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CAN TRANSNATIONAL SECTORAL AGREEMENTS HELP REDUCE GREENHOUSE GAS EMISSIONS?

Clinton Watson, John Newman, Rt Hon Simon Upton and Petra Hackmann

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For futher information, please contact Joanna Ellis, Principal Adviser, Round Table on Sustainable Development at the OECD, 2 rue André Pascal, 75775 Paris Cedex 16, tel:+33 1 45 24 14 57; fax +33 1 45 24 84 08; email: joanna.ellis@oecd.org

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This paper aims to shed light on the question of whether transnational sectoral agreements can help reduce greenhouse gas emissions, whether in a Kyoto world or not. It focuses attention on emissions intensity agreements and R&D agreements within sectors, both of which can promote technology transfer and stimulate technological change. Aluminium, cement, steel, coal-fired electricity generation and light-duty vehicles are used to illustrate the kinds of issues that would arise in adopting a sectoral approach. The paper shows that the issues in each of the sectors are different. These differences range across a broad front from production, consumption and trade patterns, industry concentration and cost structures to available technologies and opportunities for new technologies to reduce energy use and emissions. A common, but not unsurprising, finding in each sector is that there is significant regional variation in the level of emissions intensity. The paper explores the underlying causes for these differences, but recognises the complexities involved in drawing firm conclusions. Finally, the paper provides a summary of the key issues both governments and companies would need to address if they were to proceed with further work on sectoral initiatives. Annexes to the paper provide the essential data on which the main body of the paper relies in using the five chosen sectors to illustrate the possibilities presented by a sectoral approach. The reader is referred to the annexes for all details, including data sources.

I DOES A TRANSNATIONAL SECTORAL APPROACH MAKE SENSE AT THE PRESENT TIME?

1. Right at the outset we pose this question: Why would anyone wish to survey the possible usefulness of a different approach to securing greenhouse gas emissions reductions so soon after the entry into force of the Kyoto Protocol? After all, negotiators have invested over a decade following the signing of the United Nations Framework Convention on Climate Change (henceforth Convention) in assessing all possible approaches and finally crafting global instruments that, however imperfectly, seek to limit national emissions without prescribing the means by which those emissions are to be curbed.

2. Underlying this approach has been a realisation that the rate of progress in reducing greenhouse gas (GHG) concentrations will depend on how costly the transition to a low-emissions world is likely to be. So the emphasis from the outset has been on trying to find least costly solutions. If costs, particularly those occurring in the short term, are perceived to be too high, then the political response is likely to be a search for less stringent environmental commitments to lower the costs. Alternatively, the risks associated with not addressing climate change may need to be better understood.

3. From the point of view of the economics community this priority has pointed strongly in the direction of erecting an economy-wide price for carbon – either through taxes or tradable permits under an emissions cap – and leaving it to the marketplace to find the least costly way of reducing emissions. And if absolute emissions limitations are the goal, then tradable permits emerge as the “first-best” mechanism since taxes can fix the *price* of emissions (providing cost certainty), but cannot guarantee a particular *level* of emissions.

4. In terms of economic efficiency, this economy-wide “first-best” approach should not be discarded lightly. Econometric analysis indicates that a GHG emissions standard applied globally to the automotive transport sector would be significantly more costly than a cap-and-trade model, although the cost of each unit of emission reduction falls considerably over time.[1] The reason for the significant difference is that the latter option spreads the reduction burden across all sectors. The former seeks the reductions from only one sector for which demand is insensitive to price and for which there are limited alternative technological substitutes. A particular cost-related issue with a sectoral approach is the extent to which input costs across the economy might be raised as a result of a sectoral agreement. An agreement relating to a building

material such as steel, aluminium or cement may significantly raise costs for a range of other sectors such as construction and manufacturing. Competition between sectors may also be affected due to changes in relative prices. This will be particularly pronounced for sectors competing in the same market such as building materials.

5. The global architecture that has emerged, however, falls well short of a comprehensive adoption of a least cost approach and is likely to remain so. In the first place, the emissions ceiling needed to create scarcity and trigger the development of a carbon market negotiated in the Kyoto Protocol extended only to developed countries and economies in transition. This followed from the principle of common but differentiated responsibilities elaborated in the Convention. It was rooted in an acknowledgment that the *distributional* consequences of applying an instrument globally were unacceptable to those countries who had not significantly contributed to increased GHG concentrations and for whom the right to develop (as high emitting countries had done before them) was non-negotiable. While it may have been hoped by some that the coverage of a legally binding emissions cap would gradually be extended following the first commitment period, the likelihood of this now seems very low in the foreseeable future. What might have been a first step looks increasingly like a solitary step.

6. But even an initial division of the world, however arbitrary, into developed and developing countries has not eventuated as a first step. The world's largest emitter, the USA, stands outside the protocol along with Australia. Furthermore, there is no reason to believe either country will ever accede to the protocol in its current form. In the absence of these significant players it seems even more implausible that developing countries with significantly rising living standards and emissions will adopt absolute emissions caps.

7. This is not to say that at some future point – perhaps driven by unforeseen climatic events – more comprehensive coverage may not be possible. Nor does it rule out the possibility that countries that have acceded to the protocol will seek to take on additional obligations. Under this scenario sectoral agreements could complement commitments under the protocol. But for the time being, a hard-headed assessment would have to conclude that the coverage of emission caps under the Kyoto Protocol is unlikely to be extended beyond current participants in the foreseeable future. In turn, the full potential of least-cost, price-based emission reduction mechanisms will not be realised.

8. The result is that the Kyoto Protocol itself will have a very limited impact on emissions, at least with its current commitments. Those Annex I Parties who have ratified were responsible for just 46% of global emissions in 1990. If these countries meet all their targets by 2010, the reductions achieved will represent just 2% of 1990 global emissions and impacts on concentration levels will be minimal. Total global CO_2 emissions will have increased by approximately 30% from the 1990 baseline.[2] While much value will be gained through the elaboration of an emissions permits market with spill-over benefits to developing countries through the Clean Development Mechanism (CDM), the strongly upward trajectory of global emissions will not be halted.

9. The question then arises as to whether it is worth exploring other, or additional, means of seeking to reduce that growing emissions trajectory. On the one hand, the existing architecture has only been arrived at after lengthy and demanding negotiations. The Kyoto Protocol envisages the commencement of negotiations on commitments beyond the first commitment period by 2005.[3] Anything that diverts scarce resources from ensuring the successful implementation of the Kyoto Protocol, as far as it goes, might be considered an ill-timed distraction.

10. On the other hand, if there is no foreseeable prospect of a significant advance beyond Kyoto, the exploration of less comprehensive and, from the point of view of economic efficiency "second-best" options, may commend itself. This may be particularly so if such options could be pursued without prejudice to national negotiating positions on national emissions targets and if a portfolio of policy

instruments is the most effective way of tackling the climate change problem.[4] The challenge for those who advocate such an approach is to ensure that a policy mix does not become a policy mess. Overlapping instruments could undermine coherence and create transaction costs and uncertainty on the overall policy direction.

II POSSIBLE REASONS WHY A SECTORAL APPROACH MIGHT APPEAL[5]

11. There are a number of reasons why, at least *prima facie*, a sectoral approach to making global progress on reducing the rate of emissions growth might appeal. One reason is that sectoral agreements could be negotiated while a more comprehensive approach is being developed. Sectoral agreements could lower global emissions trajectories by significantly influencing the emissions-intensity of investments in some key sectors of the global economy. New plant and equipment with very long operational lifetimes in sectors such as power generation and aluminium production will continue to be installed. For example, between 2003 and 2030 $1.5 trillion will be invested in coal-fired electricity generation with around two-thirds of that investment in China and India.[6] Due to financial pressures much of the investment in developing Asia is expected to be in plant with technology that falls well short of the least emissions-intensive standard. The final nature of these investments will strongly influence future emissions trajectories.

