This is somewhat higher than the level of 1 800 which is normally taken as indicating a market which may be over-concentrated.

Several developments are expected which will affect the conversion market in the coming years. As noted in Section 4.1 on uranium supply, the United States-Russia agreement on delivery of HEU material will end in 2013 and further supplies from this source to the international market appear unlikely. Although HEU could continue to provide a proportion of Russian domestic conversion requirements (as well as uranium and enrichment requirements), this will represent a significant reduction in supply in the international market.

AREVA has announced a major programme to replace its existing conversion capacity with new facilities on the same sites in France. This is expected to begin in 2009 and be complete by 2012. The capacity of the new facilities at that time is expected to be slightly higher than the existing plants (which will be decommissioned). If market conditions are suitable, AREVA plans to expand capacity after 2012 to as much as 21 000 tonnes per year. ConverDyn has recently increased the operating capacity of its plant to 15 000 tonnes per year and plans further expansion to 18 000 tonnes by around 2012, assuming market conditions warrant it.

Table 7. **UF_6 conversion suppliers with approximate 2007 operating capacity, including HEU supplies,** (tonnes U) **and percentage global shares**

Company	**Capacity**	**Share** (%)	**HHI**
Cameco	20 200	27.5	756
Atomenergoprom	17 700	24.1	581
AREVA	16 700	22.7	515
ConverDyn	15 000	20.4	416
China National Nuclear Corp. (CNNC)	3 000	4.1	17
NUKEM	900	1.2	1
Total	**73 500**	**100.0**	**2 286**

Source: World Nuclear Association.

Cameco's agreement with the United Kingdom's NDA to market the output of the latter's conversion plant, which has a capacity of around 5 000 tonnes, is presently set to expire in 2016. However, the plant is relatively new and if the arrangement continues to be beneficial for both parties it could be renewed, or the NDA could seek an alternative arrangement to keep the plant operating. Meanwhile, Chinese conversion capacity is expected to increase in line with the capacity of the domestic enrichment plant.

One possible new entrant could be Kazatomprom, which appears keen to expand its nuclear fuel activities alongside its rapid expansion of uranium production. The company has signed an agreement with Cameco which could lead to the construction of a new plant in Kazakhstan using Cameco technology. The two companies will carry out a feasibility study as a first step in what would be a joint venture. The plant would be used for conversion of uranium produced in Kazakhstan, with the UF_6 probably being enriched in Russia. However, the joint venture could place up to 49% of the capacity under the ownership of Cameco, one of the existing major producers.

Table 8. **UF_6 conversion suppliers with projected 2015 capacity** (tonnes U) **and percentage global shares**

Company	**Capacity**	**Share** (%)	**HHI**
AREVA	21 000	28.0	784
ConverDyn	18 000	24.0	576
Cameco	17 500	23.3	543
Atomenergoprom	15 000	20.0	400
China National Nuclear Corp. (CNNC)	3 500	4.7	22
Total	**75 000**	**100.0**	**2 325**

Sources: World Nuclear Association and individual company statements.

Taking these potential developments into consideration, the figures in Table 8 show the projected shares of UF_6 conversion capacity by 2015. Given that the number of major convertors seems set to remain at four, albeit with possible shifts in their relative market shares, the HHI can be expected to remain at its present level of around 2 300.

Degree of vertical integration

Of the major conversion operators, AREVA and Atomenergoprom are vertically integrated companies with extensive operations in the nuclear fuel cycle and beyond. Cameco is a major uranium mining company with interests also in nuclear generation. ConverDyn is a specialised conversion company jointly owned by Honeywell (a diversified engineering company) and General Atomics (which is mainly involved in research and development, including in the nuclear sector).

Despite some vertical integration, conversion is normally priced as a separate service, rather than being included with other steps of the fuel cycle. Although there are occasions when end-users of nuclear fuel may purchase UF_6 as a package from a single supplier (rather than purchasing uranium and conversion separately), the two components are normally still priced separately.

The main exception to this is sales of enriched UF_6 by Atomenergoprom (i.e. a package of uranium, conversion and enrichment), where the price of each component is not specified separately. In fact, technical considerations mean only a limited part of Atomenergoprom's conversion capacity can be used to provide conversion as a separate service.

Proportion of long-term contracts

UF_6 conversion services can be bought on the spot market, where the transaction is usually in the form of a purchase of UF_6 (i.e. uranium and conversion together, but priced separately). A purchase of conversion only is also possible, by means of a swap of unconverted uranium for UF_6. However, in general the bulk of conversion supply comes directly from the conversion plant operators under long term contracts with NPP operators.

Barriers to entry

Conversion uses relatively simple chemical technology and there would be no unusual regulatory or technical barriers to prevent the construction of new conversion capacity by suitably qualified companies if it were commercially attractive. However, the experience of the incumbent operators, including operational and technological improvements made over the years, would likely give them an advantage.

There are additional factors which favour the incumbent operators. Once a plant has been built it can continue in operation for many years, meaning that established plants have low capital costs. Furthermore, the existing conversion sites are well-established as locations for the delivery of uranium and are also important storage sites for uranium concentrate and UF_6. As such, conversion plant sites are usually where uranium transactions have their physical effect, with conversion companies acting as bookkeepers when uranium is bought and sold. It may be difficult for a new conversion plant on a new site to break into the established markets, especially since the cost of conversion represents only a small proportion of total nuclear fuel costs.

As demand for nuclear fuel increases, and existing conversion plants age, additional and replacement capacity will be needed. However, it appears from present plans that additional capacity is likely to be added by existing operators, rather than by new entrants. Clearly it will normally be easier and more economic to expand existing facilities rather than build entirely new ones. However, there are potential new entrants, such as Kazatomprom (as noted above).

Transaction costs and market segmentation

To some extent, the market for conversion is divided into European and North American sectors. This is because having conversion and enrichment carried out in the same continent will generally reduce logistical and administrative costs. Since enrichment is by far the more costly service, the enrichment market is always likely to be more important than the conversion market in determining which continent is preferred for conversion.

A utility holding UF_6 in the "wrong" continent for its enrichment contracts may be able to swap material with another utility in the opposite position. However, given the disparity in the available capacities for conversion and enrichment in the two continents (more enrichment capacity is in Europe, while more conversion capacity is in North America), inevitably there is a net movement of unenriched UF_6 from North America to Europe. The additional costs of this could give a market advantage to European conversion facilities (evidenced by some difference in reported prices between the two continents).

Although Atomenergoprom has a large conversion capacity available, in practice only a small part of this is available to supply conversion as a separate service to the international market. Reasons for this include different impurities standards for the U_3O_8 feed, the remote locations of Russian conversion sites (which may cause logistical difficulties and increases transport costs) and their limited capacity for handling international standard UF_6 transport cylinders. Atomenergoprom has usually supplied enriched UF_6 as a package rather than supplying conversion as a separate service.

The Chinese conversion plant provides feed material for the enrichment plant in China and does not participate in the international market.

Product differentiation

Conversion of uranium concentrate into natural (unenriched) uranium hexafluoride is a generic process for all NPPs which use enriched uranium fuel. As with uranium concentrate, UF_6 is a commodity product with no product differentiation. Only the small proportion of NPPs using unenriched uranium does not require this step.

Balance of capacity and demand

Global demand for UF_6 conversion in 2007 is estimated to be about 61 000 tonnes. As shown in Table 7, this is significantly less than the available capacity. However, not all plants may operate at full capacity all the time. Incidents at two major conversion plants in recent years caused them to close down for extended periods, leading to some disruptions in supplies and requiring the use of inventories to meet demand.

Demand for conversion services is expected to increase in the coming years as nuclear power capacity grows, being forecast to reach well over 70 000 tonnes by 2015. As Table 8 shows, plans are already being put in place to increase capacity to at least 75 000 tonnes by that date. Further possible capacity additions are possible if the market does indeed continue to grow and construction of new NPPs increases. Although most (if not all) capacity additions are likely to be at existing conversion facilities, it seems likely that sufficient capacity will be available when needed. At the same time, a return to the overcapacity situation seen in recent years appears unlikely.

Market alliances and supplier co-operation

As noted above, the conversion plant in the United Kingdom formerly operated independently by British Nuclear Fuels has now been transferred to the NDA, which has entered into a ten-year agreement with Cameco for the latter to market the plant's output. This effectively removed one competitor from the conversion market.

The remaining convertors all operate independently. Cameco has, however, recently signed an agreement with Kazatomprom which may lead eventually to a new plant being built in Kazakhstan as a joint venture.

Public goods aspects

Unenriched UF_6 is a hazardous material and is subject to chemical safety requirements in its storage and transport. The conversion process itself presents mainly chemical safety issues, although precautions must be taken to avoid criticality incidents. Like uranium concentrate, unenriched UF_6 presents a low radiological risk. In general, it is subject to the same proliferation controls as unconverted uranium.

Trade barriers and restrictions

There are few trade restrictions which affect conversion specifically, but since conversion is a service which can only be provided along with uranium, restrictions which affect uranium may also have a bearing on trade in conversion services. For example, the exclusion of Russian uranium from certain markets (discussed in Section 4.1) also has the effect in practice of excluding Russian conversion services.

However, as noted in Section 4.1, in February 2008 the United States and Russia agreed quotas for the supply from Russia directly to US utilities from 2011 of low enriched uranium (LEU), i.e. of uranium, UF_6 conversion and enrichment. Until 2013, while deliveries of HEU material continue, the quotas are very limited. But from 2014 to 2020 the LEU quota will be equivalent to about 5 000 tU per year (about 20% of US demand), with additional supply for the first cores of new US NPPs. Russia will thus continue to have a significant, if restricted, role in US conversion supply after deliveries under the HEU agreement end in 2013.

4.3. Uranium enrichment services

Uranium enrichment is a sensitive and strategic technology, which is only possessed by a few companies in a small number of countries. These companies are almost all either state-owned or have their origins in government programmes, and the availability of the technology is carefully controlled for reasons of national security and non-proliferation. As a result, state involvement in the commercial enrichment sector is high, and the number of competitors is rather small.

Market shares

There are in effect four major concerns worldwide which presently supply enrichment services to the international market: AREVA, controlled by the French Government; Atomenergoprom, owned by the Russian Government and which controls the four enrichment plants in Russia; Urenco, a British-Dutch-German consortium with mixed state-private ownership which has plants operating in each of these three countries; and the US Enrichment Corporation (USEC), a private-sector corporation formed by privatising the enrichment operations of the US Department of Energy.

In addition, there are smaller scale producers serving domestic markets in China, operated by the state-owned China National Nuclear Corporation (CNNC), and in Japan, operated by Japan Nuclear Fuel Ltd (JNFL). There are also a small number of government agencies in other countries, such as Brazil and South Africa, which have developed enrichment technology, mainly for strategic or self-sufficiency reasons. However, these were pilot-scale operations with little or no impact on the commercial market.

There are various different technologies which can be used to enrich uranium, the main two being gaseous diffusion and gas centrifugation. Diffusion is the older technology, and has the disadvantage of requiring much more electrical energy in operation, making its operating costs much higher. On the other hand, diffusion plants offer greater flexibility in that their output can be increased or reduced somewhat in line with demand, while advanced centrifuges require continuous operation. Centrifuge plants are modular in design, with capacity being built up gradually over time in line with demand by the addition of new cascades of centrifuges. The capital costs are significant, but they are low cost once in operation.

There are only two diffusion plants still in operation, one in France (operated by AREVA) and the other in the United States (operated by USEC), each with a nominal capacity of about 10 million SWU. Projects are underway to replace these with centrifuge plants over the coming years, and this will lead to significant changes in the enrichment market over the next decade and beyond. The other operators are already using centrifuges exclusively.

At present, there is significant over-capacity in enrichment worldwide, mainly due to the very large capacity in Russia (a legacy of the Cold War). This is compounded by the availability in commercial markets of LEU derived from former Russian military HEU which is being delivered to the United States under an intergovernmental agreement between the two countries (as discussed in Sections 4.1 and 4.2, this also has implications for the uranium and UF_6 conversion markets). This arrangement gives control to USEC of an additional enrichment supply of 5.5 million SWU per year. However, these deliveries are not expected to be extended beyond 2013, which is likely to result in a significant change in the international enrichment market at that time.

Table 9 summarises the present situation in terms of available capacity, with the HEU supply being added to USEC's capacity. This compares with annual global enrichment demand which is estimated to be about 45 million SWU. However, this simple analysis does not reflect the realities of the market, in particular restrictions which effectively limit Atomenergoprom's access to a significant proportion of the overall market (these are discussed more fully below). As a result, a large part of the Atomenergoprom capacity is taken up with the re-enrichment of tailings from earlier enrichment operations (as discussed earlier, this is a source of additional uranium supply). This can be roughly estimated as amounting to around 8 million SWU per year at present, which is effectively removed from the market.

Table 9. **Major enrichment companies with approximate 2007 capacity, including USEC control of HEU material** (thousand SWU)**, and percentage shares**

Company	Capacity	Share (%)	HHI
Atomenergoprom	22 500	38.5	1 479
US Enrichment Corporation (USEC)	15 500	26.5	702
AREVA	10 000	17.1	292
Urenco	8 500	14.5	211
Japan Nuclear Fuel Ltd (JNFL)	1 000	1.7	3
China National Nuclear Corp. (CNNC)	1 000	1.7	3
Total	**58 500**	**100.0**	**2 690**

Source: World Nuclear Association.

The remaining discrepancy between available capacity and demand is likely to be the result of the diffusion plants running at below full capacity. As noted above, they have much higher operating costs than centrifuge plants and can easily be operated at reduced capacity. In particular, it is likely that the supply of HEU material to USEC from Russia is displacing some of the capacity of the US diffusion plant. It is known that the cost to USEC of the HEU-derived enrichment is less than the unit operating cost of its diffusion plant (as the cost of electricity to the plant has recently increased sharply as long-term electricity contracts came to an end). Making the simple assumption that the US diffusion plant is operating at about half capacity gives the approximate market shares shown in Table 10. We can see that the HHI, with a value of 2 690 based on capacities, falls to 2 389 when these assumptions on approximate market shares are factored in.

It is also relevant to note there that, as discussed above, enrichment capacity can to some extent be used to produce additional uranium supply, by operating enrichment plants with a lower ^{235}U assay in the tailings stream. This means that utilities can reduce their uranium demand by 10% or more, provided they have access to sufficient enrichment capacity at a price which makes this economic (i.e. provided it is less expensive to buy more enrichment than to buy more uranium). Furthermore, so long as they have surplus capacity, enrichment plant operators can physically operate their plants at lower tailings assays than that specified in contracts with utilities, effectively producing additional uranium (which they can then sell in the market). This is always likely to be an attractive option for enrichment plant operators, as their marginal costs of production will normally be less than the price paid by utilities for enrichment services.

