The total world forested area is approximately 3.9 billion hectares (Bha). This represents 30% of our land surface area. 25% of this forest area is within Europe, if the whole of the Russian Federation is included. In contrast, only 127 Mha of the European Union's (EU) 323 Mha is forest cover (39%) varying from 10% in the UK up to 50-60% for Austria, Finland and Sweden. Scotland's 16% forested area is rising, and is now the highest for at least three hundred years. 85% of EU forests are considered semi-natural, with 10% as intensively managed formal plantations and the remaining 5% natural. The area of EU plantation forests is less than for Japan alone, or for southern US pines. EU forests are predominantly high coniferous uplands, with 55 Mha (43%) being in Sweden and Finland. Hardwood plantations consist of poplars, birches, and more recently, willows for fuel biomass. Total EU harvested wood is estimated at 287 Mm$^3$ for 1997 (FAO 1999, 2001; Sedjo, 2001).

The EU's 372 million inhabitants include a workforce of 166 million and a gross domestic product (GDP) of €7T in 2000, or 65% of the USA figure. Forestry employs 700,000 people, or 7.9% of EU agricultural employment, with a further 3 million employed in wood and paper processing. This sector is more valuable to the EU economy than the chemical and mechanical construction sectors combined, at €228B, or 3.3% of EU GDP. The EU has an average timber and forest products deficit of at least $8B (Fenning and Gershenzon, 2002).

Forest industry trends affect all of European forestry

Plantation forestry in Europe has existed for at least the past 300 years. European objectives in these intensively managed areas have included wood for fuel, construction and warfare, recolonising lands laid bare by an expanding human population and indirectly, producing food. Until about 1950, the forest industry was concentrated in the northern hemisphere with spruce-pine-fir (SPF) resources. Industrial forestry for lumber, pulp and paper spread to Canada and the United States also with spruce, the southern pines, Douglas-fir, and later Populus species. Experimental planting of exotics began in the southern hemisphere about 100 years ago, with pulp mills and production forestry commencing 50 years ago. Since then emphasis for plantation forestry has shifted from the northern hemisphere to the tropics and subtropics on either side of the equator, and even to the warm temperate climates of New Zealand, Chile and South Africa (Kellison, 1999; 2002).

The shift in production forestry and in wood-based manufacturing to the lower latitudes has been caused by the adaptability of exotics, such as the long-fibred pine species of the southern USA and Mexico, and the short-fibred acacia and eucalyptus
of Australian origin (White, 1999). In their new environment wood yields are two to five times those in their indigenous environment. Tropical rotations are a fraction of those in the temperate and boreal zones. One plantation of 31,000 ha in Sao Paulo State, Brazil, has an average growth rate of 41 m³/ha/yr at harvest age of six years, enough for a captive supply to source a 700 tonne/day pulp mill. For an indigenous spruce-pine forest in Scandinavia, with a typical growth rate of 2 m³/ha/yr on a rotation of 60 years or more, 10-20x this area would be needed to support a similar sized pulp mill.

**The greatest opportunity for large scale application of forest biotechnology rests with fast-growing, short-rotation tree crops.**

Regardless of the desired attribute, research costs for tree improvement, whether by genetic modification (GM) or classical means, would be more quickly recovered from short-rotation crops. This has lead to every large pulp and paper company in the world investing in plantation forestry in the tropics and subtropics including: International Paper Company in New Zealand, Australia and Brazil; MeadWestvaco in Brazil; Stora Enso in China, Portugal and Brazil; UPM Kymmene in China and Uruguay; Sappi in South Africa and Ususu; Mondi in South Africa and Tanzania, ENSE in Spain and Uruguay.

Forest biotechnology can play an important part in satisfying future demand for wood and wood products, whilst also contributing to the ongoing development of the forest sector, as well as conserving our forest heritage, through national forest parks, preserving heritage trees and maintaining the amenity value of European landscapes. This Challenge Document raises some of the important issues surrounding the potential contribution of European forest biotechnology to these processes, by addressing three questions of crucial importance to the future of Europe's forests.

1. **What is the likely status of forest biotechnology research, development and application at the present and over the coming decade within Europe?**

   Forest biotechnology research within Europe is grouped around three main themes:

   - Improving product quantity and quality
   - Forest genomics & proteomics
   - Understanding the biotic and abiotic stress responses of trees.

   Amongst the key drivers of forest biotechnology research in Europe are EU research programmes such as Framework 6, currently being implemented, national initiatives and industrially sponsored research. With the exception of EU programmes, often with public and private sector partnerships, relatively little international coordination of forest biotechnology research activities takes place. This is unfortunate, and hampers European progress, in the face of severe competition from elsewhere. The role of the International Union of Forestry Research Organisations and the European Forestry Institute (IUFRO, 2002; EFI, 2002) in promoting consensus research activities, reporting on progress and sharing technical information is important in helping to overcome these limitations.
Forest productivity and timber quality is being improved by classical breeding and marker aided selection programmes throughout Europe. Forest biotechnologists are beginning to address the ‘domestication deficit’ compared with crop plants, whereby trees lag thousands of generations behind the annual food crops (Sederoff, 1999a). Biotechnology is contributing to this by identifying quality traits earlier and by attempting to speed up breeding cycles using genes from *Arabidopsis*, or their homologues (Pena and Seguin, 2001; Vahala *et al.*, 2001). Advances through micropropagation, somatic embryogenesis (Bozhkov *et al.*, 2002) and improved rooting techniques are also making it easier to get larger numbers of elite genotypes into the forest. Together with initiatives to convert marginal farmland to woodland, these will stimulate further improvements.