12. The potential for sectoral initiatives to contribute to particular developmental needs through enhancing technology transfer may provide an additional reason to investigate them. While developed countries might fear carbon leakage caused by a shift of carbon-intensive production to developing countries, developing countries stand in urgent need of significant investments to raise living standards. This is particularly so in respect of energy where the average person in a non-OECD country consumes only a quarter of what an average person in an OECD country consumes.[7] It is a common assumption that per capita energy consumption in non-OECD countries will need to rise to meet development needs and growing consumption from higher incomes.

13. How sharply per capita emissions grow in developing countries will depend on the accessibility and affordability of more efficient technologies. It is often suggested that rapidly developing economies should be seeking to leapfrog the emissions hike that would be implied by the use of conventional technologies. On a life-cycle cost basis newer technologies will almost always be cheaper than less efficient technologies. Their capital costs are, however, typically higher. New technologies may also require new infrastructure and advanced skills. Where there are domestic benefits, such as improved industry productivity and cleaner local air and water, a national investment case can be made. But even then, other developmental priorities may result in mass deployment of less efficient technologies at the expense of the environment.

14. A sectoral approach could conceivably make it easier to bridge the funding gap between the technologies developing countries can afford and the technology being adopted in developed countries. The task of determining what the lowest practicable emissions trajectory might be, based on leading edge technologies, will be simpler to identify if broken down to a sectoral level. The establishment of sectoral baselines based on particular technologies could prove less cumbersome than the project-by-project approach currently adopted under the CDM. It could also help make the costs of burden sharing clearer, giving all parties a better idea of the relative value of emissions reduction possibilities by sector. The gap between the investments likely to flow to developing countries under the CDM and the investments likely to be made under any plausible development path could provide an estimate, sector by sector, of just how

much additional development assistance would be required to shift emissions onto the lowest possible trajectory.

15. Secondly, taking a sectoral focus may be more manageable. By focusing on particular sectors with major emissions and/or high emissions growth, governments and businesses would be dealing with a smaller number of parties. Furthermore, it is not a novel approach – most countries already work with industry groups to improve industry performance and address environmental issues. By concentrating on a smaller number of players with more interests in common, the chances of reaching some sort of agreement may be enhanced. To the extent that there are already sectoral understandings at national or even regional levels, it may be easier to link those initiatives globally than economy-wide instruments like taxes or permit systems. On the other hand, sectoral initiatives can throw up boundary problems unless their coverage is very clearly defined.

16. In a similar vein, a sectoral approach might help wider global negotiations by taking out of the equation sectors that face particularly difficult adjustment or competitiveness pressures. Attempts to make progress across a broad front can be impeded by the narrow interests of particular affected parties. This problem has often been observed in the context of national efforts to lower border protection. The benefits of lower levels of protection are widely distributed unlike the costs which are concentrated in particular sectors. The visibility and concentration of such sectors gives them disproportionate leverage in negotiations.

17. In the context of climate change, adjustment costs may be particularly high for price-sensitive industries exposed to significant international competition from players located in jurisdictions not subject to emissions caps. The "uneven playing field" created by the division of the world into Kyoto and non-Kyoto countries gives particularly exposed sectors strong incentives to lobby governments.[8] Those sectors where multinational corporations play a big role such as aluminium and automobiles can lobby governments with more credible threats of shifting production outside of carbon-constrained countries. Those incentives could be reduced if an alternative sectoral mechanism were in place in parallel with the main treaty instruments. That said, sectoral initiatives would have to be careful not to create leakage problems between sectors with substitutable products such as competing building materials.

18. Finally, and perhaps most importantly, a sectoral approach focuses attention on where the key breakthroughs have to be made. While it is true that all manner of emissions reductions possibilities are likely to be discovered in response to general economic instruments that constrain emissions, the reality is that a relatively small number of sectors account for the bulk of emissions. The electricity and heat sector accounts for 22% of global anthropogenic emissions, transport 13% and manufacturing and construction 23% when taking into account the sector's fossil fuel combustion, electricity use and process emissions (see Figure 6 on page 30 for a sectoral breakdown of world emissions).[9]

19. The forecast emissions growth in these sectors means that nothing short of transformational technologies will be required to change direction. Such technologies are unlikely to emerge in the marketplace in the absence of very demanding emissions limitations. While several countries have ambitious targets of emission reductions of up to 75% for beyond 2050[10], the international community at large shows no willingness to contemplate the sorts of emissions limitations needed. This being the case, only sustained public and private research and investment is likely to bring such technologies forward. Even then, the widespread adoption of any promising technologies – and the "learning-by-doing" associated with those technologies – will depend on close linkages among all elements of the innovation system. A transnational sectoral approach to improving efficiencies and lowering emissions could provide a useful way of improving coordination and links between public and private researchers and facilitating technology transfer and adoption.

III WHAT MIGHT SECTORAL AGREEMENTS LOOK LIKE?

20. A sectoral approach to reducing GHG emissions would focus efforts on discrete economic sectors. The choice of sector could be influenced by any one of a number of considerations, including:

- the sector's share of global emissions;
- the sector's rate of emissions growth;
- the rate at which capital is replaced; and/or
- the rate at which new technologies are developed and taken up.

21. Sectoral agreements could be designed in many different ways. They could be designed to encourage GHG-friendly investments in certain sectors or to encourage the adoption of GHG-friendly policies by governments in the form of a tax, standard or other regulation.[11] The overall environmental effectiveness of any agreement would depend on its actual design parameters such as the stringency of commitments and the rigour with which baselines and performance could be measured. The level of participation would also significantly affect environmental and efficiency outcomes. An agreement could be negotiated with key multinational corporations with targets for these firms. Alternatively, country-wide sector targets – uniform or not – could be negotiated.

22. There are many different types of sectoral agreements. Three key elements will shape the effectiveness of any agreement and the ease with which it might be negotiated and implemented. They are: (1) the means or mechanism by which emissions are to be reduced; (2) whether the agreement is voluntary or mandatory; and (3) whether the agreement is legally binding or non-binding. Each of these elements is discussed below.

Means by which emissions can be targeted

23. The range of instruments that could be used in a sectoral agreement and what they bear on is as vast as the range of economy-wide instruments. Almost any economy-wide instrument or technology protocol can be applied to a specific sector. It is also possible for a number of instruments to be used in parallel. Listed below are the most commonly discussed mechanisms.[12] The first three directly target emissions, while the remaining instruments target technology to indirectly influence emissions save the last which targets information.

Emissions-based fixed/absolute target

24. A fixed or absolute target creates a fixed emissions level based on either a percentage of an historical baseline or a percentage of business-as-usual emission projections[13] during the commitment period. The emissions limit for a given sector could be established as a reduction below some given level or stabilization at current levels. It could even allow for some growth in emissions over current levels. Fixed targets provide certainty on emissions levels provided they are fully implemented, but create economic uncertainties because the cost of meeting the target is unknown. The Kyoto Protocol, the EU Emissions Trading System and the US sulphur dioxide (SO_2) trading scheme use this instrument.

Emissions-based dynamic[14] target

25. Rather than aim for a fixed target, it is also possible to aim for a level of emissions that is related to some other *variable* measure. This variability makes the target dynamic in that the final target is dependent on other factors over which the parties may have no direct control. For instance, an emissions target could be indexed to a variable such as GDP to allow for fewer emissions when economic growth is lower and greater emissions when growth is higher. The key point is that dynamic targets do not guarantee an overall emissions figure because the level of allowable emissions fluctuates according to the index variable.[15] They do, however, alleviate concerns arising from abatement cost uncertainty.