Table 10. **Major enrichment companies with approximate 2007 market shares** (thousand SWU) **and percentage shares**

Company	Market Share	Share (%)	HHI
Atomenergoprom	14 500	31.5	994
US Enrichment Corporation (USEC)	11 000	23.9	572
AREVA	10 000	21.7	473
Urenco	8 500	18.5	341
Japan Nuclear Fuel Ltd (JNFL)	1 000	2.2	5
China National Nuclear Corp. (CNNC)	1 000	2.2	5
Total	**46 000**	**100.0**	**2 389**

There are several significant developments taking place in the enrichment market which may alter the picture over the coming ten years and beyond. As noted above, the two diffusion plants are scheduled to be replaced by centrifuge plants. However, even after they enter operation, it will take several years for these new plants to fully replace the large capacities of the diffusion plants. The two companies concerned, AREVA and USEC, can be expected to plan a transition period during which the diffusion plants will be operated at reduced capacity while centrifuge capacity is built up. However, the end of deliveries of HEU material from Russia in 2013 may oblige USEC to increase the output of its diffusion plant at that time if insufficient alternative capacity is available. Furthermore, while AREVA's new plant will use proven Urenco-designed centrifuges, USEC is developing a new centrifuge design which inevitably involves a greater risk of delays.

Meanwhile, Urenco has started construction of a new centrifuge plant in the United States, which will provide a domestic source of competition for USEC. This is expected to start operation in 2009 and to gradually increase its capacity over subsequent years. Urenco is also planning to steadily increase the capacity at its three European plants. AREVA too is planning to construct a new centrifuge plant in the United States. This is still at the site selection and planning stage, but the aim is to begin production by 2014 and gradually increase capacity thereafter.

Atomenergoprom is also thought to be steadily increasing its enrichment capacity, spread over four sites in Russia, with the introduction of new, more efficient centrifuges. In China, CNNC is developing its enrichment plant in co-operation with Atomenergoprom and may well increase capacity to supply most or all of its growing domestic requirements. JNFL is working to increase the capacity of its plant to 1.5 million SWU/year, and may increase this further to maintain its share of Japanese domestic demand, provided it is successful in developing higher efficiency centrifuges.

A further important development could be the entry into the market of General Electric, a large diversified US corporation with wide-ranging nuclear activities, including NPP construction and nuclear fuel fabrication. GE has acquired the rights to a new enrichment technology known as Silex, developed in Australia, which uses laser excitation to separate uranium isotopes. Potentially this process offers technological advantages and could be competitive with centrifuges, but it has yet to be demonstrated at a commercial scale. However, GE has announced an ambitious schedule for developing and deploying this technology. It aims to have a commercial facility in operation in the 2010-12 timeframe, although it is likely to take some additional time to build up a significant capacity.

Table 11. **Major enrichment companies with projected 2015 capacity** (thousand SWU) **and percentage shares**

Company	**Capacity**	**Share** (%)	**HHI**
Atomenergoprom	20 500	32.3	1 042
Urenco	17 500	27.6	760
AREVA	10 000	15.7	248
US Enrichment Corporation (USEC)	8 000	12.6	159
China National Nuclear Corp. (CNNC)	3 500	5.5	30
General Electric (GE) Energy	2 500	3.9	16
Japan Nuclear Fuel Ltd. (JNFL)	1 500	2.4	6
Total	**63 500**	**100.0**	**2 260**

Sources: World Nuclear Association and individual company statements.

Meanwhile, the prospect of renewed expansion of nuclear power in Europe, the United States and elsewhere, with continued expansion in China and other Asian countries, means that enrichment demand may grow strongly in the coming years. Industry estimates show that demand may reach about 50 million SWU by 2010, growing to over 60 million SWU by 2015. Although a proportion of domestic demand in the United States and Russia may continue to be met by HEU material after 2013, net demand for enrichment seems set to increase significantly.

Taking all these factors into account, it is possible to construct a possible scenario for how enrichment supply could develop to 2015 (see Table 11). It is assumed that the diffusion plants will be gradually drawn down as they are replaced by centrifuge capacity. It is also assumed that centrifuge plants will operate at full capacity, and that their capacity will be gradually increased in line with demand. The reduction in diffusion capacity is likely to mean that total capacity and demand will become more closely aligned, as most centrifuge capacity will be constructed only when it is required to meet firm demand. This means that the proportion of Atomenergoprom capacity used for re-enrichment of tailings is likely to be reduced, as more of its capacity is used to meet growing global demand.

On these projections it appears that Urenco, with its head start in developing centrifuge capacity on four sites, will surpass the other two major non-Russian suppliers as they phase out their diffusion plants and build up their own centrifuge capacity. However, although the ranking of the main operators may change, the overall level of market concentration as represented by the HHI will remain more-or-less unchanged.

Degree of vertical integration

Of the four major enrichment companies worldwide, Urenco and USEC are specialised companies which do not have other interests in the nuclear industry (or elsewhere), while AREVA and Atomenergoprom are vertically integrated across all stages of the nuclear fuel cycle and also NPP construction. Atomenergoprom in particular also encompasses the ownership and operation of NPPs in Russia, and its domination of the market for the supply of fabricated fuel for Russian-designed NPPs in other countries allows it to also provide uranium, UF_6 conversion and enrichment bundled with fuel fabrication for these plants.

If GE enters the enrichment market, this would also represent an increase in vertical integration as this company is already a major NPP vendor as well as a supplier of nuclear fuel fabrication and NPP engineering services.

Proportion of long-term contracts

Although a spot market for enrichment does exist, the nature of the industry means that the majority of supply is conducted under long-term contracts, often with a duration of five or more years. The move towards centrifuge enrichment is likely to reinforce this, as investment in capacity additions will usually be made to keep capacity in line with contractual delivery commitments. In other words, centrifuge capacity will often only be built once the contracts for its output are already in place.

Barriers to entry

The most important barrier to entry into the enrichment market is possession of the necessary technology. Enrichment technology is extremely sensitive and strategic, and is kept under close government control and supervision, even where carried out by private-sector corporations. In addition, the spread of enrichment technology to countries which do not yet possess it is a matter of great sensitivity and is subject to controls by the IAEA and other multilateral organisations. While the transfer of enrichment technology might be possible between countries in certain limited cases, those countries which do possess the technology are usually reluctant to see it spread more widely.

Nevertheless, it may be possible for new companies to enter the market in some cases. As noted above, GE of the United States has announced its intention to enter the enrichment market with a new laser enrichment technology, which has been developed mainly in Australia. However, few companies are likely to be able to emulate this feat. GE is a very large corporation with significant existing nuclear industry interests, which has the capital required to invest in such a venture, and which is sufficiently trusted by the US Government to carry out enrichment operations (which are classified activities for national security reasons).

Another possible route for new entrants could be to share or licence the technology from existing holders. For example, Urenco has formed a joint venture with AREVA to share its centrifuge technology, which will be used in AREVA's new plant (now under construction). Although AREVA is not a new entrant, the deal will allow it to replace its ageing diffusion plant and thus remain a major enrichment producer. Atomenergoprom and CNNC are co-operating on the development of enrichment capacity in China, which is thought to include the transfer of Russian technology to CNNC.

Under certain circumstances, subject to political approval or direction, existing technology holders could thus share their technology with new entrants in a few closely allied countries. For example, Australia, Canada and South Africa have at various times discussed possible entry into the enrichment market. In principle, such an arrangement could involve the supply of centrifuge equipment without the full transfer of the technology to the host country. This could also take place within the framework of a multilateral assured fuel supply arrangement, which is discussed further in Section 7.

As noted above, there is a small number of other countries which possess enrichment technology, one or two of which could potentially develop commercial capacity independently of the existing enrichers. However, these technologies are much less developed than existing commercially deployed technologies, and very significant investment would be needed to bring commercial-scale facilities on line.

Transaction costs and market segmentation

As discussed in Section 4.2 on UF_6 conversion services, utilities will often seek to match their uranium holdings at conversion plants with their contracts for enrichment at facilities in the same continent (i.e. in Europe or in North America). This is because there is some saving on transport and other costs when conversion and enrichment are both carried out in the same continent, rather than on opposite sides of the Atlantic.

To some extent, mismatches in this regard can be overcome by utilities swapping their holdings (e.g. a utility with UF_6 in North America that it wishes to enrich in Europe may be able to swap the material with another utility in the opposite position). However, given the disparity in the available capacities for conversion and enrichment, with an excess of enrichment capacity in Europe and an excess of conversion capacity in North America, there is a need for some trans-Atlantic transport of uranium between the conversion and enrichment steps. Any impact of this is more likely to be seen in the conversion market, but in principle it could marginally favour enrichment plants in the United States.

Product differentiation

Although there are different technologies for providing enrichment services, the end product is identical. Each product cylinder containing enriched UF_6 is prepared to the enrichment level according to the customer's requirements, usually at one of several standard assays in the range of 3.5% to 5% ^{235}U. Subject to meeting international standards for purity and isotopic composition, there are no product differentiation issues affecting enrichment. However, if laser enrichment is successfully developed, its higher selectivity might allow the content of undesirable isotopes in the product, such as ^{234}U and ^{236}U, to be reduced (which would be especially useful for enriching reprocessed uranium).

Balance of capacity and demand

As discussed above, at present there is a large over-capacity in enrichment supply, at least on paper. This arises because of the large gaseous diffusion plants in France and the United States, and Russia's large centrifuge capacity. However, the high operating costs of the diffusion plants (mainly due to high electricity consumption) and the exclusion of much of Russia's capacity from the international market, effectively reduce the available capacity. The closure of the diffusion plants, expected sometime in the next ten years or less, means that significant investment in new centrifuge capacity is expected by all major enrichers in the coming years to keep up with demand. Hence, the situation of global over-capacity is likely to come to an end.

Market alliances and supplier co-operation

In 2006, AREVA and Urenco formed a joint venture, known as Enrichment Technology Company Ltd (ETC), to share the gas centrifuge technology developed by Urenco. This arrangement was designed to allow AREVA to use Urenco technology for its new centrifuge enrichment plant, now under construction at Tricastin in France. It received the approval of the three governments (Germany, Netherlands and the United Kingdom) involved in setting up Urenco, as well as the French Government and the European Commission. An important condition of this approval was that the deal only covers the sharing of technology, and that the production facilities and marketing activities of the two groups remain separate and in competition. ETC is now responsible for designing and manufacturing centrifuges, which it supplies to both partners.

It would appear possible that, subject to government approvals, ETC could potentially supply its centrifuges to other approved companies wishing to enter or expand in the uranium enrichment business. However, there are no announced plans as yet for such an extension of the company's activities. In any case, it is expected that ETC will be working at full capacity to supply centrifuges to its two shareholders for the foreseeable future, with a new Urenco plant under construction in the United States as well as the new AREVA plant, and ongoing expansion of Urenco's three existing plants.

Public goods aspects

The technology for the enrichment of uranium is extremely sensitive and strategic, and at all times is deployed under close governmental supervision in the handful of countries which possess it. Prevention of the spread of this technology to those who may wish to use it for unauthorised purposes is a clear public good which governments rightly wish to protect. This inevitably limits the commercial availability of enrichment services to a relatively small number of countries and companies.

Beyond that, uranium enrichment is subject to similar safety and environmental regulation, including radiological protection, as other similar nuclear fuel and chemical processes.

Trade barriers and restrictions

Trade restrictions on imports of enrichment services are imposed in various forms by the United States and the European Union. These are designed to protect domestic enrichers, principally by seeking to limit the access of Atomenergoprom to their markets. In the case of the European Union, this takes the form of an informal quota system, whereby the Euratom Supply Agency aims to limit the share of Russian enrichment in EU supply to no more than about 20%. In the United States, there are more explicit restrictions under "anti-dumping" legislation (as discussed for the uranium market).

One justification for these restrictions is the large proportion of the US market which has in recent years been supplied by Russia from former military HEU (as discussed above). This has effectively increased governmental control of the enrichment market, making it subject to non-commercial considerations (i.e. national security). However, Russia is now expected to end the export of enrichment from this source when the current agreement ends in 2013.

By that stage it appears that, on present trends, the current over-capacity situation will have come to an end and Atomenergoprom's enrichment plants in Russia will have a larger role to play in international markets. In anticipation of this, as discussed in Sections 4.1 and 4.2, the United States and Russia have negotiated a revised agreement which sets quotas for imports of low enriched uranium (LEU) from Russia into the US market. From 2013 to 2020, imports of LEU containing about 3 million SWU per year (about 20% of US demand) will be permitted, plus LEU required for the first cores of new NPPs in the United States. From 2021 all restrictions are expected to be lifted.

4.4. Fuel fabrication services

In the early stages of nuclear power development, several different reactor concepts were introduced in the various countries involved. Although reactors based on five of these concepts are in operation today, the great majority of existing NPPs (and almost all newer plants) are one of two broad types of light water reactor (LWR), namely pressurised water reactors (PWRs) and boiling water reactors (BWRs). Reactor types and their shares of current nuclear power generating capacity are listed in Table 12.

Table 12. Reactor types at currently operating NPPs
(percentage of global capacity)

Reactor type	Share of capacity (%)
Pressurised water reactor (PWR)	65.6
Boiling water reactor (BWR)	22.9
Pressurised heavy water reactor (PHWR)	6.0
Light water graphite reactor (RBMK)	3.1
Gas cooled reactor (Magnox, AGR)	2.4
Total	**100.0**

Source: IAEA (excludes fast reactors).

The most widespread reactor type is the PWR. Most present PWRs are derived from designs originally developed in the United States, the technology for which was subsequently transferred under licence to other countries (including France and Japan). Another PWR design, known as the VVER, was independently developed in the Soviet Union. These reactors are operated mainly in Russia and in central and eastern Europe, comprising about 15% of current PWR generating capacity. The BWR concept was also developed in the United States. Today it is the second most widespread reactor type.

The PHWR design, often known as the CANDU reactor, was developed by AECL. It has been exported to several countries, including Argentina, China, India, Korea and Romania. There are also a few PHWRs based on non-AECL designs, including most Indian plants (these result from independent development of early CANDU technology). PHWRs are fuelled with natural uranium, which makes fuel production simpler than for LWRs. In general, fuel for plants in each country is produced by national fabricators, meaning that there is no established international market for PHWR fuel.

Presently, gas-cooled reactors are operated only in the United Kingdom and are supplied by domestic facilities. Light water graphite (RBMK) reactors were developed in the Soviet Union and those remaining in operation are now all in Russia with the exception of a single plant in Lithuania. All the fuel for these reactors is produced in Russia.

Thus, competitive markets for fuel fabrication exist only for LWR fuel and the analysis below will be confined to consideration of fuel for these reactor types, which make up almost 90% of present nuclear generating capacity. In general, the fuel fabricator by default for any NPP is the original vendor of the plant (or its successor company). Normally the initial core and some reloads for a new plant would always be supplied by the plant vendor. However, beyond this initial period a competitive market has developed in which NPP owners are able to switch fuel suppliers, with all the main vendors potentially able to supply fuel for most LWR designs (although the choice of supplier may be limited for less common reactor designs).