Addressing the domestication deficit will be easier with greater understanding of the genomes of economically important European trees such as poplar, sitka and Norway spruce. European advances are being made through expressed sequence tag (EST) databases with poplar (Swedish *Populus* EST Database, 2002) and through EU funded programmes including the European Forest Genomics Network, allied to national genomics initiatives, for example in Spain and trans-national projects aimed at producing ultra-high density maps of conifers (BIOFOR 2002). Wisely, European forest biotechnologists are cooperating with already established EST and genomics projects such as the Pine Mapping Project and the $28 million US Poplar Genomics Initiative. This makes sound biological as well as financial sense, due to the high degree of homology between different pine, or spruce genomes. Scandinavian, German and French labs are likely to be in the vanguard of European forest genomics efforts over the coming decade (Plomion *et al.*, 2001; Baucher *et al.*, 1998) whilst gaining from bioinformatics technology transfer from human genome initiatives. Genomics programmes to identify quality related traits as early as possible in tree development will be of value in speeding up breeding cycles and reducing the need to plant out and grow on all of the progeny from crosses (Sederoff, 1999b). Proteomics developments will enhance this trend, as understanding of interactions between proteins, and between proteins and the environment increases, linking gene discovery with function and altering growth characteristics.

Understanding responses to biotic or abiotic environmental and physiological stresses has long been recognised as vitally important to controlling development. This is especially important for trees, with their potential contribution to ecosystems for hundreds of years, and for short rotation coppice species where balancing biomass with reproductive potential is essential. Physiological responses can be manipulated in trees to stimulate somatic embryogenesis, in turn revealing more about ontogeny (Bozhkov *et al.*, 2002); to influence production of metabolites, including lignin content and wood properties (Pilate *et al.*, 2002); and to modulate reproduction. In the coming decade, enhanced understanding of environmental effects and the effects of genome-environmental interactions upon growth and development will become more important in European forest biotechnology. The power and reach of this new understanding will be all pervasive, stretching beyond simple control of development into the areas of forest conservation and heritage trees. Inducing and controlling juvenility of rare or threatened tree species from unusual habitats, or trees of cultural significance will become increasingly important (Benson, 1999). The EU has recently announced plans for an ambitious ‘Forest Focus’ programme, to protect Europe’s forests from the effects of attacks by parasites and diseases, whilst allowing greater monitoring of forest fires, air pollution and climate change impacts.
on forest ecosystems. This complements EU policies on biodiversity, carbon sequestration and soil protection (European Parliament, 2002), requiring greater knowledge, understanding and sensitive application of sustainable forest management tools to be effective. This raises the importance question of how best to sustainably manage Europe's forests.

What is the most appropriate balance between exploitation and conservation for Europe's forests?

How can biotechnology best contribute to forest conservation?

Forest biotechnology can readily contribute to the development of each of these three main themes over the coming decade. A key issue for European forest biotechnology over the next decade is the potential contribution of genetic modification to these developments.

Are GM trees acceptable in Europe now or in the coming decade?

Forest productivity and wood quality can undoubtedly be modified by GM technologies. Lignin contents and pulp processing properties have already been modified for environmental and economic advantage (Pilate et al., 2002). This approach could be applied on a large scale within Europe's forests, reducing energy costs and environmental pollution from pulp processing. Realising these benefits from functional tree genomics requires generation times to be reduced, perhaps even to as little as the 6 mths obtained in citrange (Pena et al., 2001). Protecting Europe's trees from threatening and yield reducing pests and diseases such as Dutch elm disease, alder die-back, oak decline and chestnut blight becomes more achievable when anti-pathogen genes can be transferred to and suitably regulated in elite genotypes (Gartland et al., 2001). It is therefore timely that Europe is currently debating the conditions under which deployment of GM plants might be acceptable.

European Forest Biotechnology Potential

Forest biotechnology can improve the economic performance of Europe's forests by improving quality or yields. Examples include growing short-rotation crops of short-fibred species, including poplars in Italy, France, Belgium, Holland; eucalyptus in Iberia, France; willows in Sweden, Ireland, Scotland; birches in Sweden and Finland. These opportunities to incorporate biotechnology into forest plantations have yet to be realised. The potential of Eastern Europe's forests to contribute to forest trade should not be ignored. Plentiful supplies of labour and land for forest industries, together with relatively light regulatory burdens make Eastern Europe an attractive proposition for sighting or relocating pulp and paper mills. Additional value can also be gained across Europe from non-fibre uses such as bioremediation, conservation of threatened and endangered species, preservation of historically important and long-lived trees (Gartland et al., 2000; Mann and Plummer, 2002), tolerance of drought, wind and chemical stresses, urban forestry, control of invasive plants, and propagation of selected tree species for high-value products such as biomedicines and functional foods (Guerinot and Salt, 2001; Richardson, 1998;). These opportunities include human serum albumin, vaccines, cancer therapeutics, functional foods and nutraceuticals such as Benecol®, obtainable from genetically modified and conventionally grown trees. Within Scotland, a number of universities and research institutes have substantial forest biotechnology research programmes.
If forest biotechnology is to demonstrate its utility and public acceptability in the coming decade, it must learn from the myriad mistakes made by agricultural biotechnology, and engage with the public by being open and transparent. The work of bodies such as the Institute of Forest Biotechnology, which "works for societal, ecological and economic benefits from appropriate uses of biotechnology in forestry worldwide" will facilitate and progress this engagement (Burke, 2001).

Can forest biotechnology be shown to be working for the benefit of society?

2 What are the key broad issues likely to shape the nature and extent of forest biotechnology research, development and application in Europe over the next decade?

Regulatory, environmental, cultural & public and ethical issues will shape the future of forest biotechnology in Europe. Whilst many of these issues are relevant to trees in similar ways to food crops, there are also many issues specific to forest biotechnology.