Emissions-based intensity target

26. A specific type of dynamic target relates to reducing the intensity of emissions in relationship to some other measure. The most applicable target for a sectoral approach is targeting the production process by setting a target pegged to an input or output variable. An example of an input variable could be kilowatts of electricity used or tonnes of coal consumed. An output variable could be a unit of production such as tonnes of cement produced. Intensity targets can be imposed directly on a sector or indirectly through an efficiency standard or technology mandate that has the same effect.[16] A number of environmental agreements have used or recommended intensity targets such as the Nitrogen Oxides Protocol[17]; the UK Emissions Trading Scheme has intensity limits for certain firms.

Common standards

27. Common standards across countries can provide clear direction for the uptake of GHG-friendly technologies. Standards can apply to finished products such as energy efficiency standards for appliances or they could relate to technical requirements for new plants. Standards can target a performance level which can be based on best available technology or, more likely, on "best available technology not entailing excessive cost" which takes into account the costs of installing the technology. Japan's "Top Runner" Program sets future automobile efficiency standards at the level achieved by the most efficient products currently supplied domestically. Standards can also prescribe specific technologies. Finally, they can also set a performance level that no existing technology can meet in an attempt to push forward technology development.[18]

28. Process or production standards, i.e. any standards relating to the way in which a product is produced, can be problematic under WTO trade rules and these types of standards should be considered carefully. To be effective, participation in a standards agreement would in reality be only required only by the world's major economies because smaller economies tend to follow larger ones to ensure that their firms are not required to meet a different set of standards at home and in their major export markets.[19] In some sectors it may be possible to identify several key jurisdictions that serve as "standards-setters" for others.[20] As a first step to developing common technology standards governments could harmonise their assessment methods.[21]

Technology targets

29. A technology-based protocol could set forth medium- to long-term technology targets or obligations for a given sector. An example could be that all new coal-fired power plants built after 2010 must use integrated gasification combined cycle technology since these plants are most suited to carbon sequestration and have high efficiencies. A risk with a technology-based approach is that it may lock in technologies that prove not to be the most cost-effective.[22] Those standards which set a more stringent level for new plants than for existing plants risk prolonging the use of older, less efficient plants because the costs of new plants become higher.[23] Note, however, that standards may also be set for existing plants

to force either retirement or retrofitting. The EU Integrated Pollution and Prevention Control (IPPC) Directive, a permitting system based on best available technologies for industrial plants, is a type of technology target.

Financial support of efficient technologies

30. An agreement could support the uptake and diffusion of efficient technologies in plant refurbishments and new plants. This could be done through a multilateral fund to finance new technology investments in developing countries. Support could also be given for building local capability to ensure optimal plant operational efficiency. Governments could also provide loan guarantees and provide specialized tax and/or depreciation treatment. An extension of the current project-based CDM, or the elaboration of new sectoral-crediting mechanisms to cover entire sectors could be another possible instrument for governments. This would have the effect of increasing investment in new technologies in developing countries and increasing the opportunities for firms in Annex I countries to seek lower cost emission reductions.

Research and development

31. A technology agreement could attempt to raise levels of R&D and/or improve coordination and links between existing public and private research. Agreements could be between firms, governments or both. The focus could be on breakthrough technologies such as energy-based hydrogen, or on emerging technologies closer to being cost-competitive.[24] An agreement would need to set out clearly the ownership of new technologies and ensure that their pricing was not beyond firms in developing countries. While all countries stand to benefit from new technologies some countries may opt to free ride (i.e. receive the benefits of the new technology, but not contribute to its development). Another problem is that competitive concerns around commercial licensing terms could hinder negotiations as could unease around antitrust action.[25]

Reporting requirements

32. An agreement could focus on reporting requirements. All firms in a particular sector could be required to calculate and submit an annual inventory of GHG emissions according to an agreed calculation method. They could also be required to communicate how they are reducing emissions and how they intend to further reduce emissions.[26] A reporting agreement could be a first step towards wider commitments, all of which would depend on accurate reporting.

Voluntary or mandatory

33. An agreement developed at the country-to-country level, in conjunction with industry, could allow for governments either to apply the agreement's requirements to all applicable firms in its jurisdiction or to seek voluntary agreements with relevant firms. Voluntary agreements (VAs) permit firms to choose for themselves whether they wish to sign up and comply. The level of participation by government and industry varies. At one extreme industry negotiates targets and implements an agreement with no government involvement. At the other extreme governments set targets for the industry and undertake all monitoring. In reality an effective VA requires participation by both government and industry: lack of government involvement risks negotiating an agreement with weak targets and poor monitoring and enforcement; lack of industry involvement risks governments basing agreements on incomplete information.

34. VAs have been adopted over the last several decades and are becoming increasingly popular.[27] While VAs are now only used between a government and firms in its jurisdiction, it would not be implausible for several governments jointly to conclude a voluntary agreement with firms in their jurisdictions. The EU has been successful in concluding a number of VAs, including with European, Korean and Japanese

automobile manufacturers. A VA could in theory be negotiated between key multinational corporations and governments.

35. The diversity of voluntary approaches makes it difficult to draw general conclusions.[28] What can be said is that there is limited evidence as to their environmental effectiveness. VAs seem to provide little incentive to innovate and can be weakened by a lack of credibility. Free-riding can significantly lessen the effectiveness of VAs. A firm not participating in the agreement can obtain the same benefits (e.g. avoid the imposition of a stricter regulation) as those firms participating in the agreement while not incurring any of the abatement efforts. Agreements are more likely to be effective when an industry faces a credible threat of regulation from governments. They are likely to generate significant "soft effects" – for example, sharing information on best practice and raising awareness of emissions and energy use.[29] They may also be a useful first step to stricter mandated requirements.

36. A mandatory approach would require *all* applicable firms in a country to comply with government mandated requirements flowing from an agreement that the government had reached with other governments. Such an approach has the advantage of treating all firms in a sector equally. It does, however, run the risk of less stringent targets because governments have to apply the requirements to all firms in a sector, including those with low productivity. Poor performers have strong incentives to negotiate the least demanding targets.

Legally binding or non-binding

37. Agreements can either be legally binding or non-binding. Binding agreements include sanctions in the case of non-compliance and are enforceable through a court's decision whereas non-binding agreements have no such consequences. Non-binding agreements open to trading could deliver incentives for exceeding a target while not punishing firms that do not meet the target.[30] It is conceivable that a commitment by a country regarding one sector could be non-binding, but then translated into binding targets for the relevant companies or plants.

38. Binding approaches are more likely to be environmentally effective than non-binding approaches. If non-compliance does not trigger any sanctions and there is no reward for exceeding a target, any environmental improvements would have to rely on strong commercial and strategic interests of firms to demonstrate a change of behaviour compared to "business-as-usual". On the other hand, working out the details of a legally binding agreement would be more demanding than preparing a simpler, but probably less effective, non-binding approach. Monitoring and enforcement costs would also be much higher and new institutions may need to be formed. Hence, there is likely to be a trade-off between the administrative costs involved and the environmental effects that can be expected.[31]

IV WHICH SECTORAL AGREEMENTS SHOULD WE FOCUS ATTENTION ON?

39. Whatever the design of a sectoral agreement, it has to be effective. The perfect sectoral climate change agreement would contain all the attributes in the box on page nine. In reality the negotiation of any agreement will involve a complex set of trade-offs between these attributes in light of economic, political and institutional constraints. For example, one common trade-off is between participation and environmental effectiveness. As participation broadens, commitments tend to become narrower.

40. Bearing in mind the wide range of possible sectoral agreements the question then arises as to what type of sectoral agreement best fits the characteristics in the box. Should it be a mandatory agreement with a fixed emissions target, a voluntary emissions intensity based agreement, or an R&D agreement focusing on technological breakthroughs? This is a question that it is impossible to answer in the abstract for two reasons.