Unlike the earlier stages of the fuel cycle, fuel fabrication involves preparing fuel assemblies specifically tailored to the requirements of an individual reactor. This includes the basic shape and size of the fuel assembly (which may be common to several plants from the same NPP vendor sharing the same design), but also the exact enrichment level of each group of pellets. Furthermore, within the basic design parameters, improved fuel designs have often been developed which improve on the original fuel design. As well as the uranium fuel itself, fabricated fuel assemblies also contain other components and materials required for reactor operation or which improve performance.

The performance of nuclear fuel has a critical effect on the overall performance of any NPP, and this is an area where there have been significant improvements over the years. Fuel fabricators have been able to improve both the reliability and efficiency of their fuel, resulting in fewer reactor shutdowns as well as longer intervals between refuelling and increased fuel burn-ups. That this has taken place is itself an indication that a significant level of competition exists among fuel fabricators. However, switching fuel supplier is a technically complicated process which involves some risk to the smooth operation of the plant. The financial implications of reduced plant performance would quickly outweigh any benefit from lower fuel prices.

Market shares

The situation in the nuclear fuel fabrication market has changed significantly over the past decade. In 1997 the market for LWR fuel (excluding VVERs) was fairly evenly distributed among five major producers: Framatome-Cogema Fuels, General Electric, Westinghouse, Siemens and ABB-CE. All five of these companies operated a fabrication plant in the United States, the most open and competitive market for fuel fabrication. TVEL of Russia produced almost all of the fuel for VVERs, while fabrication requirements in other regions were mainly met by local fabrication plants. Approximate fuel fabrication capacities in 1997 are summarised by company in Table 13.

Table 13. **Approximate 1997 LWR fuel fabrication capacities by company and percentage shares**

Company	**Capacity** (tHM)	**Share** (%)	**HHI**
Framatome-Cogema	2 000	19.9	396
General Electric	1 200	11.9	142
Westinghouse	1 150	11.4	130
Siemens	1 100	11.0	121
ABB-CE	1 050	10.5	110
TVEL (Russia)*	800	8.0	64
Japan Nuclear Fuel	740	7.4	55
Nuclear Fuel Industries (Japan)	534	5.3	28
Mitsubishi Nuclear Fuel (Japan)	440	4.4	19
British Nuclear Fuels (BNFL)	330	3.3	11
Enusa (Spain)	250	2.5	6
Korea Nuclear Fuel	200	2.0	4
China National Nuclear Corp.	150	1.5	2
Indústrias Nucleares do Brasil	100	1.0	1
Total	**10 044**	**100.0**	**1 089**

Sources: NEA, World Nuclear Association (*estimate).

The HHI of 1 089 does not indicate an over concentrated market power. However, this could understate the degree of market competition in particular sectors of the market, since LWR fuel is a differentiated product and no single vendor is capable of producing every different fuel design. Furthermore, the market displays strong regionalisation. Nevertheless, the HHI from 1997 may provide a useful indication of the effects of the market consolidation which has taken place during the past decade.

As noted above, the major fabricators are also the main NPP vendors, so the consolidation in this sector has mainly reflected that in the NPP supply sector (discussed in Section 3). This consolidation, driven partly by over-capacity in fuel fabrication and the need for investment in R&D, has significantly changed the market distribution. The major steps in this consolidation are: the merging in 2001 of the nuclear fuel operations of Siemens with Framatome-Cogema Fuels, which later became part of AREVA; the merger of ABB-CE into Westinghouse in 2000 under the ownership of British Nuclear Fuels, and the 2006 sale of Westinghouse to Toshiba and other partners; and, for BWR fuel, the establishment by GE, Toshiba and Hitachi of the Global Nuclear Fuel (GNF) joint venture in 2001 (which incorporated Japan Nuclear Fuel, their previous joint venture for the Japanese market).

Thus, only three major global suppliers for LWR fuel (excluding VVERs) remain: AREVA, Westinghouse and GNF. The dominant supplier of VVER fuel remains TVEL of Russia (now part of the Atomenergoprom state holding company). Updating the figures from Table 13 based on 2007 fabrication capacity provides the results in Table 14. This indicates that, based on fabrication capacity, the HHI has risen significantly over ten years and now indicates an over-concentrated market.

Only one nuclear fuel fabrication plant has closed as a result of this restructuring, the former ABB-CE plant at Hematite in the United States. Four of the original five fabrication plants in the United States remain, but two are now owned by AREVA. However, despite the Hematite closure, small capacity additions at several other plants mean that global LWR fabrication capacity in 2007 was slightly higher than in 1997.

In analysing these data, we have to take into account that the LWR fuel market can be split into three main sectors, according to reactor type. The PWR fuel market is dominated by AREVA with a share of over 50%, while the BWR fuel market is dominated by GNF with a share of about 70%. In the VVER market, TVEL has a share of almost 100%. Nevertheless, these three sectors can be considered as a single market, because each is of sufficient size that under the right circumstances it could be attractive for a major producer presently active in one or two sectors to enter the other sectors.

Table 14. **Approximate 2007 LWR fuel fabrication capacities by company, and percentage shares**

Company	**Capacity** (tHM)	**Share** (%)	**HHI**
AREVA	3 250	31.7	1 005
Westinghouse	2 080	20.3	412
Global Nuclear Fuel	1 950	19.0	361
TVEL (Atomenergoprom)*	800	7.8	61
Nuclear Fuel Industries (Japan)	534	5.2	27
Mitsubishi Nuclear Fuel (Japan)	440	4.3	18
Enusa (Spain)	400	3.9	15
Korea Nuclear Fuel	400	3.9	15
China National Nuclear Corp.	200	2.0	4
Indústrias Nucleares do Brasil	200	2.0	4
Total	**10 254**	**100.0**	**1 923**

Source: NEA, World Nuclear Association (*estimate).

In addition to the market consolidation which has taken place in countries with long-established nuclear industries, there has been an expansion of fabrication capacity in countries where the nuclear industry started to develop later – notably China and Korea. Although these producers are presently supplying only their domestic markets, in future they could become important players on the global market.

Degree of vertical integration

As noted above, the major fuel fabricators are also the main reactor designers and vendors (or their affiliates or licensees). It remains normal practice for the NPP vendor to supply the initial core and the first reloads as part of the initial agreement covering construction of the plant. As the design of the fuel is an important element of the overall design of the reactor, the company which produced the design will often have a significant technical advantage in supplying fuel, as well as the advantages of incumbency.

Although these advantages become less decisive later in the life of a plant, as its design becomes better known by other fabricators, only a substantial cost saving or performance improvement will make it clearly worthwhile for a NPP owner to undertake the difficult process of changing fuel supplier. However, in some cases owners of a fleet of NPPs may have a policy of changing fuel suppliers from time to time, simply to ensure that a degree of competition is maintained.

Proportion of long-term contracts

The supply of nuclear fuel is generally based on long-term contracts, due to the fact that changing the fuel vendor is a very complicated and costly process. In order to change supplier, the NPP must operate for two or three years with a mixed core (i.e. both old and new fuel together), which can be complicated to license and can limit the coverage of fuel warranties from both fuel vendors. The alternative is to reload the whole core with new fuel, which is wasteful and expensive and thus would only be adopted in unusual circumstances.

Other complications of changing fuel vendor include: the need to obtain regulatory approvals and make licence amendments; differences in the methodologies used for reload safety analyses; and the need to introduce and license new or modified software for reload calculations. For such reasons, switches of fuel supplier are relatively rare, and ten-year contracts with an option for prolongation are not unusual.

Barriers to entry

Nuclear fuel is a highly engineered and specialised product, which creates a significant barrier to newcomers entering the market. Development of new fuel designs is a very complicated and costly process, which is illustrated by the fact that even experienced fuel vendors can fail in the development of new fuel designs. All recent entrants to the fuel fabrication business have been government-owned companies. Such companies enter the market not for strictly business considerations, but as a result of a political decision to increase national energy independence. The necessary know-how is obtained through a technology transfer or license agreement entered into by a NPP vendor/fuel fabricator as part of a larger agreement for the supply of NPPs.

Transaction costs and market segmentation

Compared to a fossil-fuelled power plant, the annual fuel consumption of a nuclear power plant is very small. A 1 000 MWe NPP consumes about 20 tonnes of enriched uranium per year. No special handling measures are required to transport fresh LWR fuel. Thus, shipping costs do not have a major impact on the total price of the fuel and do not lead to market segmentation. However, some NPP owners may see advantages in using a locally based supplier which can more rapidly provide support in the event of fuel-related issues during reactor operation.

Product differentiation

Historically, each reactor design company developed its own basic fuel design, in most cases with fuel pins distributed over a square lattice of between 14x14 and 18x18 pins. For VVER reactors the pins are arranged in a triangular mesh, with two different designs, for VVER-440 and VVER-1000 reactors. There are also different designs for BWR fuel, with pins arranged in 9x9 or 10x10 lattices. In the early stages of the commercial nuclear industry, there was thus a high degree of product differentiation in the nuclear fuel sector.

With the existence of spare capacity, over time the original fuel vendors sought to expand by offering reloads for their competitors' reactor designs. The role of product differentiation decreased and the LWR fuel market started to become more competitive. This process was spurred by the major consolidation which has taken place among NPP vendors/fuel fabricators. One consequence is that, with exception of GE, the major LWR fuel vendors offer both PWR and BWR fuel. Although there are a few fuel designs offered by only one vendor, for the majority of designs at least one alternative vendor exists.

While product differentiation between most PWR and BWR fuels is not very important today, there remains a technical barrier between non-Russian suppliers and VVER fuel designs. Although the basic physical characteristics of VVER fuel are very similar to other LWR fuels, the differences in mechanical characteristics due to the different lattice shape complicates the development of fuel designs by TVEL's potential competitors.

Alternative vendors for VVER fuel did emerged in the first half of 1990s. Westinghouse developed VVANTAGE-6 fuel for VVER-1000 units after winning a bid for fuel supply to the two Temelin units in the Czech Republic. In 2000, Westinghouse also signed a contract for delivery in 2003 of six lead test assemblies for one unit at the South Ukraine NPP, with 42 reload assemblies to follow in 2005. Although Westinghouse subsequently lost the contract to supply Temelin fuel from 2010 (which was awarded to TVEL), in 2008 it was awarded a major contract to supply fuel for three VVER-1000 reactors in Ukraine for five years from 2011.

An alternative design for VVER-440 fuel was developed by BNFL in the first half of the 1990s at the request of operators in Finland and Hungary, who wanted an alternative supply at a time of economic uncertainty in Russia. This fuel was loaded into the Loviisa-1 unit in Finland. However, TVEL later also regained the contract for this plant. Nevertheless, BNFL may have a future as a VVER-440 fuel supplier, possibly as an alternative supplier for NPPs in Slovakia.

Meanwhile, TVEL has been co-operating since 1993 with Siemens, now part of AREVA NP. Within the framework of this co-operation, TVEL manufactures fuel assemblies for non-Russian PWR and BWR reactors of French and German designs. It is thus possible that the expertise gained will enable TVEL to become an alternative supplier of non-Russian LWR fuel in the future.

Balance of capacity and demand

At the end of 1990s, world capacity for fuel fabrication was significantly larger than demand (by a factor of about two). Since then, the gap between capacity and demand has been closing. On one side, production capacity has decreased due to the above mentioned market consolidation and subsequent closure of some production plants. On the other side, fuel consumption has increased slightly, mainly due to power up-rates and increased capacity factors.

According to the World Nuclear Association, current LWR fabrication requirements are approximately 7 000 tHM/year, while world production capacity is just under 11 000 tHM/year. This implies that, on average, production plants are operating at about 65% of capacity, which is a comfortable margin. However, this capacity surplus could be quickly reduced in the next few years if forecasts of new NPP construction are realised. The production of non-standard fuel for first cores and initial reloads requires more capacity than the production of standard fuel, and would need to begin some years before new plants were due to enter operation. In such a case, the limiting factor is likely to be the capacity for the conversion of UF_6 to UO_2 powder, as greater capacity already exists for pelletisation and the preparation of fuel pins and assemblies.

Market alliances and supplier co-operation

As noted above, the supply of fabricated fuel is closely related to the supply of nuclear power plants themselves. As a result, alliances and co-operation between fuel fabricators generally reflect the arrangements in the NPP market, which are discussed in more detail in Section 3. However, the Global Nuclear Fuel joint venture brings together General Electric, Toshiba and Hitachi for the fabrication of BWR fuel. This arrangement continues despite Toshiba now being the majority owner of Westinghouse, and the setting up of a new joint venture between GE and Hitachi to supply BWRs.

Smaller fabricators which are not themselves NPP vendors often have a licensing arrangement with the original vendor(s) of the plants to which they supply fuel. For example, Enusa of Spain has such agreements with Westinghouse and GE, for PWR and BWR fuel respectively.

Under an agreement signed in 1993 between Russian fabricator TVEL and Siemens, some fuel for non-Russian PWRs and BWRs has been fabricated at TVEL's Elektrostal plant. This co-operation is continuing between TVEL and AREVA (following the merging of Siemens' nuclear fuel business into AREVA in 2001). Under this arrangement, fuel is manufactured by TVEL for delivery to AREVA customers in Western Europe.

Public goods aspects

Compared to other sectors of the nuclear fuel cycle, fabricated fuel presents few special hazards during storage and transport, and the technologies used in fabrication are not considered strategically sensitive. All shipments of nuclear fuel are, however, carefully tracked and all fuel assemblies have to be accounted for at all times.

Trade barriers and restrictions

Some jurisdictions impose tariffs on the import of fully fabricated fuel, which do not apply to the import of the components of such fuel (i.e. they do not apply to the import of uranium and of UF_6 conversion and enrichment services, not to the metal components used in fuel fabrication). This can act to limit competition by giving a cost advantage to a local fabrication plant. In the case of the United States, the import tariff on fully fabricated fuel is 3% of the total value of the fuel (including the contained uranium, UF_6 conversion and enrichment services). In practice, this is one of the reasons why the major international fabrication companies maintain separate plants in the United States to serve this market.

5. COMPETITION IN THE BACK-END OF THE NUCLEAR FUEL CYCLE

The most important activities in the back-end of the nuclear fuel cycle concern the management of spent fuel unloaded from operating NPPs. A typical 1 000 MWe LWR produces 20 to 30 tHM of spent fuel per year, with annual global arisings amounting to about 10 000 tHM. Since the start of the commercial nuclear industry, over 200 000 tHM of spent fuel have been generated. This total could double by 2030 if there is a significant upturn in orders for new NPPs.