Regulatory Issues-
Since 1990, deliberate release of genetically modified trees into the environment has been governed by Directive 90/220/EEC within European Union Member States. National legislation implementing 90/220/EEC requires provision of a full risk assessment and details of appropriate safety and emergency response measures, prior to approval being granted. Approximately 43 deliberate releases of GM trees have taken place since 1990 (see Appendix 2). All Member States can comment within the 90/220/EEC process. From 17 October 2002 a new Directive 2001/18 EC on the deliberate release into the environment of genetically modified organisms provides a revised generic framework within the EU. Member States have recently been consulting on national legislation implementing this Directive (Scottish Executive, 2002). Directive 2001/18 EC aims to protect human health and the environment, whilst allowing commercial (or Part C) releases, and Part B releases for any other purpose, including research. Whilst responsibility for Part B (non-commercial) decision making rests with each EU Member State, Part C (commercial-scale) applications are made to one Member State, before a collective decision is taken by all Member States and the European Commission. Any such decision would apply to all Member States. The new Directive introduces compulsory and harmonised principles of environmental risk assessment (ERA) to ensure consistent decision making; improved management of possible longer term, indirect, delayed and cumulative effects on the environment and wildlife; mandatory post-market monitoring of GMO products for unanticipated environmental effects; revised public consultation and information requirements; and increases predictability and transparency for reaching decisions on GMO releases, including resolving differences between Member States. Amongst the practical consequences of Directive 2001/18/EC are increased stringency for the ERA, and a requirement to identify and evaluate potential environmental damage (including human health) be it direct or indirect, immediate or delayed. Antibiotic resistance markers (ARMs) will be phased out from released GMOs, by 2004 for Part C (commercial) and by 2008 for Part B
consents. The Directive applies to ARMs "that may have an adverse effect on human health and the environment", potentially allowing ARMs with a significant history of safe-use in the environment. Ultimately, European Courts will decide whether the nptII gene used to convey kanamycin resistance, has any adverse effects, probably based on the 3.5 trillion GM plants already released (Stewart and Wheaton, 2001). Release consents will hereafter also be time-limited within the EU, and capable of revocation under a 'safeguard' principle in the event of significant new information becoming available, at any time. National legislation within Member States may differ on the extent of release application data made available to the public, including for example specific map reference information within the UK, and a common 90-day timetable for normally granting or refusing consent will apply across the EU. The new Directive is intended to overcome the significant impasse which has applied to release applications across the EU for several years.

International factors regulating trade in GM trees and GM wood products include TRIPS (Trade Related Aspects of Intellectual Property) requiring all countries to legislate for effective protection of plant varieties. Further World Trade Organisation (WTO) rules allow Trade Related Environmental Measures (TREMS) for environmental protection purposes, but these are unlikely to permit banning imports of GM timber or products solely on the basis of the use of GM in the production process. Invocation of the WTO Disputes Procedure would almost certainly follow any such banning of forest products on this basis, although many countries have invoked plant health related restrictions on tree or timber imports, for example to protect against further spread of the Sudden Oak Death pathogen Phytophthora ramorum on Californian timber.

One feature of European regulation on GMO releases is the near universal use of timescales optimised for agricultural crops. The timescales included may be very difficult for GM trees, with their extended development time and juvenile phase, to comply with. This may reflect the relative importance placed upon trees c.f. agricultural crops by national governments. Whilst adjustment to the EU regulatory regime is already taking place in EU accession countries such as the Czech Republic, Slovakia, Poland, Hungary and Lithuania, alternative regulatory frameworks exist in the non-EU European countries with large forest areas, such as the Baltic States and the Russian Federation. The dialogue and debate between NGOs, industry and government is likely to take a different route in these countries.

How will the potential deployment of GM trees in European countries outwith the EU be regulated?

Environmental Issues-

A long juvenile phase, prior to reproductive maturity is a feature of many commercially valuable trees. Poplar, for example, rarely flowers in less than eight years. Trees can reproduce for many decades, requiring long term monitoring of their potential for gene spread to unmodified plants over an extended radius c.f. food crops. Pine pollen, for example, can travel up to 600 km. Potential concerns over sterility and field containment have been raised widely, whilst biotechnological approaches to constitutive or inducible male sterility are not yet totally reliable (Daniell, 2000). For pulp, paper and many timber pilot project purposes, simple grafting to unmodified main scions and careful management has been proposed. In
some species, seed production is limited in many European environments, although local spread may remain possible through suckering. Seed forming potential is a double-edged sword with respect to GM trees, as if seeds are formed, potential concerns exist over the ability for introduced genes to geographically spread, whilst if no such seeds are formed, potential concerns over possible effects on complex forest ecosystem food webs are raised. Sterile seed production may overcome this potential concern. Similar questions have been raised over alterations to physical properties of trees such as reduced lignin content possibly leading to faster wood decay and perturbation of fungal communities. Recently Dale et al. (2002) have concluded that the impact of free DNA of transgenic origin upon is negligible when compared with the total amount of free DNA in the environment. Furthermore, these authors failed to find any compelling arguments to demonstrate that GM crops are innately different from non-GM crops. Each new GM tree application should be risk assessed individually, in the intended environmental niche.