41. Firstly, within any type of agreement its design and level of participation can vary enormously. For example, a fixed target agreement might base its reductions on a percentage of business-as-usual trajectories. The estimation of such trajectories is extremely difficult and negotiators could even conclude an agreement that allowed for more emissions than the true business-as-usual scenario. Clearly an agreement that only involved a handful of countries versus one that involved all of the world's major economies would have very different environmental and efficiency outcomes. But even here this would depend on the stringency of commitments negotiated – an agreement involving a few countries with tight commitments could have significant impact compared to an agreement with broad participation, but weak targets. Another important factor is how an agreement defines the boundaries of a sector's emissions. For example, for many sectors an agreement excluding emissions from the use of electricity would have very different outcomes from one that included all emissions.

Attributes of an agreement

- An agreement should be **environmentally effective** – commitments should be long-term and should lower the growth rate of GHG emissions and eventually reduce the level of emissions.
- An agreement should encourage the reduction of emissions in the most **cost efficient** way.
- An agreement should encourage the **diffusion of efficient technologies**, particularly into developing countries, and provide continual incentives for **technology development**.
- An agreement should provide incentives for the largest possible share of the world economy or relevant sectors to **participate**.
- An agreement should provide **incentives** for countries to participate in order to reduce free-riding through, for example, deterring non-participation and providing rewards for compliance and penalties for non-compliance.
- An agreement should be mindful of the fact that **economic and social development differ** across countries as do **endowments of natural resources**.
- An agreement should seek to reduce **leakage** across countries and between sectors within national economies.
- An agreement should provide countries with **flexibility** as to how to reduce emissions; they should not be prescriptive, although they could recommend low emission production processes or technologies.
- Negotiation of an agreement should involve participation by **governments and industries** to ensure decisions are based on the best possible information and to increase compliance.
- An agreement should lend itself to low-cost **implementation** and **monitoring** and should not be unduly complex.

42. The second reason is that the effectiveness of any one type of sectoral approach would vary depending on the sector in question. Historical baselines, for example, may be straightforward to calculate for one sector, but almost impossible for another given data availability and industry structure. For a highly concentrated industry an effective voluntary agreement might be able to be negotiated, whereas for a highly diffuse industry, negotiating *any* voluntary agreement would be very difficult simply because of the difficulties of bringing together a large number of firms.[32] A sector with high levels of technology adoption in which the majority of plants already have the best available technology may not be suited to any

emissions based agreement. An R&D-based agreement focusing on breakthrough technologies might be the more appropriate choice.

43. To provide a more concrete feel for the potential – and difficulties – of sectoral agreements, this paper focuses its attention on five key sectors of the global economy that total 32% of global anthropogenic emissions:[33]

- Aluminium – 0.9% of emissions, but a very high emissions intensity of 12.7 tonnes of CO_2 per tonne of aluminium (5 times that of steel and 14 times that of cement).
- Cement – 4.6% of emissions.
- Steel – 5.2% of emissions.
- Coal-fired electricity generation – 15.8% of emissions (70% of electricity and heat generation emissions).
- Automotive transport – 11.3% with light duty vehicles accounting for 6.7% of emissions.

44. There is no single type of sectoral agreement that self selects for any of these sectors. To provide a more realistic basis for discussion in looking at these five sectors, the paper focuses attention on two types of sectoral agreements: agreements on emissions intensity targets and agreements to pursue R&D.

45. Agreements based on emissions intensity targets provide flexibility in how emissions are reduced and transparency. They allow for differentiation of commitments with three main options possible: a uniform base level intensity; identical percentage cuts over existing emissions; or non-uniform percentage cuts over existing emissions. Emissions intensity agreements are, in principle, compatible with emissions trading. The existence of a trading scheme would provide financial incentives to firms to reduce emissions and would reduce economic costs associated with the agreement. The possibility of linking a sectoral trading scheme to trading schemes operating within national emissions caps would need to be further developed.

46. R&D agreements could provide a direct way for governments and firms to improve technology diffusion and induce further technology development – the key to significantly shifting long-term global emission trends.[34] We note, however, that R&D agreements cannot be considered as stand-alone solutions for bringing about the change required. Such agreements would need to form part of a broader policy mix that might include regulatory measures to provide direct incentives for the ongoing development of new technologies and improved uptake of already existing technologies.[35]

V SECTORAL ANALYSIS

47. This section provides an overview of each of the five globally significant sectors chosen and the issues that would be raised if an emissions intensity agreement and/or R&D agreement were to be contemplated. The background material for each sector is drawn from the detailed Annexes attached to this paper. For ease of comprehension and comparability, regional data is categorised into the same 14 regions where possible.[36] Unless otherwise referenced, all statistics and data can be found in the Annexes. A table containing the key data on each sector can be found on page 29.

Aluminium (refer Annex A)

48. Consuming an average of 15 000 kWh of electricity per tonne aluminium has been coined “solid electricity”. Globally, electricity costs average around a quarter of operating costs, although they can be higher than 35% in countries where other costs are lower and/or where electricity bought from the grid is more expensive. More than 95% of the electricity is used in the smelting stage of the production process and emissions from this electricity use, along with perfluorocarbon (PFC) and anode emissions, make the smelting stage the key emitting stage. Smelting accounts for 80% of all primary production aluminium GHG emissions. In 2004, emissions from the aluminium industry amounted to 390 Mt CO_2, 0.9% of total anthropogenic emissions.

49. With primary production of 30.0 Mt and secondary production about 7.7 Mt in 2004, the aluminium industry is distinctly smaller in scale than steel or cement. It is, however, experiencing significant growth, with primary aluminium production having doubled in the last twenty years. Growth since the mid 1990s has been particularly strong. The recycling of scrap (secondary production) now accounts for an estimated 22% of aluminium production, with most of this occurring in OECD countries where aluminium has been used intensively for many years and where scrap is more readily available. The share of secondary production is expected to continue to increase given its much lower capital costs and increasing availability of scrap. Stricter environmental regulations will also encourage increases in secondary production given that emissions are 5% of primary production per tonne of aluminium.

50. Primary aluminium production comprises three stages: bauxite mining, alumina refining and aluminium smelting. Australia and Latin America are now the largest mining and refining regions, while China and North America are the largest smelting regions accounting for 22% and 17% of world production. The primary aluminium industry has undergone significant consolidation in recent years and is now relatively compact with five companies representing 41% of world production in 2004. The top ten account for 54%. Significant economies of scale mean that small primary production plants are not economically viable.

51. Aluminium is heavily traded, reflecting the metal’s light weight and the fact that plant investment is driven around the world by where electricity is competitively priced and reliable. The availability of materials and the price of labour are also considerations, but proximity to consumers is not a driver in this industry. Of all production, 77% is traded across borders. Western Europe and the USA, while accounting for only 22% of world production, account for 44% of world consumption (each consumes roughly a quarter). Japan produces no aluminium, but accounts for 7% of consumption. Inter-regional trade is not restricted to neighbouring regions, although there is a tendency to trade more with neighbouring regions, for example, 55% of Australia/New Zealand exports are bound for Japan and Korea.