This spent fuel initially generates a considerable amount of heat, and so is stored under water in cooling pools (usually at NPP sites), where it often remains for an extended period. However, after a few years of cooling it may be moved into interim storage, which is usually dry storage. This can either be in shielded metal casks (similar to those used for transporting spent fuel), or in a purpose-built storage facility which may serve several NPPs. For the longer term, some countries have nuclear policies which allow the reprocessing of spent fuel and the recycling of extracted materials in new nuclear fuel, while others intend to dispose of spent fuel as waste in a geologic repository.

The back-end of the fuel cycle also encompasses services connected with the management and storage of all types of radioactive wastes, and also for the decommissioning of NPPs and fuel cycle facilities.

5.1. Spent fuel reprocessing services

When spent fuel is removed from the reactor it contains approximately 96% by mass uranium (U) and plutonium (Pu). By reprocessing the spent fuel, U and Pu can be separated from the waste products to allow them to be recycled. Subject to national policy and to the necessary regulatory framework being in place, utilities owning spent fuel can contract for their fuel to be reprocessed, allowing them to recycle the contained U and Pu as new fuel for their reactors. Pu is used in mixed-oxide (MOX) fuel (a mixture of uranium and plutonium oxides), the fabrication of which is discussed in Section 5.2 below.

Reprocessed uranium (RepU) can also be recycled, and this has taken place in a few countries. Residual levels of contamination in RepU mean that it requires special handling in dedicated facilities. However, the enrichment and fabrication of RepU fuel are essentially the same as for fresh uranium. The limited markets for such services are supplied by the same companies that supply regular enrichment and fabrication, and they have not been considered as separate markets in this report.

Although civil reprocessing facilities have been built and operated in seven countries (China, France, India, Japan, Russia, the United Kingdom and the United States), reprocessing has only been offered to the international market by state-controlled nuclear fuel companies in France and the United Kingdom. Their customers have been mainly utilities in Western Europe and Japan. Russia (and previously the USSR) has also provided reprocessing services to operators of Soviet-design nuclear plants built in other countries. The US Government adopted a policy of direct disposal of used nuclear fuel in 1977, which ended civil reprocessing activities in the United States and also removed from US utilities the option of reprocessing their spent fuel in other countries (although this policy is now being reviewed as part of the Global Nuclear Energy Partnership (GNEP) programme, discussed below).

In general, reprocessing has been provided as a service, i.e. the utility remains the owner of the spent fuel and all the separated materials produced during reprocessing (including wastes). This means that all products and wastes will be ultimately returned to the country where the fuel was irradiated. The former USSR originally provided a "take back" service for spent fuel for Soviet-design reactors in other countries, but such arrangements have now been terminated.

As the growth of nuclear power stalled in many countries in the 1980s and 1990s, interest in reprocessing also declined. Low uranium prices prevailing in the 1990s made recycling less economically attractive. Although some long term reprocessing contracts remain in effect and commercial reprocessing activity continues in both France and the United Kingdom, few new contracts for reprocessing have been signed in recent years. However, the rapid rise in uranium prices in recent years has led to renewed interest in developing reprocessing and recycling for the future.

All reprocessing facilities built to date are based on the Purex process, which involves chemical separation of U and Pu in aqueous solution from fission products and minor actinides. The U and Pu are then conditioned for future use, while wastes are prepared for interim storage and eventual disposal. Reprocessing and recycling can lead to an overall reduction in waste volumes and in long term radioactivity, as compared to direct disposal of spent fuel. However, the separation of Pu has led to proliferation concerns.

Several different technologies for potential future reprocessing facilities are under development, with the aim of further reducing the volume and radiotoxicity of wastes, and enhancing the proliferation resistance of recycling facilities. Several international initiatives have been launched to support such development, mainly led by France, Japan, Russia and the United States. These are discussed in more detail in Section 7. These potential future processes include:

- Evolutionary technologies based on aqueous separation methods, aiming at co-extraction of U and Pu (or U, Pu and neptunium).
- Aqueous processes using new extractant molecules, either with separation of minor actinides (possibly followed by their transmutation in either a fast reactor or an accelerator-driven system), or group separation of actinides in an integrated fuel cycle with the prospect of recycling in fast reactors.
- Innovative methods based on pyrochemistry, which could allow the treatment of different types of nuclear fuels (metal, carbide, oxide or nitrite) with high fissile materials content, or fuels with a high burn-up.

If nuclear capacity expands significantly in the coming decades, leading to the development and deployment of new reactor and fuel cycle technologies, commercial reprocessing and recycling are likely to become important components of the nuclear fuel cycle.

Market shares

Reprocessing is, like enrichment, a sensitive and strategic technology which has always had strong government involvement. As noted above, the technology has been developed in a small number of countries, while the number of commercial operators is even more limited.

Historically, the global market for commercial reprocessing has represented about 20% of discharged LWR fuel assemblies, amounting to about 30 000 tHM in total. This has been shared by three reprocessing facilities: AREVA's La Hague site in France, Sellafield in the United Kingdom (now owned by the government's Nuclear Decommissioning Authority (NDA) and operated by contractors Sellafield Ltd.), and Atomenergoprom's Mayak site near Chelyabinsk in Russia. The Rokkasho-mura reprocessing plant of Japan Nuclear Fuel Ltd. (JNFL) was expected to enter commercial operation in 2008. Table 15 summarises information about these reprocessing plants.

In 2006, the total amount of spent fuel reprocessed was approximately 1 115 tHM, of which 90% was processed at La Hague. The Sellafield plant was undergoing an extended shutdown for repairs and upgrading; it restarted in 2007 and was expected to resume full production in 2008.

Table 15. **Major reprocessing companies with 2007 capacity and cumulative amount of LWR fuel reprocessed** (tHM/year)

Owner/operator	Facility	Nominal capacity	Production in 2006	Cumulative production	Capacity share (%)	HHI
AREVA	La Hague	1 700[a]	1 015	22 700	44.7	1 998
Japan Nuclear Fuel Ltd. (JNFL)	Rokkasho -mura	800[b]	0	0	21.1	562
Atomenergoprom	Mayak	400[c]	100	4 000	10.5	445
NDA / Sellafield Ltd.	Sellafield	900[d]	0	4 000	23.7	110
Total		**3 800**	**1 115**	**30 700**	**100.0**	**3 115**

Source: CEA.

a. In January 2003, AREVA was authorised to modify the operating conditions of the two La Hague plants: UP2-800 (which started up in 1994, to reprocess French fuel) and UP3 (which started up in 1990, initially to reprocess fuel for foreign utilities). The individual capacity of each plant was raised to 1 000 tHM/y, with a limit for the two plants combined of 1 700 tHM/y.

b. The Rokkasho-mura plant started test operation in 2006 and was expected to start commercial operation in 2008.

c. The RT1 plant at the Mayak site, near Chelyabinsk, has been operational since 1976. It has a nominal capacity of 400 tHM/y, but is presently limited to 250 tHM/y by regulatory authorities.

d. Thorp (Thermal Oxide Reprocessing Plant), located at the Sellafield site, started operation in 1997 with a capacity of 900 tHM/y. The plant was shut down from April 2005 until mid 2007 for repairs and upgrading following an internal leak.

If nuclear generating capacity expands more rapidly in the coming decade and beyond this is likely to lead to increased interest in reprocessing and recycling, especially with the expected emergence of new reprocessing technologies. Reprocessing projects being considered in China, India, Russia and the United States, as described in Table 16, could increase global capacity and change market shares in the 2030 timeframe.

Table 16. **Expected future LWR fuel reprocessing facilities in the 2030 time frame**

Country	Company	Facility	Capacity (tHM/y)	Status in 2007
China[a]	CNNC		800	Planned
France	AREVA	La Hague	1 700	Operational
India[b]		Tarapur & Kalpakkam	500	Extension planned
Japan[c]	JNFL	Rokkasho-mura	800	Starting-up
Russia[d]	Atomenergoprom	Zheleznogorsk	1 000	Planned
United Kingdom[e]	NDA	Sellafield	?	Re-start
United States[f]			2 500	Planned
Total projected for 2030			**~ 7 000**	

Source: CEA.

a. China intends to develop a domestic closed nuclear fuel cycle, including a large commercial reprocessing plant. As a first step, CNNC has designed and constructed a 50 tHM/y pilot plant.

b. India is constructing two reprocessing facilities in addition to the three already operating at Tarapur, Kalpakkam and Trombay. The current 200 tHM/y capacity should reach 500 tHM/y after completion of these facilities (Bhabha Atomic Research Centre, June 2007).

c. The Rokkasho-mura plant will have a capacity of 800 tHM/y, whereas the annual arising of spent fuel from Japanese NPPs is over 1 000 tHM/y and may reach 1 200 tHM/y by 2010. A decision to build another reprocessing plant for the longer term (2045) is foreseen, but the present priority is to start the first plant at Rokkasho-mura and fully initiate the MOX fuel programme.

d. The RT1 plant may operate until 2020 to reprocess VVER-440 and BN600 spent fuel. For the longer term, Atomenergoprom may develop non-aqueous reprocessing technologies with the aim of having a pilot plant of 50-100 tHM/y in operation by about 2015. A new commercial-scale plant (RT2) of 500 to 1 000 tHM/y could then be constructed at Zheleznogorsk using such technology.

e. The NDA presently plans to close Thorp once existing contracts are fulfilled, expected between 2012 and 2015. However, a national review of the longer term management options for spent fuel is underway, following decisions by the UK Government on the future of nuclear power.

f. The Energy Policy Act of 2005 states: *"The Energy Secretary… shall conduct an advanced fuel recycling technology research, development, and demonstration program to evaluate proliferation-resistant fuel recycling and transmutation technologies that minimize environmental and public health and safety impacts as an alternative to aqueous reprocessing technologies deployed as of the date of enactment of this Act in support of evaluation of alternative national strategies for spent nuclear fuel and the Generation IV advanced reactor concepts".* In 2007, the Department of Energy selected four consortia to receive contracts for technical and deployment studies to examine the cost, scope and schedule for conceptual design studies for an initial fuel recycling centre and an advanced recycling reactor, which the DOE expects to build as part of its activities under the GNEP programme.

Also within this longer term perspective, regional reprocessing/recycling centres could potentially be established under multilateral arrangements now under discussion (see Section 7). A leading example of such proposals is the Global Nuclear Energy Partnership (GNEP), launched by the United States, which is described as a *"cooperation of those States (as of now 16 full partners and 22 candidates partners or observers countries) that share the common vision of the necessity of the expansion of nuclear energy for peaceful purposes worldwide in a safe and secure manner. It aims to accelerate development and deployment of advanced fuel cycle technologies to encourage clean development and prosperity worldwide, improve the environment, and reduce the risk of nuclear proliferation"* (GNEP Statement of Principles, 16 September 2007).

Degree of vertical integration

As noted in other sections of this report, AREVA and Atomenergoprom are fully integrated suppliers of nuclear fuel cycle materials and services, as well as of being NPP vendors. The NDA is also active in some other stages of the fuel cycle, notably MOX fuel fabrication; most of its other activities are for the UK market only. JNFL also provides enrichment, MOX fuel fabrication and waste management services in the Japanese domestic market; it is mainly owned by the ten major Japanese utilities.

Proportion of long-term contracts

The nature of reprocessing/recycling of spent fuel requires a long-term relationship between supplier and customer, covering the period from unloading of spent fuel from the reactor through reprocessing, MOX fuel fabrication and return of radioactive waste. Completion of these processes extends over several years. For example, AREVA signed a contract in 2007 to reprocess 235 tHM of spent fuel from Italy which may continue to 2025.

Furthermore, the design, construction and commissioning of a reprocessing plant is a financial venture which requires support from the customers, due to the high capital costs and long commissioning period. Both the commercial reprocessing plants operating today in Europe (La Hague and Thorp) were supported from the outset by long-term contracts with customers which included provision of capital for their construction. Utilities often entered these contracts in order to satisfy legal and political requirements to reprocess their spent fuel, at a time when rapid growth in nuclear capacity and uranium demand was expected.

Barriers to entry

As for enrichment, the most important barriers to entry are possession of the necessary technology and the high level of investment required. To achieve economies of scale requires a large plant, which in turn means that sufficient reprocessing contracts must be in place to support the decision to invest. For existing plants, this equates to an annual flow of spent fuel from approximately 30-50 nuclear units. Constructing and operating a facility also requires strong involvement by the government of the hosting state, and full compliance with international non-proliferation requirements.

Another barrier to entry is the now fully amortized existing facilities, which will make it difficult for new facilities to compete so long as excess capacity remains in the market. Investment in new reprocessing plants is only likely once there are strong economic incentives, such as increased front-end fuel cycle costs and/or radioactive waste disposal costs, leading to increased demand for reprocessing.

Also, given the very long timeframes associated with construction of reprocessing facilities, there are important risks for private sector investors beyond the technological and economic risks associated with the plant itself. These include political, policy and licensing risks. As a result, private investors are unlikely to provide capital for reprocessing facilities without strong government involvement and guarantees.

Transaction costs and market segmentation

Transporting spent fuel from reactors to distant reprocessing plants, and returning MOX fuel and wastes, is a complex process with significant costs. This has not prevented spent fuel from Japan being reprocessed in Europe, despite the need for a fleet of specially-designed ships, so clearly under the right circumstances a global market can exist. However, the costs and logistical challenges of such transports are likely to favour more local suppliers where they exist. For example, reprocessing of Japanese fuel in Europe is expected to be much reduced in future, once sufficient capacity exists in Japan.

When the extracted plutonium and uranium are required for recycling, they are sent to facilities for fabrication of MOX or RepU fuel. The overall economics, proliferation resistance and security of the recycling process can be enhanced by locating reprocessing and MOX fuel fabrication facilities on the same site, thus avoiding the need to transport plutonium between sites. This means that reprocessing and MOX fabrication are increasingly likely to be performed by the same supplier in future, and thus effectively to form a single market segment.

Product differentiation

All the commercial plants currently in operation are based on the Purex process. The end product is thus equivalent, even though its final state may differ (for example, uranium can be delivered in nitrate or oxide form). However, an important consideration is the characteristics of the final wastes to be returned to customers, which must conform with the requirements of customers' national safety authorities.

Differentiation also exists in the capacity of operators to treat a wide variety of spent fuel, including the ability to handle fuels with increased burn-ups and higher initial enrichment. Companies can also differentiate themselves by offering additional services for spent fuel management, interim storage, and development of storage and disposal facilities. In the future, with the development of Generation IV reactors and associated fuel cycle facilities, product and service differentiation could increase.

Balance of capacity and demand

In spite of the recent extended outage of the Sellafield facility in the United Kingdom, present facilities have not been running at full capacity. However, it is expected that improved prospects for nuclear power in the coming years will lead to the capacity of existing facilities being fully used, and to the development of new facilities as listed in Tables 15 and 16. In Japan, the 800 tHM Rokkasho-mura plant will not be sufficient to reprocess all of the 1 200 tHM annual fuel arisings expected in the medium term.