_In what ways do GM trees differ from non-GM trees?_

Concerns also exist over the potential spread of herbicide resistance to other species. Whilst there are doubts over the large scale use of herbicide resistant trees in Europe, any such spread may not be noticed until herbicide application. Ascertaining the effects of escaping herbicide or insect resistance genes upon adjacent species fitness requires further research. Perhaps more important, however, is whether gene spread from GM trees to other species will lead to any significant environmental damage, or significant biodiversity effects. There are many views on what constitutes biodiversity, and the scale upon which biodiversity should be considered. This applies in particular to the uncertain relationship between potential indicator species and total biodiversity, especially so in complex ecosystems like forests. Lindenmayer et al. (2000) have proposed a series of structure based alternative indicators, based on scale, from the simple stand up to landscape level. These reflect the structural complexity of stands, species composition, connectivity between structures and overall heterogeneity. Boyle et al. (2001) have reaffirmed this concept embracing five forest scale levels, from stand to forest, watershed, landscape and regional scales.

Within Europe, plantation forests have existed for more than 300 years, and are recognised as harbouring most of forest biodiversity (Nature Conservancy Council, 1991; Johnson and Kirby, 2001), especially if replacing farmland. Worldwide, more than 185 Mha of plantation forests exist (FAO, 2000; Peterken, 1993). As the European Union’s Common Agricultural Policy lurches towards inevitable reform, converting low grade farmland into forests has never been more needed, to aid wood productivity and protect fragile rural economies. If sensitively managed, plantation forests may allow pressures on old growth forests to be reduced. In Central and Eastern Europe, the need to relieve pressure on old growth forests is intense and plantation forests perhaps including GM trees may play a valuable part in balancing productivity needs with maintaining biodiversity. The need for massive new forests in countries like Bulgaria and Portugal has been recognised and is being acted upon by environmental groups (Forests for Life, 2002). If deployed on a large scale, GM plantation forests may be combined with refuges for non-GM trees, linked by rides to overcome any potentially adverse biodiversity effects (Johnson and Kirby, 2001). These might also be adjacent to, but not replacing old woodland areas, likely to be rich in biodiversity (Peterken and Game, 1984, Mellin, 1995). Linking these biodiversity reserves and applying multiple conservation strategies at
different scales across Europe, can spread the burden of risks from production oriented GM forestry (Lindenmayer et al., 2000).

Analogies with invasive or weedy plants have often been used to denigrate the potential benefits of GM trees. Considerable evidence refutes the concept of GM trees being exotic introductions (Hancock and Hokanson, 2001). Unlike many exotics which become invasive when introduced into a new area, trees are generally poor competitors c.f. existing weeds. Additionally, GM trees tend to be modified for one, or at most a very few traits, making the comparison with invasive species bringing thousands of new genes to a situation inappropriate. Rather, each potential GM tree release should be assessed against well-established criteria for determining colonizing ability (Baker 1965, 1974). Of eleven GM trees species released in N. America assessed against these weediness traits, none were found to exceed randomly selected non-weeds (Keeler, 1989).

Is it appropriate to predict transgene release risks by considering the phenotypic traits introduced, any fitness effects and the overall invasiveness of the GM tree species?

This is a logical corollary of substantial equivalence, and appears to be borne out by independent analysis. Considering the biological fitness effects of the introduced trait, rather than the trait production process, has been acknowledged as a constructive way forward in forming risk assessments for GM trees (Johnson and Kirby, 2001).

The potential for introduced gene expression to cease, via gene silencing, has also been raised as a possible concern for GM tree deployment. The site of gene insertion may be a relevant consideration in this regard, but until more is known about the influence of sequence context upon modulation of gene expression and expression stability, this cannot be adequately resolved. Similar potential concerns relate to the risk of other unexpected effects, which by their very nature, are unanticipated. Whilst the long lifespan of trees c.f. food crops must be noted, there is no substantive evidence that gene expression in GM trees is any less stable than in unmodified similar tree genotypes. It is more productive to consider these aspects from a 'relative risk' perspective when compared to unmodified trees.

Regional variations in environmental conditions and the need to avoid genetic monocultures are likely to be significant factors in any large scale deployment of GM trees within Europe. Lindgren (2001) has suggested that as many as 50 differently adapted breeding populations for conifers in Sweden alone, requiring many different genotypes to be genetically modified. Strict regulation of monocultures means many different transformation events will need to be produced prior to field testing and ultimate deployment. These two factors will slow down any trend towards deployment of GM trees within Europe.

What is the role of forest ecosystems in carbon sequestration and dealing with climate change?

The relationship between climate change due to anthropomorphic CO₂ emissions, and the ability of forests to sequester carbon is a controversial one, because the limited available data can be interpreted in many ways.
Amongst the key issues which all forestry policies and efforts to reduce global warming must address, regardless of individual attitudes to GM trees or forest biotechnology are:

1. Recent evidence that up to 20% of the total CO$_2$ increase is due to forest destruction alone (Valentini et al., 2000).

2. The total rise of atmospheric CO$_2$ levels has been ~30% less than anticipated by climate models (Wolfsy et al., 2001), which has been recently attributed to a combination of re-afforestation activities in Western Europe and North America, and to the previously unrecognised carbon sequestering abilities of mature forest soils worldwide (Valentini et al., 2000).

3. Although immature forests are strong carbon sinks due to the photosynthetic growth and the laying down of increasing gross quantities of wood, once a forest matures, sink capacity is likely to be reduced. Carbon sequestration as wood in mature or ancient forest is in equilibrium, while some further sequestration continues into forest soils (Schulze et al., 2001).

4. When mature or ancient forest is harvested, however, the bulk of the carbon sequestered in the soil is rapidly released due to its continuing respiratory processes, while harvested timber has an approximate half life of 15 years, before releasing its carbon back into the atmosphere (Wolfsy et al., 2001). Fast rotation plantation forests such as GM poplars, pines or spruces, are probably carbon neutral overall, while mature or ancient forests are weak but consistent sinks, and contain substantial reservoirs of fixed carbon best left undisturbed.