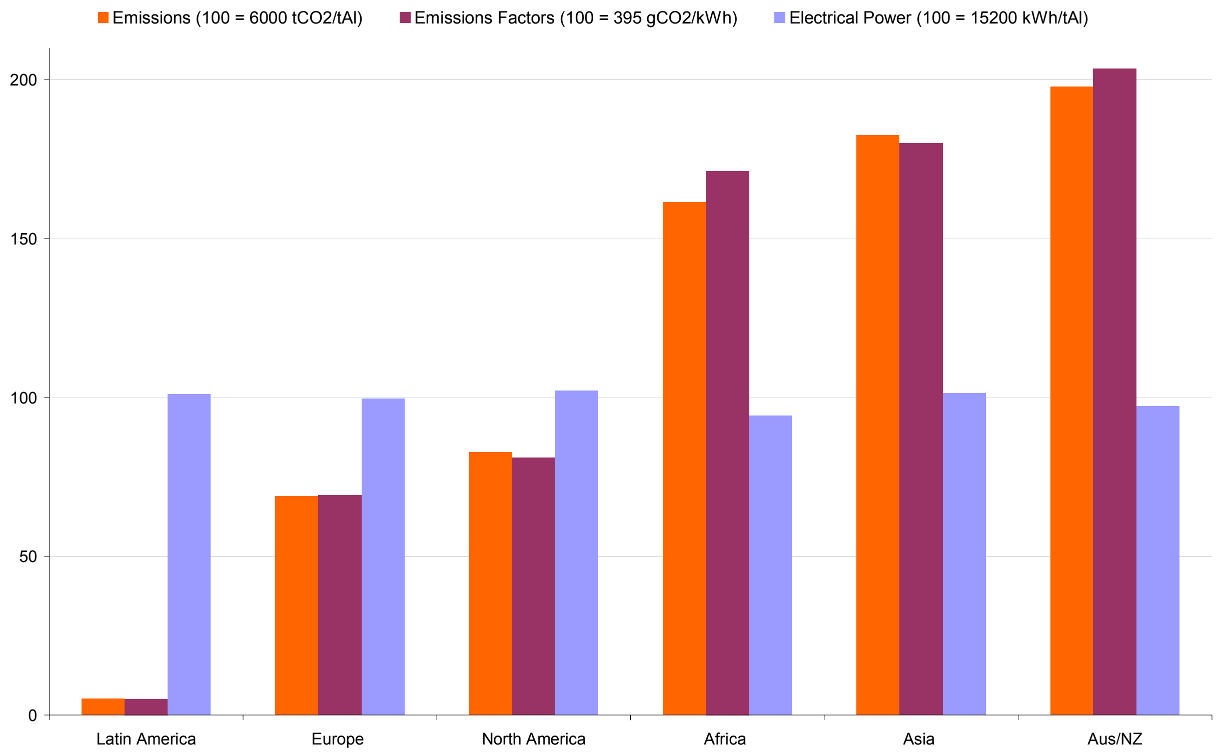
52. The uncertainty regarding growth in China greatly affects global consumption projections. Based on a simple linear extrapolation consumption over 1994–2004 shows that world consumption will rise to 42 Mt by 2020. China’s share of world consumption would rise to 28%.

53. Two types of technology dominate the smelting process. The first is Söderberg cells which are typically old, small and inefficient. They account for 27% of world production. A large share of the Former Soviet Union’s capacity is in this older technology, although in absolute terms, the OECD still has just as much capacity in Söderberg cells. Prebake technology is the other alternative and accounts for the remaining 73% of world production. There are a number of variants of this technology with point feeder prebakes being the most efficient and predominant type. The significance of electricity costs and the energy efficiency of prebake technology (it uses up to 20% less electricity than Söderberg cells), has meant that all new investment, regardless of location, is now in prebake point feeder technology.

54. Non-OECD countries do not have significantly higher emissions intensities than OECD countries. On average the production of one tonne of aluminium in the OECD emits 12.6 tonnes CO_2. In developing countries the figure is a little higher at 13.0 tonnes CO_2.[37] Process emissions (i.e. emissions excluding electricity) in some non-OECD plants can be as low as plants in the OECD. Emissions intensities for secondary production by region are not available, but developing countries account for little of this production. On average emissions from secondary production, per tonne of aluminium, are 5% that of emissions from primary production.

55. Emissions from electricity account for 57% of emissions emitted during the smelting stage. Figure 1 shows how these emissions vary across regions (data is not available in the 14 regions). The electricity used per tonne of aluminium is strikingly similar across regions indicating that plant efficiencies and the technology used are not too widely dissimilar. That said, there is still some difference essentially due to technology, operating efficiency and plant size. Emissions intensities are highest in those regions with predominant use of coal-fired electricity – Australia/New Zealand[38], Asia and Africa. Intensities are very low in Latin America where hydro electricity is the predominant source.

Figure 1 Primary aluminium electricity-based emissions intensities by region, 2003



Sources: International Aluminium Statistics (2005) and IEA Statistics.

56. The remaining smelting stage emissions are PFC emissions at 22%, anode-related emissions at 18% and 3% other. Since 1990, PFC emissions have been reduced by an average of 73%. There is considerable variation among plants ranging from less than 0.1 to 24.5 tonnes CO_2 equivalent per tonne of aluminium, although most plants have an intensity of less than one. The variation is due to the technology used and plant operating performance. Data on the variation by region were not developed for this project nor on the variation in the other emissions groups.

Negotiating an agreement in the aluminium industry

57. Negotiating an agreement in the aluminium industry would be made easier because the industry is fairly concentrated. There have already been two voluntary initiatives related to reducing GHG emissions negotiated under the auspices of the International Aluminium Institute, whose members represent 99% of global aluminium capacity. The high level of trade and high electricity costs have repeatedly led governments to make special arrangements for the sector. This suggests that the sector is one of, if not the most, susceptible to carbon leakage. Any country that raises electricity prices, whether as a result of environmental regulations or not, risks aluminium production migrating. On the other hand, migration may be less of a problem in terms of GHG emissions than in other sectors as the technology used in different regions does not differ as much as it does in other sectors and all new investment appears to be using the best available technology.

Negotiating an emissions intensity agreement

58. Any emissions intensity agreement would need to target primary production in which 80% of the emissions take place at the smelter. These include emissions from the use of electricity, PFCs and anode-related emissions. Consideration would need to be given to how secondary production could be rewarded given that its production reduces electricity use and emissions by 95% per tonne of aluminium compared to primary production.

59. An emissions intensity agreement may not be appropriate for the following reasons:

- CO_2 emissions intensity figures covering the whole of the smelting process are not available by region and even if they were available they may not be able to be released in those countries with only one or two smelters due to data confidentiality.

- Electricity is the source of 50% of emissions and it is often costly for a country to increase its share of non-fossil fuel electricity and importing cleaner electricity from another country is not always possible.

- All new investment already uses the most efficient technology.

- Plant efficiencies do not seem to differ considerably if data on electrical power use and OECD and non-OECD emission comparisons are to be a guide (more information on PFC emissions and anode emissions by region is needed to confirm this).

- The proportion of secondary aluminium is already expected to continue increasing its share of total aluminium production.

60. On the other hand, around 40% of world production is not produced at point feeder prebake plants and an emissions intensity agreement could hasten the rate at which this technology is replaced. An agreement could also accelerate the rate of increase in secondary production. Where there are differences in plant efficiencies an agreement could provide incentives for improvements. One could argue that the high proportion of electricity-related emissions is not a barrier to an agreement and that aluminium production should be encouraged to move to countries with clean electricity.

61. An agreement that set the intensity target below that of the current best performers might also bring forward near-term innovations which have not yet been commercialised. One possible near-term innovations for improving smelter energy efficiency is the wetted drained cathode. This technology can be retrofitted into existing smelting potlines and supporting infrastructure with cell modifications. Wetted

cathodes are anticipated to lower energy consumption of a Hall-Héroult cell by 10% when compared to a modern Hall-Héroult cell.

Negotiating an R&D agreement

62. An R&D agreement focusing on shifting the technology frontier may be more appropriate for this sector, although an emissions intensity target could complement it by providing incentives to firms to bring about technological change. While the aluminium industry has continuously improved smelting efficiencies through incremental changes, the basics of the Hall-Héroult smelting process remain unchanged.

63. Longer term alternative technologies are the carbothermic reduction and kaolinite reduction processes. These alternatives have higher onsite carbon emissions, but their electrical demands are significantly lower which results in lower overall emissions on average. The carbothermic process, the subject of extensive research for more than forty years, is the only non-electrochemical process that has shown potential for aluminium production. It is anticipated to save 20% in energy and be economical at a much smaller scale than Hall-Héroult facilities. The kaolinite reduction process is anticipated to save about 11% of energy required. Even though these alternative processes offer significant benefits to aluminium firms through lowering energy and raw material costs, governments could partner with the industry to increase the chances of these technologies becoming commercially feasible on a sufficiently large scale.