Market alliances and supplier co-operation

There are several types of co-operation within the reprocessing/recycling industry, ranging from co-operation in the construction and operation of present facilities to the promotion and development of the reprocessing option for the longer term.

JNFL's plant at Rokkasho-mura was built following a technology transfer agreement signed with AREVA in 1987, and is similar to the UP3 facility at La Hague. In December 2005, this technical assistance contract was extended to cover the commercial start-up of the plant. The two companies signed a global partnership agreement in September 2007 to co-operate on improving the industrial effectiveness of their plants, and to make joint efforts to promote recycling activities on the international scene. AREVA has also signed technical support contracts with British Nuclear Group (former operator for the NDA of the Sellafield site) in relation to the vitrification of high level waste.

Within the GNEP programme, the US Department of Energy has invited proposals for the construction of demonstration reprocessing/recycling facilities. Several companies have formed consortia to explore technical and business models for such facilities.

Public goods aspects

Reprocessing, like enrichment, uses strategically sensitive technology which is subject to strict non-proliferation controls. In addition, the storage and handling of separated plutonium requires stringent security precautions. As a result, reprocessing is confined to a small number of sites in a few countries possessing advanced nuclear technology.

However, as noted above, new reprocessing technologies are under development which will avoid the production of separated plutonium. This may make it possible in future for reprocessing plants to be built in additional locations around the world. Furthermore, multilateral reprocessing facilities under international control are also under consideration in the framework of proposals for assured fuel supply (described in Section 7).

In to the multilateral non-proliferation controls of the IAEA, in many cases the international supply of uranium and fuel cycle services requires a nuclear co-operation agreement to exist between the supplier and recipient country. This will often give the supplier country some rights in perpetuity over the subsequent use of the nuclear materials supplied, including the right to approve its reprocessing and recycling.

Trade barriers and restrictions

Beyond the restrictions imposed for non-proliferation reasons noted above, there are no specific barriers to trade in reprocessing and recycling services. The number of trading partners in these activities is limited, and normally there is a significant political involvement in establishing and managing the necessary legal, regulatory and commercial frameworks.

There is little or no trade in the Pu and RepU produced in reprocessing, which remains the property of the utilities owning the reprocessed spent fuel. Such materials remain in storage until such time as the utility decides to recycle them, with the fuel cycle industry acting as a service provider.

5.2. Mixed-oxide fuel fabrication services

MOX fuel is composed of a mixture of uranium and plutonium dioxides, with the fissile content of the plutonium effectively replacing the need for enriched uranium. The uranium in MOX fuel can be natural uranium, but often depleted uranium (i.e. the tailings from an enrichment plant) is used. Fast reactors use MOX fuel, but such reactors are few in number. To date, most MOX fuel has been fabricated for use in LWRs, as a direct replacement for standard uranium fuel.

As noted in Section 5.1 above, those utilities which have had some of their spent fuel reprocessed remain the owners of the separated plutonium and uranium. Most such utilities have made use of MOX fuel, or intend to do so. MOX fuel fabrication is thus offered as a service, mostly by the same companies that operate reprocessing plants.

In general, the use of MOX fuel in LWRs requires specific regulatory approval, and often requires upgrading of fuel handling and re-fuelling facilities (mainly on account of the higher radiation levels in the fuel). Thus, not all LWRs are licensed or equipped to use MOX fuel, even if it would be technically feasible to load such fuel. In addition, for technical reasons, most LWRs can only use MOX fuel in a fraction (usually less than one-third) of the core.

MOX fuel fabrication activities began in the 1950s in Belgium and the United States, and have since been carried out in France, Germany, India, Japan, Russia and the United Kingdom. However, as with reprocessing, few commercial facilities have entered operation. Only facilities in Belgium, France and the United Kingdom have supplied the international market in recent years. Germany and the United States, which operated demonstration facilities, later abandoned MOX fuel fabrication, while India, Japan and Russia operate smaller scale domestic facilities.

The Belgonucléaire MOX fuel plant at Dessel in Belgium started operation in 1973. It was refurbished in 1984-85 to increase the nominal capacity to 35 tHM/y for LWR MOX fuel. However, the weak market for MOX fuel led to the permanent shutdown of this plant in 2006. In France, MOX fuel fabrication was initially carried out at the Cadarache site, which had a capacity of 40 tHM/y for LWR MOX fuel when it was shut down in 2003. A second plant at the Marcoule site, known as MELOX, started operation in 1995. Its capacity was expanded in 2003 from 100 tHM/y of LWR fuel to 145 tHM/y to compensate for the shutdown of the Cadarache plant. A further increase of 50 tHM/y was implemented in 2007.

In the United Kingdom, MOX fuel fabrication was carried out until 1999 at the MOX Demonstration Facility (capacity 8 tHM/y) at Sellafield. A larger scale plant, the Sellafield MOX Plant (SMP) started commissioning in 2001. However, technical and other difficulties have delayed its entry into full production, and to date it has produced only a small amount of MOX fuel. Its output is gradually being increased, but owner NDA does not expect that the plant will achieve its original design capacity of 120 tHM/y; its eventual capacity may be about 40 tHM/y.

In 1999, the US Government decided to build a MOX fuel fabrication plant to process 34 tHM of excess weapon-grade plutonium into MOX fuel for use in domestic PWRs. This plant is now under construction at the Savannah River site in South Carolina, but no firm start-up date has been announced. A plant for LWR MOX using former military plutonium had been planned in Russia to match the plant now under construction in the United States. However, Russia now plans to use plutonium only in fast reactors, notably to fuel a new large fast reactor (BN-800) presently under construction.

Japanese utilities are important customers for the European MOX fabrication plants, as the plutonium separated from Japanese spent fuel in the European reprocessing plants is expected to be returned to Japan in the form of MOX fuel. For the longer term, the Rokkasho-mura reprocessing plant in Japan is expected to be followed by a MOX fuel fabrication plant (known as J-MOX) with a capacity of 130 tHM/y by about 2012. Other customers for the three European MOX fabricators have included utilities in Belgium, France, Germany and Switzerland. By the end of 2006, a total of more than 2 000 tHM of MOX fuel had been loaded into 39 LWRs in these countries.

Thus, at present, the only large scale MOX fabrication plant in operation worldwide is the MELOX facility at AREVA's Marcoule site. The expected increase in production at the Sellafield MOX Plant will provide an alternative supply source in the near term, while additional capacity in Japan and the United States is expected to come on line in the next few years.

On the demand side for MOX fuel, the market has been contracting in recent years. In Belgium, two reactors were licensed to load MOX fuel fabricated with the plutonium (about 4 tHM) recovered during the reprocessing of 530 tonnes of spent fuel covered by a 1978 reprocessing contract. The use of MOX fuel started in 1995, with the last batch loaded in 2006. The government has not permitted any new reprocessing contracts to be signed since 1998, and thus the use of MOX fuel in Belgium has come to an end.

In France, twenty PWRs have been licensed to use MOX fuel. By the end of 2004, 52 tHM of Pu had been recycled in LWR MOX, fabricated at Dessel, Cadarache and La Hague. Under a 2005 agreement between Électricité de France (EDF) and AREVA, the latter will reprocess sufficient EDF spent fuel to supply about 100 tHM/y of MOX fuel until 2014.

German utilities began loading MOX fuel in LWRs in 1966. The use of MOX fuel continues in plants owned by utilities E.ON, RWE and EnBW, using plutonium separated under past reprocessing contracts. However, since 2005 German law has not permitted any new reprocessing contracts to be signed, so MOX fuel use is expected to end when Pu from current contracts is fully utilised. In Switzerland, the Beznau and Gösgen plants continue to use MOX fuel, but the government has imposed a ten-year moratorium on new reprocessing contracts.

The Japanese MOX fuel programme has experienced several delays. To date, deliveries of MOX fuel have been made to Fukushima-3 (in 1999) and Kashiwazaki-3 (in 2001) from the Dessel plant of Belgonucleaire. However, approval for loading this fuel has not yet been granted by Japanese authorities. Additional fabrication will be carried out at MELOX, and contracts have recently been signed for this. Once the Rokkasho-mura reprocessing plant is in full operation and is followed by the J-MOX plant in about 2012, it is expected that MOX fuel will be used in 16-20 reactors, depending of the licensing and political situations.

In future, it is possible that plutonium could be used in MOX fuel other than by the utility owning the spent fuel from which it arose (including its use in other countries). This could be the case where a utility is unable to use MOX fuel itself, due to technical or legal restrictions. For example, the United Kingdom has no domestic MOX recycling programme despite having a large stockpile of plutonium. However, non-proliferation and other concerns are likely to severely limit any such trade in plutonium-containing products in the foreseeable future.

In the longer term, the development of new advanced reactor designs with closed fuel cycles using new proliferation-resistant reprocessing technologies could involve significant changes in fuel fabrication requirements for the recycling of reprocessed materials. The development of new fuel designs within such advanced fuel cycles, probably involving increased automation and remote operation, will require significant levels of research and development over the coming years. This is likely to lead to the development of new technologies, initially under government control, which will need to be deployed commercially at an appropriate stage.

5.3. Radioactive waste management and decommissioning services

The handling and disposal of all types of radioactive waste is subject to specific regulations and legislation in each country, which allocate responsibility for the management and storage of waste at each stage. The final disposal of radioactive waste is a matter of national policy, as well as international agreements such as the IAEA's Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. It is normally the responsibility of a special government agency or other approved body established for the purpose in each country.

The management of radioactive waste is initially the responsibility of the utility operating the nuclear power plant or the operator of the fuel cycle facility where the waste is generated. This applies to low level waste (LLW) and intermediate level waste (ILW) generated during operations, as well as spent fuel removed from reactors (which constitutes high level waste (HLW), if it is not to be reprocessed). These operators generally retain ownership and responsibility for these wastes, and any further wastes generated during their handling or treatment, until such responsibility can be taken over by the national organisation charged with its disposal. There are thus no commercial organisations competing to dispose of radioactive wastes, as there are for some other types of industrial waste.

A similar situation exists with respect to the eventual decommissioning and dismantling (D&D) of nuclear facilities at the end of their operating lives. Operators remain responsible for their nuclear sites until essentially all radioactivity has been removed. D&D activities also generate considerable quantities of additional radioactive wastes, for which the operator will also remain responsible until they can be handed over for final disposal. These activities may take many years to complete, with much experience to date involving research facilities, fuel cycle plants, and military nuclear facilities.

While the operators of nuclear facilities remain responsible for radioactive wastes and for decommissioning, numerous companies exist for the commercial provision of equipment and services to assist with the management of wastes and for decommissioning. Specific sub-sectors of this overall market include the provision of reprocessing services and MOX fuel fabrication services for the management of used nuclear fuel, which are discussed in the sections above. Other services for spent fuel management (in cases where fuel is not reprocessed) include fuel casks for storage and transport, and for re-racking fuel storage pools to increase capacity.

Examples of products and services for other types of waste and for decommissioning include decontamination equipment, remote cutting equipment, packaging and handling technologies, etc. Such products are provided by a wide range of companies, ranging from the major nuclear fuel manufacturers already described in previous sections of this report, through other nuclear engineering companies, to smaller companies specialised in particular aspects of waste management or decommissioning.

In a few countries there are government-owned nuclear sites containing large quantities of older radioactive wastes and redundant nuclear facilities. Some governments have contracted out the management of such sites to private companies through a competitive tendering process. Although ultimate responsibility for the site remains with the government, such arrangements put the ongoing waste management and decommissioning activities under the control of the company awarded the site management contract, which would normally last for ten years or more.

Such long-term site management contracts are the norm for government nuclear sites in the United States (which include many activities besides waste management and decommissioning). In the United Kingdom, the government's NDA is awarding similar contracts for the management of that country's older nuclear sites.

Overall, this is a complex sector with activities ranging from multi-year contracts for managing a large site with large quantities of waste, to small sub-contracting activities and the supply of small-scale equipment for waste handling. The companies involved include some of the large nuclear companies also active in other sectors discussed in this report, as well as other large engineering companies. There is thus some degree of vertical integration with other nuclear activities, although there is no obvious connection between marketing waste management services and marketing other products and services.

There are also many smaller specialised companies involved in providing products and services in one or more sub-sectors of the waste management and decommissioning market. Little information is available directly or through proxy indicators to assess the market shares of individual companies in a meaningful way. However, it is clear that there are many companies involved and multiple suppliers are available for each main market sub-sector.

While, as noted above, long-term contracts may be awarded for management of large nuclear sites, in the great majority of cases contracts for waste management and decommissioning activities are awarded for a single project or supply of equipment for a specific purpose. There is considerable technical innovation in this area, with companies striving to offer improved equipment and techniques which will give them a competitive advantage. In general, the only barriers to entry are possession of technology or know-how which meets a need, and offers some advantage over the available alternatives in terms of cost or another factor, such as radiological protection, waste storage volume, etc. This means that the products and services provided are often highly differentiated, but the wide variety of situations found in waste management and decommissioning activities means that the best product in one case may not be the most suitable for another.

Most of the various sub-sectors of this market are global in nature, in that site operators will normally seek out the best solution to meet their particular requirements. A technology which offers an advantage can quickly be adopted by users in many countries. The product or service must normally be provided at the site where the waste or facility to be decommissioned is located, but transport or logistical factors will rarely be significant impediments for this type of activity. There are generally no trade barriers or similar restrictions which apply to waste management and decommissioning activities.

6. COMPETITION IN SERVICES FOR MAINTENANCE AND UPGRADING OF EXISTING NUCLEAR POWER PLANTS (NPPs)

The overall market for maintenance and upgrading of NPPs is a complex and diverse one, which can perhaps best be seen as a series of smaller markets. The activities covered range from routine maintenance and inspection services carried out during a regular refuelling outage, to major upgrading projects such as replacement of steam generators and reactor pressure vessel heads.

The owners of a NPP naturally aim to maximise the amount of electricity generated, and thus the income produced, by their plant. This provides a strong incentive to minimise the amount of time that the plant spends in outages. At the same time, a high standard of maintenance is required to keep the plant operating safely and efficiently, and in particular to avoid unplanned outages due to malfunctions or other problems during operation.

LWRs, which form the great majority of NPPs worldwide, require refuelling outages at intervals of between one and two years. In order to maximise plant load factor, intense activity takes place during such outages, with many maintenance and inspection activities routinely taking place in addition to refuelling. Wherever possible, additional activities such as equipment replacement and upgrading will also be scheduled to take place at the same time. Refuelling outages typically last for five to six weeks, but can be shorter or longer than this depending on the amount of additional work which has to be completed.