5. Using non-wood products (e.g. steel, concrete, bricks, plastic and the burning of fossil fuels for heating and cooking) release 9-30x more CO$_2$ than wood (Sutton, 1999). Overall, utilising more wood in place of non-renewable resources, is likely to ease global warming problems - provided the wood is produced in an environmentally responsible manner, that does not contribute to further forest loss or degredation.
How can forest biotechnology support renewable energy?

Wood has been used as a source of energy by humans since pre-historic times. Although the data is uncertain, most wood harvested globally is probably still used for domestic cooking and heating by people living in developing countries. However, if sufficient quantities of wood can be produced in an environmentally responsible manner, more of Europe's energy could be provided via clean burning wood-chip power stations. This approach is widely used in Scandinavia, and increasingly applied in the rest of Europe, using willows and poplars. Legislation requiring greater use of non-fossil fuels such as biomass chips, is promoting this trend. Few other renewable energy sources can match the 24 hour a day, year round supply flexibility of wood. Plantation forests of short rotation trees, perhaps with increased lignin content and calorific value increased by GM, could greatly increase the supply of sustainably harvested biomass chips, and together with careful control of moisture content and combustion techniques, such as gasification and pyrolysis, release significant amounts of energy without substantial environmental damage.

Cultural and Public Issues-

Forests have always been important to mankind, providing shelter, fuel, food, recreation, helping to maintain complex webs of biodiversity and reduce greenhouse gases. Perhaps due to their longevity, trees bring pleasure to generation after generation. GM plants in contrast, are seen by many Europeans as potentially being imposed upon them by global corporations. Lack of public trust in science and especially non-medical applications of biotechnology, is evident after the reassuring messages given by various governments prior to deaths from new variant Creuzfeld-Jacob disease in the UK and other countries and numerous similar episodes leading to a technophobic media-frenzy across Europe. Media stimulation and manipulation of public hysteria through GM scare stories should not be overlooked. Campaigns such as 'Frankenstein Forests' have led to increased sales or audience share when reporting tidings of woe or doomsday scenarios, but similar coverage is not given when, independent evidence refuting some of the wilder claims becomes available (e.g. Monarch butterflies; USDA, 2002). The role of some NGOs in promulgating often sensational claims in pursuit of new members or fundraising campaigns, alongside legitimate potential concerns through web sites and lobbying campaigns, has undoubtedly affected European public opinion towards GM issues adversely, although public interest in the topic may be waning as the threatened environmental pandemics in countries embracing GM technologies have failed to materialise.

In Holland, the Terlouw Commission spent $5M on public consultation and debate trying to identify the conditions under which the Dutch public would accept GM foods. As a consequence of this public debate, or of the withdrawal of participation by 17 environmental NGOs part way through the process, a significant increase in public acceptability of GM foods has taken place (van Lelyveld, 2002; Commissie Terlouw, 2002). Philosophers have observed that NGOs on the whole tend to adopt categorical rather than flexible stances on GM issues, insisting that GM foods for example, can never be acceptable under any circumstances (de Wilde, 2002). The withdrawal of Dutch NGOs en bloc from the Terlouw Commission process is a good example of this. In the UK, where a voluntary moratorium on commercial scale GM planting exists, ostensibly until farm scale field trials are concluded and analysed in 2003, a public debate is now being undertaken, in part as a result of the valuable
role played by the Agriculture & Environment Biotechnology Commission (AEBC, 2002). This type of debate is being repeated throughout Europe.

**Can public trust in scientists be re-established?**

In some European Union Member States, resistance to the central role of Brussels may also restrict public confidence on commercial planting of GM trees, as Directive 2001/18/EC requires community-wide decision making. This may be more valuable for forest biotechnology than for agriculture, as there are more than 10 million forest owners in Europe, so reaching a true consensus is especially important.

The level of public confidence in European regulators will be a crucial factor in the fate of GM forests in Europe. Currently there are no commercial applications of GM trees anywhere in Europe, with papaya being the likely first example. Whilst there is no doubt that the public should have a voice in decision making over GM trees, as articulated by Mayer (2001), Campbell and Asante-Owusu (2001) and now enshrined within Directive 2001/18/EC, this process must strike a multi-faceted balance between NIMBYism, the need for sustainable development (considering economic, ecological and societal viewpoints; Doering, 2001) and increased demand for wood and wood products throughout the world.

**Can forest biotechnology work alongside forest certification?**

Forest certification allows third party accreditation that timber or timber products on sale to the consumer (often logo-bearing), have been produced and harvested in an environmentally responsible manner. The logic being that once developed countries consumers can be persuaded that their purchasing decisions make a difference to 'saving the world's forests', and preferentially avoid non-certificated products, then the trade in unsustainably harvested timber will be depressed.

This idea arose in the early 1990's from concerns that the world's natural forests were being grossly over-exploited, especially in tropical regions, with consequent loss of biodiversity and habitats for endangered species in the affected areas. Although probably true, much of the data about the world's forest resources (including the rates of forest loss and degradation) are highly unreliable (Fenning & Gershenzon, 2002). In addition, there is a widespread but mistaken perception that this certification was principally being undertaken by, and for the benefit of, timber companies and a few wealthy individuals in the countries concerned, who were selling the timber for high prices in the developed world. Although this behaviour does undoubtedly occur, the certification movement ignores >96% of the predicted total wood harvest for 2000-2001, which is not traded internationally (FAOSTAT, 2002). Nevertheless, forest certification schemes have the potential to be a powerful force in regulating for the better, the harvest of timber from forests. There are however, at least 70 such schemes in existence, differing widely in criteria and objectives particularly with respect to plantations and the application of forest biotechnology (Forests Forever, 2002; Nilsson, 2001a). The confusion being generated by this is probably greater than the definitional problems affecting the sale of 'organic food'.
**Will the European public be able to see the wood for the FSC certified trees?**