Cement (refer Annex B)

64. At 1 930 Mt CO_2 the cement industry emits 4.6% of global anthropogenic GHG emissions.[39] The production of clinker accounts for around 90% of cement emissions. Around 50% of cement emissions arise from the chemical process of converting limestone to lime to produce clinker. The emissions generated from creating the energy for this account for 40% of emissions due to 90% of the energy deriving from fossil fuels, in particular coal. Offsite electricity and transport emissions account for the remaining 10% of emissions. Developing countries account for 70% of global cement emissions. This figure is set to rise as developing countries continue to have higher demand for their construction and infrastructure sectors.

65. China is by far the largest producer of cement, accounting for 44% of the 2 186 Mt of world cement production. Its production is more than the next 27 largest countries combined. Western Europe is the second largest producer at 11% followed by South and East Asia at 8%. The industry has undergone significant consolidation over the past decade to the point where the five largest companies represent 42% of global capacity and the ten largest 55%. However, this high concentration does not tell a complete story. In the cement sector there is a vast number of very small firms. For example, estimates for the total number of firms in China are from 5 000 to 8 300 and the top five cement producers in Russia account for only 10% of production capacity.

66. Cement is primarily consumed close to where it is produced for two key reasons. The first is that raw materials for cement production are widely available. The second is that cement is a costly product to transport relative to its value, particularly over land. Only 5.8% of production is traded, with 40% of this traded between regions. More than half of the extra-regional exports are exported to neighbouring regions. The largest exporters are Western Europe, Japan and India while the USA is by far the largest net importer of cement, importing a net 21 Mt or 18% of its consumption.

67. Cement production consists of three main stages: raw material preparation, clinker production (the binding agent of cement) and finish grinding. The production of clinker involves the calcination process of

converting limestone to lime and is the most energy and emissions intensive stage accounting for up to 90% of total emissions.

68. Clinker can be made either in energy-intensive and small-scale vertical kilns or in more efficient, larger scale rotary kilns. Mid-1990s figures show that rotary kilns have mostly superseded vertical kilns and account for around 90% of production capacity. Only in China were vertical kilns dominant – recent figures show that vertical kilns still account for 75% of production. There are four different types of rotary kilns: wet, semi-wet, semi-dry and dry. Drier kilns are much more energy efficient. Because of the long technical life of cement plants (greater than 50 years) and because dry kilns have higher capital costs, dry kilns have not yet supplanted wet kilns. The wet process remains dominant in the Former Soviet Union and Australia/New Zealand and is still significant in the USA, Canada, India, Eastern Europe, Latin America and Africa.

69. Figure 2 shows the CO_2 intensity of cement production in the 14 regions. The figures include process emissions from the calcination process, emissions from energy use and offsite emissions from electricity and transport. It is apparent that there is no clear relationship between CO_2 intensity and the level of economic development, although Japan has the best performance driven by its exclusive use of dry kilns and very high operating efficiency. The following factors drive lower GHG intensities:

- A lower clinker-to-cement ratio, i.e. more use of additives in the cement mix (this lowers emissions from the calcination process and lowers energy use).

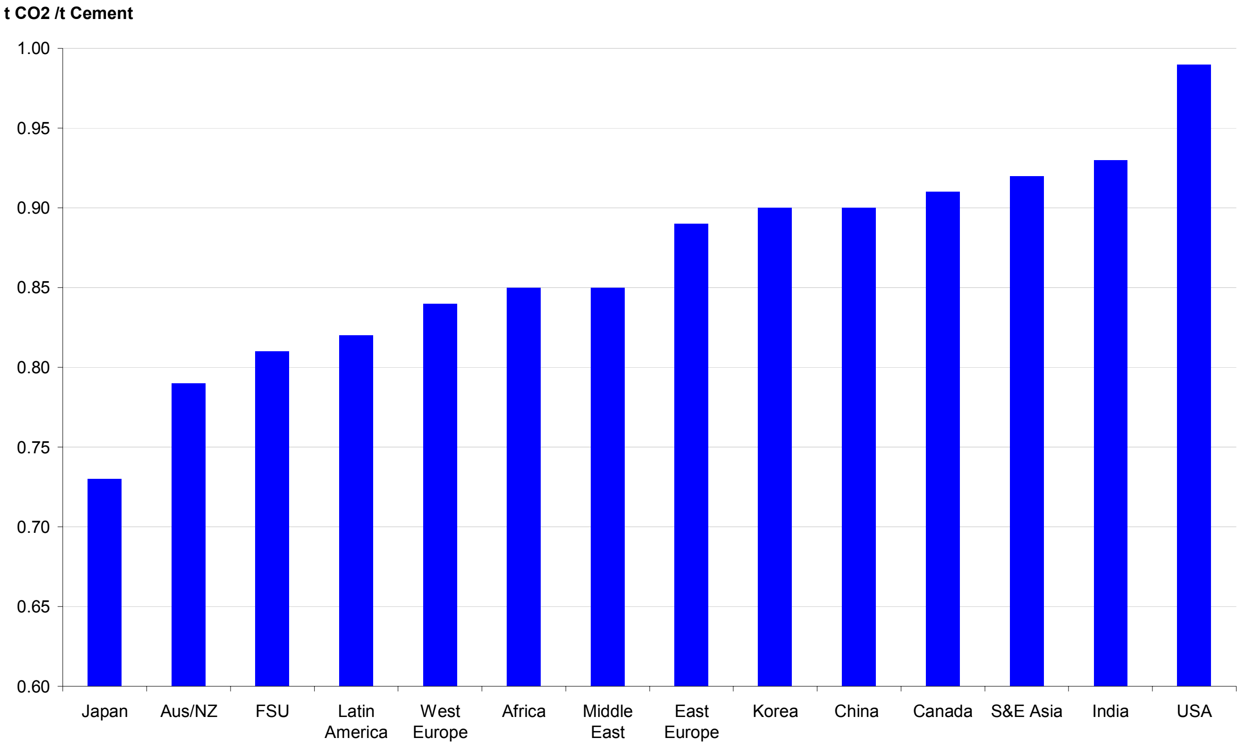
- Better operating efficiency and maintenance, and higher use of newer technology, in particular dry kilns, to lower energy use.

- Lower carbon fuel sources for burning in kilns: lower use of coal, particularly poor quality coal, and higher use of natural gas and alternative fuels such as bio-derived fuels.

- Drier raw materials, in particular limestone (lower moisture content reduces energy use and lowers pre-processing requirements).

70. The keys to reducing emissions are thus in lowering the clinker-to-cement ratio, improving energy use and lowering the CO_2 intensity of fuel. It is estimated that the increased use of fly ash and blast furnace slag (the two most common additives) to lower clinker requirements could reduce emissions by an average of 7% by 2020 with more than 34% possible in the USA, Canada and Australia/New Zealand. Improving plant efficiency through adopting more dry kilns and improving operating efficiency to lower energy consumption is estimated to reduce emissions by an average of 11% by 2020. Fuel switching from high-carbon to low-carbon content fuels is estimated to reduce emissions by an average of 3% by 2020. An aggressive effort to move toward bio-derived fuels such as municipal paper wastes, biomass and agricultural wastes as a substitute for fossil fuels could lower emissions by between 6% and 16% by 2020. In total the widespread adoption of best practice and technologies could reduce emissions by an average of 33% by 2020 over BAU.

Figure 2 Cement CO_2 intensities by region, 2000



Source: Humphreys and Mahasenan (2002).