The effective management of outages is thus a key factor in the overall performance of NPPs, and a whole section of the nuclear industry has developed in order to provide the range of services that NPP owners require for the activities which must be completed in these relatively short periods of time. Often the on-site workforce at a plant will more than double during an outage, as contactors bring in additional specialist staff to complete specific tasks.

With many different activities going on in parallel during an outage, much effort must be devoted to planning the outage in advance and to managing the work during the shutdown period. There may be several different contractors and sub-contractors engaged in different activities simultaneously, which requires careful scheduling and efficient logistics to ensure that all activities can proceed smoothly. Indeed, the management of outages is itself a specialist service offered by a number of companies. While some NPP owners (especially those with several NPPs) keep such expertise in-house, others prefer to contract outage management to a specialist engineering consultancy firm.

Non-routine major upgrading and replacement projects may also be carried out during a routine outage, which will normally need to be extended for this purpose. For any particular plant, such activities will take place only rarely, and will represent a significant additional investment by the plant's owner. Such major refurbishments and upgrades are usually carried out to improve the reliability of the plant and often with a view to extending its operating lifetime. An additional motive may be to increase the plant's electrical output.

Market shares

Much of the activity in these markets involves the same companies that are involved in the construction of NPPs, or at least were involved in the major programmes of reactor building of the 1970s and 1980s. They include the main NPP vendors, a range of specialist nuclear engineering companies, and also divisions of some large general engineering companies (some of which have specialist nuclear subsidiaries or sections). Such companies are normally the lead contractors for nuclear projects, but they will also call on many other companies for services and equipment as required.

With the lack of orders for new NPPs in recent years, there has been considerable consolidation in the entire nuclear engineering sector. Some companies abandoned the nuclear market or sold their nuclear divisions, while some specialist companies merged or were taken over by others. The remaining companies have been mainly reliant on the business of maintaining, back-fitting and upgrading the existing reactor fleets, rather than building new NPPs. The size of these markets has increased over the years as regulatory changes have required existing NPPs to be backfitted with up-to-date equipment, and as many utilities have begun planning for life extensions of their plants. This trend is likely to continue, so strong demand for the whole range of such services can be expected to continue.

If this is combined with a significant increase in the construction of new NPPs, which will to a large extent call on the resources and skills of the same group of companies (and employees), there could be shortfalls in the availability of expertise, equipment and manufacturing facilities. If companies are increasingly able to win business in the construction of new NPPs, there is the possibility that this will deplete their ability to participate fully in the markets for services and equipment for outages and upgrading of existing NPPs. This could result in it becoming more difficult and/or costly for NPP owners to find the expertise required to complete routine maintenance and major upgrades in a timely and cost-effective manner.

However, the nuclear engineering companies which have emerged from the consolidation of the lean years are now looking forward to renewed nuclear expansion and are thus expanding their workforces and capabilities. Other engineering companies, including those which abandoned nuclear activities in the past, are also looking to re-enter these markets. As ever, markets may take some time to respond, but there are clearly signs that service and equipment providers are responding to the prospect of a nuclear revival, notably in the United States where plans for new NPP orders are progressing (as discussed in Section 5). In addition, some larger nuclear utilities which have a significant in-house capability to provide services to their own NPPs, may also be able to offer such services to other utilities.

Little detailed information is available about the market shares of individual companies, but it is clear that despite consolidation there remain a significant number of companies involved in the various sub-sectors of this market. Especially for larger projects, the involvement of the original NPP vendor or its successor company may still be preferred by the plant owner, and in some cases it may be all but essential for the provision of specialist expertise about the plant. But there are also many cases where alternative suppliers can be used and the project is open to competitive tendering. Even where the original NPP vendor is involved, in some cases it may only have a limited role as a consultant.

Nevertheless, there remain certain specialist sub-sectors where there may be no alternative suppliers or where one supplier dominates. This is more often the case for less common designs of NPP, where it may not be worthwhile for alternative suppliers to develop the necessary expertise. In such cases, the original NPP vendor may maintain a large market share.

Degree of vertical integration

As noted above, among the major providers of services and equipment for NPP outages and upgrading are the main NPP vendors and constructors. In general, such companies can expect to remain involved to some extent in future work on the NPPs which they have supplied, and they may well have a competitive advantage in providing services and equipment for their own plant designs. Such companies are also the main suppliers of nuclear fuel fabrication services, where again they may have a competitive advantage with their own designs (as discussed in Section 3.4).

Indeed, it is common for new NPPs to be supplied with an initial contract for the supply of fuel and services for the first few years of a plant's life. Such a situation cannot be considered unusual for such a complex and high technology product as a NPP, and would normally be expected by customers when they make their choice of vendor in the first place.

However, especially beyond these first few years, many NPP owners will be willing to consider alternative suppliers for at least some of the services and equipment they require for outages and maintenance. The NPP vendors themselves have often been keen to win business on other designs of NPP, and other specialist companies have developed to offer nuclear plant services to most designs of plant. In general, the competitive advantage of the original NPP vendor appears to decline after the first few years of operation, although for some activities it may never disappear entirely.

As noted elsewhere in this report, there are presently only two companies, AREVA and Atomenergoprom, able to offer a fully comprehensive range of products and services for NPPs, including uranium and other fuel cycle services. Westinghouse may also emerge as a more integrated provider as a result of partnerships with Toshiba and its other shareholders, including Kazatomprom. Such vertically integrated companies are able to offer customers for new NPPs everything from complete fuel supply to the full range of plant services. This could potentially limit competition in the markets for outage services. However, such comprehensive contracts are unlikely to last for more than the first few years of a plant's life, and it appears that they are offered at the request of customers.

Proportion of long-term contracts

As mentioned above, an order for a new NPP is likely to include some provision of services for maintenance covering at least the first few years of a plant's operation. This will include normal warranty cover, but may be extended to cover the provision of further services and equipment for a period of some years.

However, in most circumstances NPP owners are able to select contractors from a range of competing suppliers and service providers. They may choose either to manage outages in-house or to make use of an independent outage management company. In the latter case, there may be benefits in forming a longer term relationship for outage management through a multi-year contract covering several outages, so that experience gained by the contractor with that particular plant will continue to be available. In other cases, contractors may only be awarded contracts to carry out one-off tasks and provide specific equipment as required.

Major refurbishment or replacement projects would normally be the subject of a special tendering or negotiating process leading to single project contracts with one or more suppliers.

Barriers to entry

There are rather fewer companies active in the nuclear engineering market at present than was the case in the 1980s, due to consolidation and to companies abandoning nuclear activities. If the market grows in the coming years as expected there will be increased incentives and opportunities for engineering companies to enter or re-enter the market. However, nuclear projects generally require special standards to be met, and companies wishing to supply products and services for use in the nuclear industry will often require certification. Obtaining such certification, and maintaining its validity, involves some investment of time and effort in technical assessments and administrative procedures, which may prove a disincentive if the market for the company's products is small and/or uncertain.

For example, the American Society of Mechanical Engineers (ASME) sets codes and standards for nuclear engineering and issues certificates (known as N-type Stamps) for nuclear-related component manufacturing. Companies have to demonstrate their ability to meet nuclear standards to be awarded these approvals, which involves some investment on their part. Other countries have equivalent schemes. The European Union is considering adopting a common requirement for such certification, but at present each member state is responsible for its own standards.

Certain activities may require proprietary knowledge of some plant systems and technologies, which may give an advantage to the original plant vendor or equipment supplier, but almost all systems and components in a nuclear plant can be replaced with those provided by alternative suppliers. Some sensitive nuclear technologies are subject to restrictions, but this does not affect the vast majority of maintenance activities at NPPs.

Transaction costs and market segmentation

Insofar as nuclear engineering services consist of the provision of expertise and consultancy services there are few transaction costs and essentially a global market exists. In general, NPP owners have a strong financial incentive to seek out the best equipment or service provider for their needs, from any part of the world. Most of the larger nuclear engineering companies, and many smaller ones too, operate in many countries.

Even for the supply of larger components such as replacement steam generators and turbines, the potential financial advantages of having the best performing equipment installed in the shortest possible time will normally outweigh any additional transaction costs associated with geographic location of the manufacturing facilities. Although some NPP owners may prefer to deal with domestic suppliers, this is unlikely to be for purely financial reasons.

Product differentiation

The market for products and services related to maintenance and upgrading of NPPs is large and diverse. Competing suppliers in each sub-sector of the market are constantly developing and improving their offerings to gain a competitive advantage. Furthermore, for many types of product and service there are differing requirements for each design of NPP, and different NPP owners may prefer different methods for carrying out equivalent tasks.

Thus there is a high degree of product differentiation in many sub-sectors. However, this is associated with many specialised market niches and a high degree of innovation, meaning that suppliers need to be flexible in their offerings and tailor them to the needs of each customer.

Balance of capacity and demand

As discussed above, demand for products and services for maintenance and upgrading of existing NPPs has been steady or growing slowly over recent years. Although the number of NPPs has hardly increased, demand for upgrades and refurbishments has remained fairly strong. Meanwhile, much of the surplus capacity existing from the earlier period of rapid nuclear expansion has disappeared. In such stable market conditions, a rough equilibrium between capacity and demand has been established.

There are now signs that demand may increase more strongly in the coming decade, especially since much of the demand related to new NPPs also calls on the same capacities which are required for maintenance and upgrading projects. In most sub-sectors, however, there is likely to be sufficient time for the market to respond with additional capacity.

Nevertheless, constraints in the availability of supply capacity and expertise in some specialised areas is a possibility. For example, capacity to supply major replacement components such as steam generators or reactor pressure vessel heads may be limited if the manufacturing capacity is fully occupied making components for new NPPs. This may lead to some supply bottlenecks, at least for the first years of any renewed nuclear expansion.

Market alliances and supplier co-operation

Many activities at NPPs involve more than one supplier, which requires some degree of co-operation or at least co-ordination between them. In some circumstances this may extend to the formation of more formal arrangements, such as consortia, to bid for major projects. Other forms of formal co-operation include licensing agreements for the use of certain technologies, and agreements covering marketing activities in specific geographical regions.

This is a normal feature to be expected in a large and diverse high technology market with many suppliers. The formation of competing consortia combining a range of skills and capabilities is often necessary to meet the needs of customers, especially for larger projects. Many such alliances are limited to a single project and do not necessarily imply a long-term relationship between companies, which often continue to compete for other contracts.

Public goods aspects

In common with other nuclear activities, NPP maintenance and upgrading projects are subject to licensing and regulations to ensure the continued safe operation of the plant. Most plant modifications require prior approval by regulators, who are also responsible for ensuring that the work is carried out satisfactorily before the plant re-enters operation. Contractors themselves usually have to be pre-approved and authorised to work on nuclear projects.

The transfer of sensitive nuclear technology is restricted under non-proliferation controls. The international supply of technology which is considered "dual use" (i.e. which could have non-peaceful applications), will generally require a special export licence. However, in most cases the supply of products and services to existing NPPs is not affected by this. In rare cases, subsequent to the supply of a NPP, a country may become subject to more stringent non-proliferation restrictions which prevent the supply of further products and services. This was the case, for example, with NPPs supplied in the past by Canada and the United States to India.

Trade barriers and restrictions

In general, there are few formal trade restrictions which apply specifically to the international trade in products and services for the maintenance and upgrading of existing NPPs, beyond those which apply to the supply of the NPPs themselves. A few governments have a deliberate policy of developing their domestic nuclear industry and may require national utilities to procure such products and services from domestic suppliers whenever possible. This is often done in co-operation with foreign partners under a technology transfer deal which is part of the original agreement covering the construction of NPPs. While such agreements may not exclude foreign companies entirely, they are likely to restrict the scope of the products and services which are open to international competition.

In some cases, the supply of components and equipment across international boundaries may be subject to customs duties and import taxes, in common with other engineered and manufactured products.

7. IMPLICATIONS FOR COMPETITION OF PROPOSED MULTILATERAL FUEL SUPPLY ARRANGEMENTS

7.1. Overview of current proposals

At present, countries wishing to develop a nuclear power programme would normally have to rely on fuel cycle suppliers based in countries with established nuclear programmes. However, concerns about the availability of adequate supplies and the desire for energy independence may result in some countries being reluctant to rely on these established international suppliers.

The alternative of developing the full range of fuel cycle facilities domestically is unlikely to be achievable for most countries, due both to the high costs involved and to difficulties in obtaining the necessary technologies and equipment. Furthermore, the spread of sensitive nuclear technologies, particularly those for enrichment and reprocessing, would lead to heightened proliferation concerns in some regions.

With many countries now showing interest in launching a nuclear programme in the coming years, this matter is now receiving increased attention. Various proposals have been made by different countries and organisations to establish multilateral arrangements for assuring the supply of nuclear materials and fuel cycle services, while avoiding the spread of sensitive nuclear technologies. These proposals are being discussed as part of an initiative launched by the IAEA.

It is beyond the scope of this report to consider or take a view on the benefits of these proposed arrangements for addressing security of supply or proliferation concerns. However, establishing any such arrangements could potentially affect the level of market competition in the global nuclear industry, and to this extent the Expert Group has considered the possible impact of some of the broad types of arrangement currently under discussion.

For the purpose of evaluating the possible impact on market competition, the approximately twelve proposals being considered by the IAEA have been divided into three broad categories. These are described below based on the preliminary information available. The potential arrangements are then considered against the indicators of market competitiveness used elsewhere in this report.

Category 1: Stockpile controlled by an independent multilateral agency

Some proposals involve an independent multilateral agency (probably the IAEA) controlling a stockpile of nuclear material (a virtual or physical fuel bank, or a combination of the two). Users of nuclear fuel would obtain their supplies from the market through normal commercial arrangements, but the multilateral agency would act as a guarantor and arbitrator in case of a disruption of supply. To establish the fuel bank, existing supplier countries would provide the agency with physical and/or virtual reserves of LEU. This would remove or reduce the incentive for additional countries to develop their own enrichment and reprocessing capabilities.

The fuel bank would thus provide a back-up supply at competitive prices for fuel users on a non-discriminatory, non-political basis. It would be utilized when pre-determined criteria were met, such as when government action prevented an enricher from honouring commercial commitments. A physical reserve, in the form of enriched uranium hexafluoride (UF_6) or uranium dioxide (UO_2), would be under the agency's control, and would be stored at one or more secure locations, either in supplier countries or in third countries. A virtual reserve would be based on commitments by governments to make LEU available to the agency. In principle, reserves of fabricated fuel could be established, but this may not be practical because of the great variety which exists in fuel assembly designs.

There are several legal issues which would need to be resolved in order to operate such an arrangement, including the granting of consent rights by the supplier for the agency to transfer the material to user countries, as well as licensing and transport requirements. In the event that a physical reserve was held, this would require host country agreements, and possibly transit arrangements with neighbouring countries.