The Forest Stewardship Council (FSC) scheme does certify some forest plantations, but only if they meet strict environmental and social criteria, including a plan to turn all or part of the certified area into more natural forest or wilderness area. The intentional use of GM plants (including trees) is categorically banned from all FSC certified areas, even if part of a scientific trial with legal consent (Cauley, 2001). The FSC scheme was created by environmental NGO's, including the Worldwide Fund for Nature (FSC, 2002). By preventing even experimental testing in these forests, the FSC is hindering and perversely preventing the very dialogue between forest biotechnologists and environmentalists that is urgently needed (Strauss et al., 2001). Resolution of the issues surrounding deployment of GM trees requires environmental release, probably on an incremental scale, until sufficient quantitative data has been accumulated to form robust conclusions. In contrast, the Pan European Forest Certification scheme (PEFC, 2002), which grew out of EU ministerial discussions between 1993 and 1998, has no such requirements for plantation forests, provided the certified area meets all legal obligations.

Forest industry analysts and the United Nations FAO have noted that forest certification is more a timber marketing tool, than a conservation strategy (Nilsson, 2001b). The FSC (UK)'s own analysis appears primarily concerned with the marketing value of the FSC scheme (Scrase et al., 1999). Forestry is already a low margin - high volume, capital intensive industry, the extra burdens and costs imposed by forest certification schemes are a powerful disincentive to further investment, particularly in forest plantations and biotechnology. Certification campaigners may be ignoring environmental damage done by consumption switching to non-renewable alternatives to wood consumption, such as concrete and steel in construction, as the price tag on certified timber rises.

**What are the demand trends for wood?**

The FAO (1999, 2001) notes that the consumption of industrial timber for the year 2000 was 1.6 - 2.2 bn m$^3$ globally, and is growing at an annual rate of ~1.7%. A near 25% increase in consumption over 1996 levels is projected for 2010 (Zhu et al., 1999). Across the EU, 2001 per capita wood consumption is estimated at 1.6 m$^3$ (FAO, 2001), equating to 585 Mm$^3$ for its 372 million inhabitants. Whilst Scotland and some other European countries are increasing their wood harvest, from 4.6 to 8.4 Mm$^3$ by 2016 (Forestry Commission, 2002; Scottish Forest Industries Cluster, 2002), by the middle of the 21st century, harvested wood levels will decline due to the assymetric age profile of Europe's managed 'semi-natural' forests. This will increase Europe's timber trade deficit and constrain freedom of action to redress this imbalance (European Parliament, 1997; 1998).

**Can forest biotechnology aid sustainable wood supply?**

**Ethical Issues**-

The value humankind places on forests brings with it great responsibilities to anyone proposing significant change to this key feature of our landscape.
Do we have the right to interfere with the natural order of our forests? Who should be making management regime decisions potentially impacting on the forests of entire continents? Should all large forests be left to manage themselves, or should management strategies sensitive to the centuries of history reflected within them be undertaken? Is all genetic modification unnatural and going against the wishes of a 'Creator', as argued by Prince Charles (Windsor, 2000)? Is it really necessary to create plantation forests of GM trees to satisfy demand for wood?

These are just some of the legitimate ethical questions raised about GM forests. Environmentalists, ethicists, philosophers and concerned scientists have pondered these difficult issues which will need to be addressed prior to any possible future deployment of GM trees, especially in plantation forests. Whilst scientists have shown convincingly that species are not the immutable watertight compartments they were once thought to be (Davies, 2001), not everyone is convinced that genetic modification can be a natural process. In Scandinavia, very few applications for field trials of GM trees have been made in recent years, and at least one large forestry company, Stora Enso, has publicly adopted a no GM trees stance. In contrast, other European forest biotechnologists have pointed the way towards trees with improved pulp processing properties and consequently less environmentally damaging processing needs (Pilate et al., 2002), towards pest and disease resistance, to restoring threatened trees to our landscapes (Gartland et al., 2000), and to greater productivity from smaller areas allowing more of our ancient forests to remain unfelled, using GM technologies (Victor and Ausubel, 2000). Despite laudable and highly successful efforts within many European countries to recycle paper and wood, processing prices for recycled products remain stubbornly high, where defined markets exist have been established at all. Demand for pulp and paper is projected to increase by 50% in the next two decades and despite 65% of European newsprint currently using recycled fibres, this will place even greater strains on our forest environments (Waste & Resources Action Programme, 2002).

These tensions and ethical dilemmas impact on every one of our lives, every single day, as we build houses, print memos, read newspapers or heat our food. Finding ways to reconcile these conflicting demands and concerns whilst satisfying the needs of developing economies, where increased demand for wood parallels rising living standards, without ruining our precious ‘green lung’ forest assets is probably the greatest environmental challenge facing us in this century.

**Future European Forestry Trends**

More fibre farming is likely to shift to the near-tropics where the manufacturing plants will eventually produce pulp for shipment to paper and paperboard plants in the temperate and boreal zones for local consumption. A similar scenario will develop for engineered wood products, inclusive of laminated veneer lumber (LVL), oriented strand board (OSB), medium density fibreboard (MDF), glulam, etc. This will take effect once a substantial portion of the huge inventory of standing timber from the EU and especially in surrounding countries has been utilised or protected due to environmental lobbying (Nilsson, 2001b). This trend is already developing with the
Japanese environmental movement to discouraging timber imports from old-growth forests in Asiatic Russia.