Negotiating an agreement in the cement industry

71. Negotiating an agreement in the cement industry would be challenging. Carbon leakage does not appear to be a significant issue for the sector, either now or in the future, although it could be an issue for neighbouring countries where freight costs are low. As already noted, cement production is spread among many plants and companies across the globe and the level of international trade is very low. At the same time, a consolidation of the traditionally fragmented cement industry is under way through mergers and acquisitions, and through growth of large national players in emerging economies such as China and India. This increasing consolidation process may be accompanied by the establishment of a global cement industry institution, and thus better enable the cement industry to become a strong partner in sectoral agreements.

72. Cement is fundamental to construction and infrastructure and an agreement that indirectly raised the cost of cement may affect development needs in developing countries, particularly China. The participation of China would be pivotal in any agreement given its production and consumption. Encouraging efficient dry kilns and developing local skills to enable the more efficient operation of plants could, however, lower costs.

Negotiating an emissions intensity agreement

73. An emissions intensity agreement may be appropriate for the cement industry. There is significant variation in emissions intensities suggesting significant scope for improvement. As already noted, estimates of the potential to reduce emissions using current methods suggest emissions could be reduced by an average of 33%. An agreement could serve to provide incentives to countries to adopt these more

efficient technologies and practices. An agreement whereby all regions were required to reach Japan's level of efficiency in 2020 would result in emissions being 16% lower than they would otherwise be. Given the emission reduction estimates discussed, an agreement could seek emissions intensities even below Japanese levels (Japan's estimated reduction potential is around 35%).

74. An emissions intensity agreement with a uniform target for all countries would be difficult to conclude because the ability for each country to reduce emissions differs considerably according to industry structure, level of economic development, and natural resource endowments. Some countries may find it difficult to reduce clinker ratios because of limited availability of additives near cement plants. Regulations pertaining to building materials and public perceptions concerning blended cement may also be a barrier. Some countries may be restricted in substituting coal for lower carbon fuels and increased use of alternative fuels depends on improving accessibility through better organised waste collection and distribution. Dry kilns are costly and some countries with high moisture limestone such as Russia and Ukraine may require additional investment to adopt this technology. That said, rapid modernisation is possible. Poland and Romania opened their cement industries to capital investment by multinational corporations. Poland has reduced its energy intensity dramatically over the last ten years and now has one of the lowest intensities in the EU.

75. An agreement that sought percentage cuts based on existing intensities would probably be more suitable because initial starting positions would be taken into account. Those regions with higher estimated emission reduction potentials such as the USA, Canada, South and East Asia and Australia/New Zealand could be required to make steeper reductions. Those countries/regions with low use of the best available technology such as China would require financial assistance or indirect assistance through a mechanism such as a sectoral CDM which would provide firms in Annex I countries with incentives to invest in new technologies in non-Annex I countries.

Negotiating an R&D agreement

76. Cement appears to be well suited to an R&D agreement. Cement production is currently dependent on clinker which places a natural limit on reduction potentials. Aside from reducing the amount of clinker, a long-term option for reducing emissions is to find an alternative binding agent to clinker. Geopolymer binders are one example and it is estimated that their substitution of clinker could reduce CO_2 emissions by up to 80%. Geopolymers have not yet been successfully commercialised as a cement replacement on a large scale. Seeking an alternative binder to clinker represents a real R&D option for governments and cement companies around the world. There are other candidates for R&D such as new kiln concepts, but an alternative binder offers the best hope of significantly reducing emissions.

Steel (refer Annex C)

77. The iron and steel industry is the largest energy consuming manufacturing sector in the world. Taking into account all onsite emissions and the indirect emissions from electricity use, iron and steel production accounts for an estimated 5.2% of total world GHG emissions at 2 165 Mt CO_2. Of these emissions, 64% are emitted in non-OECD countries, even though their share of global production is only 51%. However, when allocating emissions on a consumption basis (i.e. after taking trade into account), OECD and non-OECD countries emit roughly the same amounts. This suggests that imports to the OECD embody a higher proportion of carbon than that produced in the OECD.

78. In the last five years global crude steel production has increased 34%, driven by strong demand in China. China is now the world's largest steel producer and consumer, accounting for 26% of world production and 26% of world consumption. Equivalent figures for Western Europe are 16% and 18%; for Japan 11% and 8%; and for the USA 9% and 11%. Demand for steel is closely linked to per capita incomes

with consumption intensities tending to fall after per capita income rises above about USD 10 000. It is therefore not surprising that Brazil, Russia, India, China, Eastern Europe and Turkey are expected to be the highest growth areas over the next ten years.

79. In some countries steel is dominated by a small number of large producers such as Australia and Korea. In others, such as China, it is characterised by a large number of small producers, although a number of very large efficient firms have emerged in recent years. Despite recent consolidation, the steel industry is less concentrated than cement and aluminium. The ten largest companies account for 28% of crude steel production and the next largest ten account for an additional 8%. By 2010, further consolidation could result in the ten largest firms accounting for 30–35% of world production.

80. Trade plays a major role in the steel market. About 30% of world production is traded across borders and 18% across the 14 regions. Japan, the Former Soviet Union and Latin America are the largest net exporters. China, South and East Asia, the USA and the Middle East are the largest net importers. A significant proportion of trade is between neighbouring regions. For example, 88% of Canadian exports and 53% of Latin American extra-regional exports are to the USA. The importance of trade reflects different cost structures in different countries. The cost of producing steel slabs in Russia, for example, is 36% less than in North America due to Russia's low raw materials cost. Labour costs range from 3% of the total cost in China to around 20% in OECD countries.

81. As with aluminium, there are two production processes for steel. The first is integrated steelmaking which dominates world production at 66%. This process uses iron for most of its raw material input. The basic oxygen converter route dominates integrated steelmaking at over 90%. This process has been gradually replacing less efficient open hearth furnaces since around 1965, although open hearth furnaces still account for 28% of production in the Former Soviet Union and 4% in India. The second production process is electric furnace steelmaking. This process mostly uses scrap for its iron units, has risen considerably in the last 25 years and now accounts for 24% of global production. Electric furnace plants are often called "minimills" because they are smaller than integrated plants and require less output to be profitable. They account for more than half of total steel production in the Middle East, South and East Asia, Africa and the USA, but little in the Former Soviet Union and China.

82. The integrated process is on average around 4.5 times more emissions intensive than the electric furnace process. This is because the reduction of iron ore to pig iron, carried out in the blast furnace, requires a large amount of heat and reducing materials provided by coke. Electric steelmaking uses much less energy because the steel only requires remelting and re-refining. It does, however, use three times as much electricity as integrated steelmaking. Emissions intensities therefore tend to be higher for those regions with predominant coal-fired electricity such as China and Australia.

83. Figure 3 shows emissions intensities for integrated and electric steel by region based on a sample of firms. Variations in emissions are primarily due to the amount of fossil fuel needed in the integrated steelmaking process. Lower fossil fuel use is associated with high operating efficiencies, superior plant maintenance, the use of newer technologies, and larger plants which generate economies of scale.