Category 2: Fuel supply guarantees provided by multiple supplier countries

In the framework of the GNEP, it is proposed that a consortium of nations with advanced nuclear technologies should provide other countries with reliable access to nuclear fuel using a leasing approach. In exchange, user countries would commit to forego the development of enrichment and reprocessing technologies.

According to the US Department of Energy, under such a leasing agreement, the supplier would assure fuel availability and would take responsibility for final disposition of the spent fuel, including the security and safeguards arrangements. This could potentially include taking back the spent fuel for recycling. The arrangements could apply to existing reactor designs as well as new advanced reactor types which are under development.

GNEP also aims to develop new reactor and fuel cycle technologies, including NPP designs with generating capacities appropriate for the electricity grids and industrial needs of developing countries, as well as advanced recycling fast reactors and reprocessing technologies that can separate actinides (transuranic elements) as a group rather than producing separated plutonium.

Category 3: Fuel cycle facilities under multilateral control

Proposals under this category involve the establishment of one or more international fuel cycle centres to directly provide enrichment services. In principle, this approach could also be used for reprocessing, but such proposals are less developed. Countries would own a stake in such a facility, entitling them to a share of production, but would not have access to the sensitive technologies involved.

The existing facilities of Urenco (in Germany, the Netherlands and the United Kingdom) and Eurodif (in France) provide examples of multilateral ownership of enrichment plants (although with important differences from present proposals). Urenco was established by a tripartite treaty, with entities from each country owning one-third of the company and with one plant being developed in each. Eurodif was established as a joint venture involving five countries (the host country, France, plus Belgium, Iran, Italy and Spain). The original intention was to provide enrichment services to the investing partners, but enrichment has never been supplied to Iran.

In 2007, Russia announced the establishment of the International Uranium Enrichment Centre, based on its Angarsk facility. It has invited other countries to join the centre, which will initially be supplied by the existing capacity at Angarsk, but which could be expanded if required. So far, only Kazakhstan has become a partner in the project, but others may follow. Separately, Germany has proposed the establishment of an international enrichment centre under IAEA control.

Under current proposals, governments (or approved commercial entities) would buy financial stakes in an existing or new facility, in exchange for a guaranteed share of production. This could involve conversion of an existing national facility (as with the Russian initiative) or construction of new plants in partner countries, perhaps to establish a series of regional centres. Under some proposals, such plants would have extraterritorial status, which would require new legal and political arrangements.

7.2. Assessment of potential impact on market competition

The proposed multilateral fuel supply arrangements provide a conceptual framework for developing a future fuel supply network. Only limited detail has been developed in these proposals to date; however critical points* in devising effective mechanisms for assurance of fuel supply include that the arrangements should be commercially competitive, free of monopolies, and free of political constraints. Also, back-up sources of supply should be available in the event that suppliers are unable to provide the required material or service. However, this being said, there are fundamental differences between the schemes that could impact how fuel cycle markets operate in the future. This assessment is intended to help identify the areas where the schemes may have common and divergent impacts on market competition.

Market shares

There would be little expected immediate impact on the existing international fuel market from proposals in Category 1. Only a modest amount of material is likely to be stockpiled, while existing commercial arrangements would continue in normal circumstances. However, there may be concerns that such schemes would serve to protect the market shares of existing suppliers (or supplier countries) in an expanded future market by preventing or discouraging new entrants.

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* As recommended by the independent expert group on "Multilateral Approaches to the Nuclear Fuel Cycle", INFCIRC/640, IAEA, 22 February 2005.

Category 2 schemes could serve to concentrate the nuclear markets through combined contracts for NPP construction and fuel supply (including potential spent fuel take-back services), thus excluding suppliers unable to offer the full range of services. Category 3 could also result in segmented supply markets concentrated around large regional facilities. Both these categories could also potentially serve to protect the market shares of existing suppliers in an expanded future market. However, they could also result in additional facilities being established under independent commercial control.

Degree of vertical integration

The consolidation which has taken place in many nuclear sectors in recent years, together with other forms of joint venture and co-operation, has led to the emergence of more vertically integrated suppliers. So far, this has had a limited impact on contracting practices, but many suppliers are now in a position to offer a wider range of products and services.

In principle, Category 1 schemes would be expected to have no direct impact on the degree of vertical integration. Category 2 could further encourage or even require the vertical expansion of existing suppliers to encompass both NPP construction and the entire fuel cycle (particularly if spent fuel take-back were part of the contractual package). Category 3 could also encourage greater vertical integration based on large regional suppliers.

Proportion of long-term contracts

Most fuel materials and services are currently purchased under long-term contracts, with only a small percentage of contracts generated on the spot market (~10%). In principle, Category 1 schemes could place less of a premium on long-term contracts if physical/virtual back-up supplies were readily available. However, in practice the quantities involved in creating and maintaining fuel reserves are not likely to have a significant impact on contracting practices. Indeed, they are unlikely to be comparable with the inventories that utilities presently hold, in addition to their long term contracts.

For Categories 2 and 3, long-term contracts would also continue to be of mutual interest to fuel users and suppliers. Thus, little change might be expected from current levels of long-term contracting. However, it is clearly important for competitive markets that the duration of contracts is not over-long. The ability of users to change supplier after some reasonable interval is essential if markets are to remain competitive.

This means that, following the initial choice of NPP design/vendor, customers should not be tied to the same supplier indefinitely for all fuel supply, maintenance and upgrading services. In the longer term, it may not be in the customer's best interest to forego the ability to choose among competing suppliers in the market in exchange for a guaranteed fuel supply. Different customers will have different priorities, and these may change with time.

Barriers to entry

Proposed assured fuel supply arrangements would by design serve to restrict or discourage entry to certain sectors of the future fuel cycle supply market (in particular, enrichment and reprocessing), in order to limit the spread of sensitive technologies. Thus, such arrangements might act as a barrier to entry for potential new suppliers (at least, for those based in countries without existing facilities). On the other hand, if they resulted in the establishment of additional fuel cycle facilities, operated on a commercial basis and under separate control from existing facilities, they could introduce additional competition into the market.

Transaction costs and market segmentation

As discussed elsewhere in this report, there are factors which limit supplier access to all customers. If assured fuel supply schemes were successful in making nuclear power accessible to more countries with modest up-front investment in domestic nuclear infrastructure, this could broaden and deepen the global nuclear markets. On the other hand, the development of regional suppliers under governmental ownership or control could result in strong regional segmentation of markets. In general, it will be important for competitive markets to maintain commercial relationships between suppliers and customers, and to ensure that customers are not tied to a single regional supplier.

Product differentiation

Uranium supply, conversion and enrichment are fungible commodities/services, meaning that any supplier can supply any reactor. Different levels of enrichment are required, but these are often standardised. This also means that a stockpile of LEU, containing material with a few different enrichment levels, could be used as a back-up supply for almost all reactors.

However, each reactor design uses a different design of fabricated fuel. Although more than one supplier is available for most existing NPPs, in general fuel from different suppliers is not easily interchanged. For new NPPs, fuel will often be a proprietary design and is initially supplied only by the NPP vendor or their licensees. On the other hand, fuel fabrication uses much less sensitive technology than enrichment, and plants exist in a wider range of countries. When significant new nuclear programmes are developed, additional facilities could be constructed locally or regionally.

Balance of capacity and demand

The existence of some overcapacity in any market helps to ensure competition. If nuclear power capacity expands in future, any existing overcapacities are likely to disappear and new supply will be needed. For schemes in Category 1, the existence of a fuel bank could in principle reduce the need for spare capacity. As noted above, the magnitude of such stockpiles is unlikely to be large enough to have a significant impact on the markets. Nevertheless, given that the aim is to reduce incentive for additional countries to develop nuclear facilities, the effect on competition could be negative to some extent.

With Categories 2 and 3, the impact on capacity would depend on the detail of the schemes adopted. As noted above, if the effect was to protect the market shares of existing suppliers, allowing them to expand with limited competition from new entrants, the impact on competition would likely be negative. However, if the schemes resulted in additional capacity being developed, operated on a commercial basis and under different control from existing facilities, the effect would be to increase overall capacity and potentially enhance competition.

Market alliances and supplier co-operation

In recent years there has been considerable consolidation in the NPP and nuclear fuel markets, resulting in fewer, larger, international providers. This has been supplemented by various alliances and joint ventures as the major participants have sought to broaden the range of goods and services they can offer, and extend their geographical reach. This process may have some way to run, but further major consolidation now seems unlikely in most sectors.

Category 1 schemes would be unlikely to have any significant impact on this. For Categories 2 and 3, again the impact could depend on the details of any scheme adopted. Some co-operation between existing suppliers and new entrants may be necessary for the establishment of new facilities, especially where the transfer of proprietary technology is required, but the eventual aim should be to create additional independent commercial operators able to compete in regional and global markets.

Public goods aspects

Each of these fuel supply schemes could produce legal and liability issues that might restrict the sale of materials to some customers, and which could require additional regulations for international fuel supply agreements. However, the principal objective of all assured fuel supply schemes is to protect the public goods of reducing the proliferation of sensitive nuclear materials and technologies.

Trade barriers and restrictions

Currently, there are certain trade barriers/tariffs and import restrictions imposed on some fuel cycle markets to protect domestic suppliers, e.g. imports from Russia to the United States and the European Union. Assured fuel supply schemes are unlikely to have any immediate effect on such restrictions. In the longer term, the development of assured fuel supply schemes could potentially reduce or remove the perceived need for such restrictions, resulting in more open markets. However, where countries develop nuclear programmes partly as a way to strengthen energy independence, this may result in more such restrictions. It will be important for the future competitiveness of nuclear markets that such restrictions are kept to a minimum, and are of limited duration.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Summary and conclusions for each market sector

Design, engineering and construction of NPPs

After a long period of consolidation and retrenchment due to the lack of new orders in most countries since the 1980s, this sector appears poised for a major expansion in the coming decade and beyond. Despite the prolonged market depression since the 1980s, the remaining NPP vendors have continued to develop their designs and are now offering considerably improved products to those available during the last major periods of nuclear expansion.

At least in the major markets, where there is the potential for a series of orders, there is likely to be strong competition between four or five vendors. Despite some market distortions, notably where vendors dominate their home markets, a global market with several independent and competing vendors has emerged which provides a genuine choice of supplier to potential customers. However, differences in the regulatory requirements for NPP designs between countries, which can lead to significant up-front costs for vendors wishing to enter new markets, may effectively limit the choice available to utilities, particularly in smaller markets.

In the longer term, there is the prospect of the emergence of additional important NPP vendors. The most probable of these are those who have benefited from technology transfer deals with the existing vendors, and have gone on to develop the technology further themselves and eventually reach the status of independent vendors able to offer their distinct designs on the global market. Such companies may well emerge in Korea and China. New vendors based on more innovative reactor designs developed independently of the existing vendors may also emerge, but this is less certain and is likely to take longer.

Uranium supply

The uranium market does not appear to be over-concentrated at present, and the analysis in this report indicates that it is likely to become less concentrated in the next few years as production increases in response to rising demand. There are a significant number of new uranium production facilities expected to enter operation, some under the control of existing major producers but many will be new entrants or smaller producers with growing production. Although consolidation is likely to occur as smaller producers either merge with each other or are taken over by larger producers, the trend is expected to be towards reduced market concentration. However, the possibility of a merger of two of the major producers could be a cause for concern if it led to the merged company controlling a very large share of global production.

Trade restrictions on uranium imports into the United States and the European Union have largely been in response to the availability in the market during the 1990s of significant uranium stockpiles of various types in Russia, which helped to depress uranium prices. However, the availability of such material in international markets is likely to be reduced in coming years, not least as Russian domestic demand is expected to increase. Thus the practical impact of these trade restrictions on the market can be expected to be further reduced, even if the measures themselves remain in force.

UF_6 conversion services

There are effectively only three major suppliers of UF_6 conversion services to the global market, with a fourth supplier which is mainly limited to providing uranium, conversion and enrichment as a package. From a market competition perspective, this indicates that the market is more concentrated than would be desirable. Indeed, the market has become more concentrated recently with the conversion plant in the United Kingdom coming under the marketing control of Cameco, in addition to that company's own plant in Canada. However, the alternative to this situation was that the UK plant would have been permanently shut-down. This arrangement currently extends to 2016, after which time the future of the UK plant remains uncertain.

The role of conversion plants as the main storage locations and clearing houses of the uranium market may mean that it is more convenient for market participants if there is a relatively limited number of sites. This facilitates trade in uranium as well as in conversion services. Together with the fact that conversion represents only a small fraction (around 5%) of the total cost of nuclear fuel, this means that new conversion facilities on new sites may have difficulty in establishing themselves. Present expansion plans indicate that the existing major suppliers will expand their capacity as required and little change can be expected in the degree of market concentration.

Uranium enrichment services

The enrichment of uranium uses technology which is among the most sensitive in terms of non-proliferation, which means that there are important limitations on its dissemination and use. This technology is possessed by a limited number of countries, and is entrusted by governments to only a small number of commercial operators, which inevitably limits market competition in this sector.

However, the enrichment supply industry is undergoing major changes which will re-shape it over the next ten years and beyond. The remaining older gas diffusion plants in France and the United States will be replaced by new centrifuge plants, while there is also the prospect of laser enrichment technology being commercialised. There will be at least two and possibly as many as four new enrichment plants in the United States by 2015, each operated independently by competing suppliers. The large enrichment capacity in Russia is also expected to play a larger role in the international market. These developments are likely lead to shifts in the market shares of the existing suppliers.

The prospects for the emergence of new suppliers are less certain. Small enrichment plants are in operation in Japan and China, which could potentially expand their capacity as demand for enrichment grows. Other countries, including Australia, Canada and South Africa, have shown interest in investing in enrichment capacity, possibly using equipment purchased from existing technology holders. Enrichment is one of the main issues being discussed in the context of multilateral fuel supply arrangements, where proposals include the establishment of new facilities under international control, or under the joint control of a group of countries.

Fuel fabrication services

Unlike the generic front-end services discussed above, fuel fabrication is essentially a bespoke service to prepare fuel assemblies to the exact requirements of each NPP. The design and reliability of fuel can significantly affect the overall performance of a plant. Indeed, fuel design can be considered an integral part of the design of the NPP itself. It is no accident that the original fuel suppliers for all NPPs are the NPP designers and vendors themselves, who may have a technological advantage over other fabricators for their own designs of NPP.

Hence, some NPP operators may not consider that the commercial risk involved in changing suppliers is justified by the potential savings on fuel costs, and may maintain a long-term relationship with the original plant vendor as fuel fabricator. Nevertheless, significant competition does exist in the fuel fabrication market, particularly in the United States, and switching of suppliers is not uncommon. For NPPs of more common design there may be a choice of up to three potential fabricators, and as a matter of policy some utilities consider switching suppliers every few years. There is considerable innovation in fuel design, which has led to substantial improvements in NPP output and performance. This is mainly driven by competition among fabricators.