Plantation forestry in the EU and surrounding countries will accelerate in the coming decade as marginally productive agricultural land is reclaimed. The UK, France and Germany will eventually increase their forest land base due to agricultural reform, raising the EU average. Save for a small portion of those lands, however, tree crops of long rotation will be the norm. That small portion will support tree crops of poplars, and to a lesser extent willows and eucalypts. It is there that forest biotechnology is most likely to have greatest impact during the next decade, with trees engineered for tolerance to herbicides, pests and stress factors, and for improved growth, form, adaptability and enhanced wood properties. Both types of crops would benefit the environment by being modified for increased carbon sequestration, and speciality crops could be engineered for bioremediation purposes.

Even though the benefits may be long in coming at current rates of progress, biotechnology research will continue during the next decade on urban forestry, preservation of trees of ancient and historic value, and control of invasive species. Urban forestry initiatives promise to yield high investment returns, especially for the modification of trees tolerant to air and soil pollutants that will only be exacerbated by an increasing human population. A secondary benefit will be to rid candidate species of traits undesirable for landscaping, such as odiferous fruit and sloughing bark.

3 What might be the consequences over time of NOT fully developing forest biotechnology in Europe?

The consequences of not fully developing forest biotechnology in Europe will depend upon the extent of the refusal to embrace these technologies. Essentially there are three main possibilities for the next decade:

- Accept all aspects of forest biotechnology, including GM trees
- Reject GM trees, but embrace tree genomics and other forest biotechnologies
- Refuse to embrace any forest biotechnologies

Refusal to embrace any aspects of forest biotechnology would mean Europe adopting a most extreme position. The consequences would be severe for European scientific capabilities in forest conservation, since ex situ micropropagation via tissue culture is important in rejuvenating and multiplying unusual trees of cultural, historical or numerical significance. Understanding of tree physiology and forest bioinformatics in Europe would fail to develop at rates similar to international competitors such as the USA and Canada as few opportunities to apply the knowledge gained from tree genomics and proteomics within Europe would exist.

Not accepting GM trees within Europe, or failing to prevent the actions of genetic terrorists will continue to destroy the very field trials designed to investigate potential concerns, would have severe repercussions for the development of forest biotechnology in Europe. Scientific capabilities in tree molecular biology, aspects of risk assessment and tree physiology within Europe would be damaged as there
would be no opportunities to test the effects of knocking out or adding single gene functions in trees. Modifying tree growth and development would become impractical without the possibility of field trials and ultimate deployment within Europe. Relevant scientific expertise would be lost to Europe, instead migrating to more receptive environments. European investment in forest sciences is in decline, especially outwith Scandinavia, for example in areas such as forest pathology, as increased competition and 60-year low commodity prices take effect. Failing to embrace forest biotechnology can only lead to an erosion of expertise and understanding of forest environments and the biological implications of forest perturbations. Although forest biotechnology would continue to grow elsewhere, important questions involving strategies for disease and pest resistance in European oak, elm, alder, and willow species would be severely hampered and probably condemned to failure without the tools of genetic modification being available. Europe's ability to react to emerging pest and disease threats would be severely compromised by such a rejection. Re-establishing the highly specialised types of expertise and facilities needed within European forest biotechnology at some later date would without doubt be time-consuming, highly expensive and less likely to be as successful than maintaining and developing forest biotechnology expertise from a basis of continuity.

Without GM tools to speed up breeding cycles, genetic gains from European tree breeding programmes would take longer to be translated into quality or productivity benefits when compared to early adopters elsewhere. Improvements to adaptability, enhancing wood properties to yield higher value products whilst reducing energy usage, tolerance to chemical inputs, and engineering optimum productivity on sites stressed by drought, excess water, extreme temperatures, air or soil contaminants would all become more difficult to achieve without forest biotechnology research. European society would also be denied the benefits of establishing new longer rotation forests, including spruce, pine and fir, on abandoned agricultural land, to increase carbon sequestration and contribute to environmental remediation. Once pulp, fibre or tree metabolites can be produced more cheaply, or at higher quality in competitor countries such as China, Malaysia, India, Canada, the USA, and Chile, the European forest sector would contract, as the trends to shift growing, and processing capacity South, to regions able to deliver 20-fold higher yield rates would accelerate further. This trend would threaten 3.7 million jobs currently worth €228bn, within the EU alone. The European timber trade deficit could only increase in these circumstances, from the current $8bn for the EU alone.

Weakening Europe's competitive position in the forest sector in this way would adversely effect trade deficits, lead to substantial job losses and damage the rural environment already under great strain in many European countries. These adverse effects would not merely be limited to the major afforested countries currently within the EU, but would also severely damage the ability of future waves of accession countries including the Czech Republic, Slovakia, Hungary, Poland and Lithuania as well as those further afield such as Bulgaria and the other Baltic States, to generate the domestic productivity necessary to cope with EU entry costs.

If the EU does reject forest biotechnology, it will fall further behind the progress made in other parts of the world. This could be especially damaging if, the Russian Federation, for example, were to take advantage of forest biotechnology fully. Faced with a choice between EU-sourced, possibly certified forest products and cheaper, or higher quality products obtained using biotechnology from adjacent forests,
processors and the end user are highly likely to seek better value for money. Being overly cautious about the science and deployment of forest biotechnology products will result in competitive disadvantage, as Europe faces in agronomic cropping when compared to North America, China and most recently India. Societal involvement from the beginning is crucial to gain reasoned acceptance of forest biotechnology. Without a combination of the two factors: research, inclusive of deployment of transgenic trees, and societal input, a favourable outcome will fail to materialise. Europe faces a stark choice between either embracing the evolving forest biotechnology or becoming unnecessarily dependent upon the rest of the world for timber, pulp, and paper products, with little consideration given to Europe’s values and preferences.
Information Sources


International Union of Forestry Research Organisations (IUFRO, 2002)


Pan European Forest Certification Scheme (2002) See: http://www.pefc.org/content.htm


APPENDIX 1: FOREST BIOTECHNOLOGY AND SCOTLAND’S TREES

- Forests cover 16% of Scotland’s land area, the highest coverage for at least three hundred years. This includes 60% of the UK conifer harvest (4.8 Mm$^3$) and 42% of lumber production annually.