However, while in principle each fabricator/vendor is also able to fabricate fuel for plants designed by other vendors, they will only do so where there is sufficient demand to justify the necessary investment. Thus, for operators of less common designs of NPP the number of potential suppliers may be more limited, and in some cases there may in practice be no alternative fabricator to the original plant vendor.

The fuel fabrication market has consolidated over recent years, as the main NPP vendors have consolidated. This has brought the fuel fabrication operations of several different NPP vendors (which supplied different designs of NPP) under common ownership. It now appears that the market for fuel fabrication is more concentrated than would be desirable. For some market sub-sectors there is effectively no competition.

As new NPPs are ordered over the coming years, they will be of newer designs which require new fuel designs. Initial fuel loads will inevitably be supplied by the original vendors, who will add new capacity when and where necessary. In some cases, where a large nuclear programme is undertaken, additional capacity may be provided by the licensing of fuel designs to new local fabrication plants.

However, for the longer term development of a competitive market for these designs of fuel, it will be necessary for alternative suppliers to emerge in the international market. This is a matter to which purchasers of NPPs will need to give due consideration when making their choice of reactor technology. Experience has shown that one way to ensure a choice of fuel supplier is to choose a NPP design which is being built in larger numbers, as such designs are likely to be better served by alternative fabricators. The emergence of, say, four or five standardised NPP designs worldwide would potentially encourage a competitive fuel fabrication market to develop.

Spent fuel reprocessing services

Commercial reprocessing plants are in operation in three countries (France, the United Kingdom and Russia), with a new plant due to enter operation in Japan in 2008. Much of the capacity of these plants is used to reprocess domestic arisings of spent fuel, but the three existing plants also reprocess spent fuel from other countries under contracts with foreign utilities. Most reprocessing is carried out under long-term contracts which were entered into some years ago. Several utilities which previously reprocessed spent fuel have subsequently changed policy and are now storing the fuel instead.

As the prospect of significant future expansion of nuclear power is again being considered, the potential for reprocessing and recycling spent fuel is attracting renewed interest. Some currently available NPP models (such as AREVA's EPR) are designed to allow greater use of mixed-oxide (MOX) fuel. For the longer term, the development of new reprocessing technologies is being pursued by several countries. However, along with enrichment, reprocessing technology is highly sensitive from a non-proliferation perspective, particularly if it can be used to produce separated plutonium.

An important new initiative to address this is the Global Nuclear Energy Partnership (GNEP), launched by the United States. Among other things, this aims to develop and demonstrate more proliferation-resistant reprocessing technology. Any increase in reprocessing capacity is likely to be restricted to a small number of technology holding countries, or be subject to multilateral control. The more widespread use of reprocessing is also likely to depend strongly on the adoption of new advanced reactor designs (often referred to as Generation IV designs) which will allow full advantage to be taken of the recycled materials. The timescale for the commercialisation of such designs is expected to be around 2030.

Mixed-oxide fuel fabrication services

Utilities which have had a proportion of their spent fuel reprocessed have thus acquired quantities of plutonium, which can be used to fabricate MOX fuel for use in some existing LWRs. There are presently two commercial plants in operation, in the United Kingdom and France. Fabricated fuel has been supplied to several European countries and to Japan. This has so far been a limited market, driven mainly by the desire of the utilities concerned to utilise their plutonium. MOX fuel fabrication is thus tied to the future of commercial reprocessing, and in the longer term to the deployment of advanced reactor types using fuel containing recycled materials.

Radioactive waste management and decommissioning services

In general, utilities remain responsible for the management of radioactive waste arising in their plants. One management strategy for spent fuel is to reprocess and recycle it, as discussed above. In other cases, spent fuel is simply stored at NPP sites in pools or in dry stores or casks. Eventually spent fuel and other types of waste are to be handed over to a national authority or agency responsible for its disposal. For decommissioning a similar situation exists, with decommissioning wastes being stored or sent for disposal in a national facility.

Thus, commercial activity in this sector is generally limited to the provision of services, technology and equipment. Many specialised companies are involved, as well as many of the main nuclear industry companies. In general, there is a high degree of competition and innovation in the sector. There is some overlap with the markets for maintenance and upgrading of NPPs, so some of the same considerations apply. An increase in work on construction of new NPPs may divert resources away from other sectors served by nuclear engineering firms. However, those companies dedicated to technologies and equipment for radioactive waste management are unlikely to be affected. Any increase in demand for their services as a result of nuclear expansion will take some years to materialise.

Services for maintenance and upgrading of existing NPPs

With the lack of orders for new NPPs in recent years, the reactor vendors and other nuclear engineering companies which have emerged from the resulting consolidation and contraction have been increasingly reliant on the business of maintaining, back-fitting and upgrading the existing reactor fleets. Such activities are often important in the context of extending NPP operating lifetimes and improving performance and output. With life extensions now planned for a large number of existing NPPs, the demand for major upgrading projects is likely to remain high. There now appears to be a good balance between capacity and demand in this sector with a good degree of competition in most sub-sectors of what is a multi-faceted market.

However, if there is significant increase in the construction of new NPPs in the coming years this situation could change. Construction of new plants will often involve the same companies as are involved in the maintenance and upgrading sector. It could potentially become more difficult to find competing suppliers able to undertake both routine maintenance tasks and larger upgrading projects in a timely fashion. When considering the industrial capacities needed for an expansion of nuclear power, regard must be given to the capabilities needed to maintain and upgrade existing NPPs.

8.2. Supplier dominance of market sectors and vertical integration

The major suppliers in each of the main market sectors discussed above, and their approximate market shares, are set out in detail in the relevant sections of this report; Table 17 shows a summary of the major suppliers in each sector, classified according to the level of market share. This indicates that the most concentrated sectors are enrichment and fuel fabrication, with in each case one supplier having over 30% of the market and others in the 20% to 30% range. Reprocessing is also a concentrated market, although this is a smaller and less well-developed market than the other two.

Table 17. **Summary of major suppliers in nuclear industry sectors by approximate market share**

Market sector	Share > 30%	30% > Share > 20%	20% > Share > 10%
NPP construction*	—	AREVA Westinghouse	Atomenergoprom General Electric
Uranium supply	—	Cameco	AREVA Atomenergoprom Rio Tinto
UF_6 conversion	—	AREVA Atomenergoprom Cameco	ConverDyn
Enrichment	Atomenergoprom	AREVA USEC	Urenco
Fuel fabrication	AREVA	Westinghouse	GNF
Reprocessing	AREVA	JNFL NDA	Atomenergoprom

* Including consolidated companies, based on all operating NPPs.

However, the table also illustrates that no sector in the front-end of the fuel cycle has a single company with an overwhelming dominance, with each having at least four competing suppliers. The analysis in this report found that the largest actual market shares in any sector were just over 30%, and no indication was found from presently available information that these shares are likely to increase significantly as the sectors expand over the next ten years. Indeed, in some sectors, notably uranium supply, it appears that the market may become less concentrated over the coming years. In the fuel fabrication market, given that fabrication for a new NPP is usually supplied initially by the NPP vendor, future market shares will be shaped to a large extent by the market for new NPPs. It is likely to take time for a competitive market to emerge for fabrication of fuel for new NPP designs.

In the market for the design, engineering and construction of new NPPs, it is difficult to assess the future market shares of the various vendors, as this will depend on their relative success in winning future orders. However, it is clear that in most regions there is significant competition between at least three or four major suppliers, each of which is offering attractive and competitive NPP designs. In this, the NPP market compares favourably with certain other engineering-based industries with complex high-technology products, notably the aerospace industry. Early indications are that each major NPP vendor will win a significant share of new orders over the next decade. In the longer term new suppliers may also emerge, at least in regional markets.

Table 18. **Summary of vertical integration across major nuclear industry sectors for selected companies**

Market sector	AREVA	Atomenergoprom	General Electric	Westinghouse
NPP construction & maintenance	Yes	Yes	Yes	Yes
Uranium supply	Yes	Yes	No	No*
UF_6 conversion	Yes	Yes	No	No
Enrichment	Yes	Yes	Planned	No
Fuel fabrication	Yes	Yes	Yes	Yes
Reprocessing	Yes	Limited	No	No
MOX fuel	Yes	Limited	No	No

* Kazatomprom, a uranium supplier, owns 10% of Westinghouse.

Table 17 also illustrates that several companies have a significant share of more than one sector, i.e. there is a degree of vertical integration across several of the market sectors. The main vertically integrated companies and the sectors in which they operate are shown in Table 18. Insofar as such companies supply nuclear equipment, services and materials as a package (for example, the supply of a NPP in conjunction with a long-term contract for uranium supply and fuel cycle services), this may lead to a reduction in competition in some sectors. In particular, other fuel cycle companies (which are not also NPP vendors) may be at a disadvantage, as might NPP vendors which could not also offer the full range of fuel cycle services.

To date, such comprehensive arrangements are rare, with most customers preferring to contract separately for each service, at least beyond the initial years of a new NPP's operating lifetime. However, in future some customers may prefer the perceived security of receiving a complete package of services from a single large supplier. So far, only AREVA and Atomenergoprom can be considered as fully vertically integrated, but if comprehensive provision is preferred by some customers, it is likely that others will increasingly try to position themselves to meet this requirement.

8.3. Implications of proposed multilateral fuel supply arrangements

Assured multilateral fuel supply arrangements involving the establishment of one or more fuel banks (Category 1 in Section 7) would be expected to closely resemble current market conditions, and would not be expected to have a significant impact on international nuclear markets. However, they could potentially serve to protect the market shares of existing suppliers and to discourage new market entrants in some sectors. On the other hand, some existing trade restrictions could be removed, giving suppliers access to additional customers.

Arrangements in involving guarantees provided by supplier countries or the establishment of multilateral fuel cycle centres (Categories 2 and 3) could potentially result in nuclear infrastructure remaining concentrated in a limited number of supplier countries. These arrangements would require user countries to enter long-term partnerships with supplier countries or participate in multilateral centres in order to secure fuel services, and to forego their own fuel cycle programmes. Such ties could reduce the ability of customers to choose from competing suppliers in the market.

Category 2 and 3 arrangements could also lead to more vertical integration in the industry, particularly if orders for new NPPs were coupled to fuel leasing and take-back. However, they could also be structured to encourage the establishment of additional fuel cycle facilities under independent commercial control, which could add to overall supply and increase competition. In addition, as with Category 1 arrangements, some existing trade restrictions could be removed and supplier access to customers increased.

Two additional important points must be kept in mind. Firstly, many of the details of the proposed fuel assurance arrangements have yet to be developed, so it is difficult to assess exactly how they will impact market competition in the nuclear industry. Secondly, future markets could function using a combination of more than one of the arrangements discussed. Market competition concerns could arise over the dominance of one mechanism over the others, and their overall influence on free market mechanisms.

The analysis here and in Section 7 provides a first step in understanding the market implications of multilateral fuel supply arrangements. Further evaluation of the proposals may be warranted when additional details have been developed. The unknowns to be further refined include: mechanisms for contract transfers among suppliers in case of a contract disruption, the IAEA role in managing a fuel bank, the development of contracts that link NPP sales with fuel cycle supply assurances, and the role of third-parties in providing storage of fuel supplies and of spent fuel.

8.4. Key findings and recommendations

- Competitive markets for the supply of goods and services for the construction, operation and fuelling of nuclear power plants are an important factor in ensuring the overall competitiveness of nuclear power, thus helping its benefits to be more widely spread. Governments should encourage and support competition in these markets, and actively seek to prevent concentration of market power where it unduly limits competition.

- An important policy aim of some national nuclear programmes is the development of a domestic nuclear capability. This may necessarily involve some protection of infant industries, with national investment focused on a single supplier to avoid duplication. However, care should be taken not to permanently exclude competitive pressures, which should be allowed to strengthen as market and industrial sectors mature.

- While longer term development and demonstration of new nuclear power technologies may require government support and funding, competition is a great spur to innovation and technological development, helping to improve the products and services available. As fledgling technologies mature and reach the stage of commercial deployment, they should be increasingly subject to the competitive pressures which will allow them to achieve their full potential.

- Strong non-proliferation controls on sensitive nuclear materials and technologies are vital for the existence of open and competitive global markets in the nuclear industry. Such controls will necessarily involve some market restrictions and limitations. Nevertheless, non-proliferation controls are consistent with the development of new capacities by competing suppliers to meet the growing requirements of nuclear programmes around the world.

- Other restrictions and tariffs on international trade in goods and services for nuclear power plants can unnecessarily add to the costs of nuclear power. Governments should aim to eliminate or reduce them to the extent possible.

- The best assurance of supply of nuclear fuel and other essential goods and services to NPPs worldwide is the existence of a geographically diverse range of independent suppliers competing on commercial terms in all market sectors. Governments should seek to create the necessary legal and regulatory frameworks in which such a situation can develop. Furthermore, the harmonisation of such frameworks between countries, especially for the approval of new NPP designs, would increase customer choice and enhance competition in nuclear markets.

Appendix

LIST OF EXPERT GROUP MEMBERS

Belgium	Mr. Yvon VANDERBORCK	Belgonucléaire
Canada	Mrs. Penny BUYE	Cameco Corporation
Czech Republic	Mr. Radim VOČKA	Nuclear Research Institute
	Mr. Lubor ŽEŽULA	Nuclear Research Institute
France	Mr. Mehdi DAVAL	Commissariat à l'énergie atomique (CEA)
Germany	Mr. Ernst Michael ZÜFLE	Westinghouse Electric Germany
Japan	Dr. Koji NAGANO **(Co-Chairman)**	Central Research Institute of Electric Power Industry (CRIEPI)
Korea	Mr. Whan-sam CHUNG	Korea Atomic Energy Research Institute (KAERI)
Netherlands	Mr. Gert C. VAN UITERT	Ministry of Economic Affairs
United States	Mr. David SHROPSHIRE **(Co-Chairman)**	Idaho National Laboratory
	Mr. James NEVLING	Exelon Generation Company
European Commission	Mr. Zsolt PATAKI	Euratom Supply Agency
Invited Expert	Mr. Marc GIROUX	AREVA NC (retired)
Invited Expert	Mr. Adrian COLLINGS	World Nuclear Association
Secretariat	Mr. Martin Taylor	OECD/NEA

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Market Competition in the Nuclear Industry

Nuclear power plants require a wide variety of specialised equipment, materials and services for their construction, operation and fuelling. There has been much consolidation and retrenchment in the nuclear industry since the 1980s, with the emergence of some large global nuclear companies. Electricity market liberalisation in many OECD countries has meanwhile placed nuclear plant operators under increased competitive pressure.

These structural changes in both the producer and consumer sides of the nuclear industry have had implications for the level of competition in the nuclear engineering and fuel cycle markets. With renewed expansion of nuclear power now anticipated, this study examines competition in the major nuclear industry sectors at present, and how this may change with a significant upturn in demand.

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