- Softwood supply is projected to exceed 8.4 Mm$^3$ by 2016.

- The UK currently imports 90% of its paper, 80% of its lumber and 35% of its wood-based panel consumption, together costing more than £6 billion.

Data Sources: Scottish Forest Industries Cluster http://www.forestryscotland.com
Forestry Commission http://www.forestry.gov.uk

Selected Examples of Scotland’s Forest Biotechnology Expertise

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<tr>
<th>RESEARCH BODY</th>
<th>EXPERTISE</th>
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**APPENDIX 2: GM TREE FIELD TRIALS IN EUROPE**

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<th>Species</th>
<th>Countries</th>
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<tr>
<td><strong>Apple</strong> (&lt;i&gt;Malus domestica&lt;/i&gt;)</td>
<td>Belgium (1)</td>
<td>Fungal scab resistance</td>
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<td></td>
<td>Netherlands (1)</td>
<td>Fungal resistance (hordothionin)</td>
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<td></td>
<td>Sweden (1)</td>
<td>Rooting ability (&lt;i&gt;rol&lt;/i&gt; genes)</td>
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<td><strong>Paradise apple</strong> (&lt;i&gt;Malus pumila&lt;/i&gt;)</td>
<td>UK (1)</td>
<td>Markers (&lt;i&gt;nos, nptII&lt;/i&gt;)</td>
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<tr>
<td></td>
<td>Netherlands (1)</td>
<td>Fungal resistance</td>
</tr>
<tr>
<td><strong>Eucalyptus</strong></td>
<td>Spain (1)</td>
<td>Markers</td>
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<tr>
<td>&lt;i&gt;Eucalyptus grandis&lt;/i&gt;</td>
<td>UK (1)</td>
<td>Markers</td>
</tr>
<tr>
<td>&lt;i&gt;Eucalyptus globulus&lt;/i&gt;</td>
<td>UK (1)</td>
<td>Markers</td>
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<tr>
<td></td>
<td>Portugal (1)</td>
<td>Markers</td>
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<tr>
<td><strong>European aspen</strong> (&lt;i&gt;Populus tremula&lt;/i&gt;)</td>
<td>Denmark (2)</td>
<td>Markers</td>
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<tr>
<td></td>
<td>Norway (1)</td>
<td>Phytochrome A synthesis</td>
</tr>
<tr>
<td></td>
<td>Germany (2)</td>
<td>&lt;i&gt;rol&lt;/i&gt; genes, glufosinate/glyphosate tolerance</td>
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<td><strong>Aspen hybrid</strong> (&lt;i&gt;P. alba x tremula&lt;/i&gt;)</td>
<td>France (6)</td>
<td>Altered lignin and markers (&lt;i&gt;cinnamoyl CoA reductase&lt;/i&gt; and &lt;i&gt;o-methyl transferase&lt;/i&gt;)</td>
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<td></td>
<td>Spain (1)</td>
<td>Growth tests (&lt;i&gt;glutamine synthetase&lt;/i&gt;)</td>
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<tr>
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<td>UK (1)</td>
<td>Altered lignin (&lt;i&gt;cinnamoyl CoA reductase&lt;/i&gt; and &lt;i&gt;o-methyl transferase&lt;/i&gt;)</td>
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<td><strong>Cottonwood poplar</strong> (&lt;i&gt;Populus deltoides&lt;/i&gt;)</td>
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<td>Markers</td>
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<td></td>
<td>France (2)</td>
<td>Insect resistance, male sterility, and herbicide resistance (Bt toxin, and glufosinate tolerance)</td>
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<td></td>
<td>UK (1)</td>
<td>Altered lignin (&lt;i&gt;cinnamoyl CoA reductase&lt;/i&gt; and &lt;i&gt;o-methyl transferase&lt;/i&gt;)</td>
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<td>Germany (1)</td>
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<td><strong>Quaking aspen</strong> (&lt;i&gt;Populus tremuloides&lt;/i&gt;)</td>
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<td><strong>Plum</strong> (&lt;i&gt;Prunus domestica&lt;/i&gt;)</td>
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<td>Plum pox potyvirus resistance</td>
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<td><strong>Norway spruce</strong> (&lt;i&gt;Picea abies&lt;/i&gt;)</td>
<td>Finland (2)</td>
<td>Markers</td>
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</table>
Olive  
*Olea europea*  
Italy (2)  
Water stress and disease resistance, improved rooting (*osmotin* and *rol* genes)

Scots Pine  
*Pinus sylvestris*  
Finland (2)  
Markers

Silver Birch  
*Betula pendula*  
Finland (4)  
Markers, *nitrate reductase*

Cherry  
*Prunus avium*  
Italy (3)  
Improved rooting (*rol* genes)

Orange  
*Citrus sinensis*  
Spain (1)  
Markers

**TOTAL**  
43

*European GM Tree Field trials by Country*

<table>
<thead>
<tr>
<th>Country</th>
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<tr>
<td>France</td>
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<td>Finland</td>
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<td>United Kingdom</td>
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<td>Germany</td>
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<td>Portugal</td>
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<tr>
<td>Sweden</td>
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**Data Sources:**
Joint Research Centre (JRC) of the European Commission. August 2002. Advisory Committee on Release into the Environment (ACRE) Minutes (UK). N.B. Data may include use of transgenic pollen in field trials.