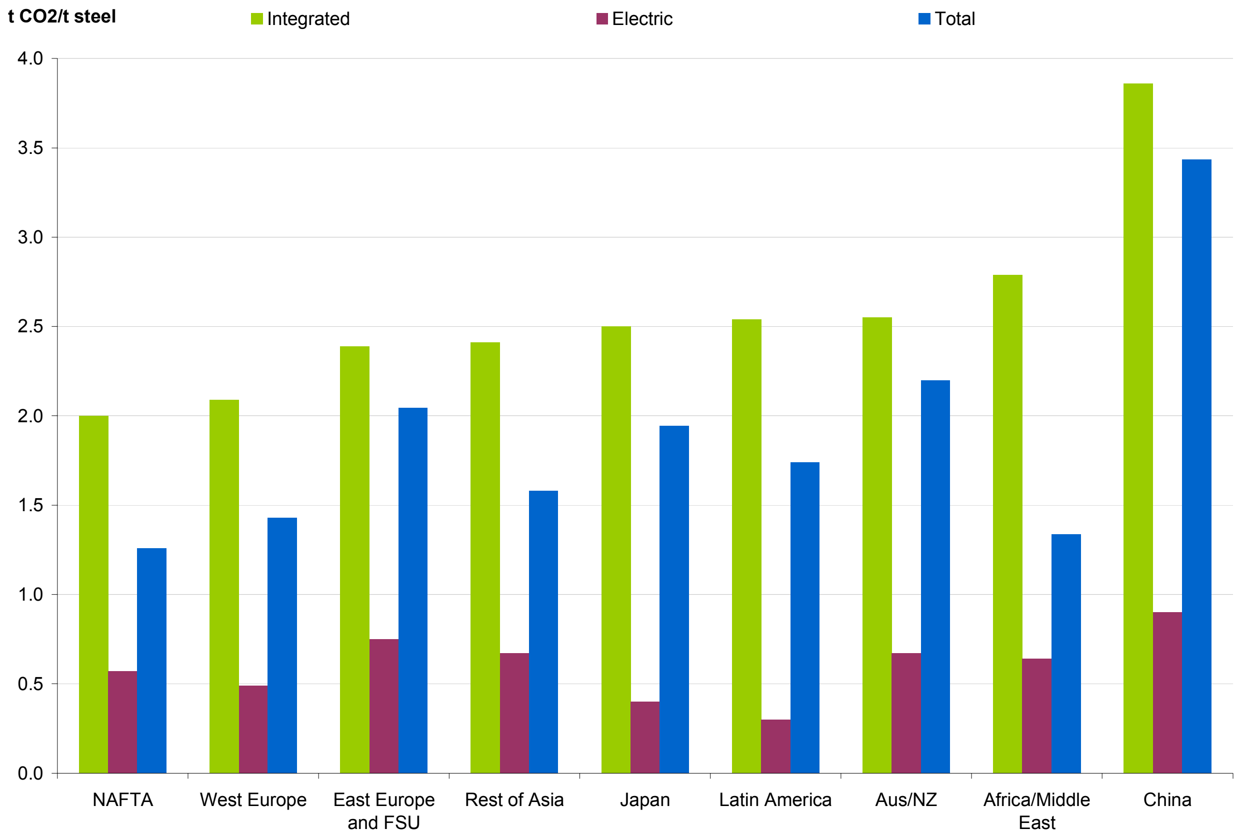
Negotiating an agreement in the steel industry

84. Negotiating any agreement in the steel sector may prove difficult. Some countries still view the steel industry as a strategic sector and it is often a large employer. Recent attempts to conclude an agreement on steel subsidies at the OECD have been unsuccessful. The industry is very cyclical and often has problems with overcapacity which heightens political sensitivities. In addition, the industry is fairly fragmented with production facilities in almost every country of the world. The International Iron and Steel Institute (IISI) covers only around 30–40% of world capacity. On the other hand, the coverage of the IISI does provide a

valuable co-ordinating point and its membership includes nearly all the world's major steel producers drawn from over 50 countries.

85. The prospect of carbon leakage may not provide a strong enough impetus to conclude an agreement. While the risk of carbon leakage may be considered moderate due to the significant level of trade at around 30% of production, steel is a non-homogeneous product and demand is relatively insensitive to price changes.[40] Steel producers can also respond to stringent environmental regulations by increasing production from scrap-based secondary production. It is probable that lower value added steel is more susceptible to migrating to non-carbon constrained countries because it generally requires a lower level of technology and skills. Those countries that currently face more stringent environmental regulations are more likely to have a greater proportion of higher value added output and are therefore less at risk of losing production to non-carbon constrained countries, at least in the short term. That said, countries currently concentrating on the lower value added products may also aspire to higher valued products in the longer term at which point the question of carbon leakage on these products will also arise.

Figure 3 Steel CO_2 intensities by region, 1995



Sources: International Iron and Steel Institute (2004a) and Mæstad (2000).

Negotiating an emissions intensity agreement

86. An emissions intensity agreement for the steel sector would have most impact on emissions if integrated steelmaking was targeted given its much higher intensities. Any agreement that targeted integrated steelmaking would have the effect of lowering emissions intensities from integrated steelmaking and shifting more production into electric furnace steelmaking. However, complete substitution is not

possible because secondary steel is not suitable for all applications. An agreement should therefore consider how to reward an increased proportion of electric furnace steelmaking given its superior environmental performance. This could be achieved through the earning of emission credits.

87. A range of technologies such as coke dry quenching, top-pressure recovery turbines, continuous casting and furnace gas recovery facilities exist that could improve plant efficiency and lower emissions. If all regions were to achieve near universal adoption of these technologies by 2020, emission reductions would amount to 173 Mt CO_2 in 2020, a reduction of 1.7% over the status quo. However, compared to other industries this is not a significant reduction. The substitution of scrap and direct reduced iron for pig iron in steelmaking, operating efficiency, plant maintenance, plant size and the type of steel produced are more important considerations, but data on these factors and the effect of these factors are much more difficult to measure. The capacity to estimate emission reduction potentials is therefore difficult and this would make the negotiation of an emissions intensity agreement complex. Further, emissions data for the industry is patchy meaning intensity data is not particularly reliable. It may be easiest for any intensity agreement to set a common target based on a slightly discounted value of best practice, although countries with smaller plants would find this very difficult to meet.

88. There are many new technologies at various stages of development and early commercialisation that could potentially reduce CO_2 emissions in the steel making process. These processes are not, however, universal substitutes for blast furnaces or direct reduced iron processes. Their applicability depends on (1) specific capacity size requirements; (2) the availability, price and quality of iron-bearing materials including scrap; and (3) the relative prices of metallurgical coal, lower grades of coals, natural gas and electricity. Their economic potential to reduce CO_2 emissions depends heavily on site-specific factors such as the availability of CO_2 storage capacity and the emissions factor (kgCO_2/MWh) of the power generation sector. In certain cases, they entail higher emissions than current blast furnaces. While accepting that these technologies cannot be applied everywhere, an emissions intensity agreement could accelerate their development and rate of uptake.

Negotiating an R&D agreement

89. There is a range of alternative technologies that could significantly lower CO_2 emissions. Carbon capture and storage offers a longer term possibility for steel plants, but would require significant external infrastructure. Substituting methane, hydrogen or biomass for coke in the reduction of iron ore are possible methods for cutting plant emissions, but the availability of these feedstocks is not yet sufficient. The Ultra Low CO_2 Steelmaking (ULCOS) initiative in the EU is one example of a public-private venture aiming to reduce emissions and is an initiative that other governments could potentially support or co-ordinate their actions with.

Coal-fired electricity generation (refer Annex D)

90. Emissions from coal-fired electricity generation account for 15.8% of global anthropogenic GHG emissions. They constitute 70% of emissions from electricity and heat generation. Emissions are projected to increase by 60% over 2003–2030 with developing countries accounting for close to 90% of this growth. Chinese emissions are expected to grow by 260% to account for 35% of the sector's emissions by 2030.

91. Coal currently accounts for more than 50% of electricity generation in China, India, Australia/New Zealand as a group, Eastern Europe and the USA. It will remain the electricity sector's main fuel over the next three decades in both the OECD and developing countries. By 2030, China and India together will account for 44% of worldwide coal-based electricity generation. Over 2003–2030 investment in coal-fired electricity generation plants is expected to amount to 1 400 GW with around two-thirds of these plants to be built in developing countries, especially in developing Asia. The scale of this investment is striking at

around $1.3 trillion. In general plants in developing Asia are, and will continue to be, less efficient than coal plants in OECD countries.

92. Of the three types of coal-fired plants operating today – pulverised fuel combustion, fluidised bed combustion and gasification – pulverised plants are by far the most common, accounting for more than 90% of capacity. Pulverised plants are broken into two groups: subcritical and supercritical. Supercritical plants have higher steam pressure, steam temperatures and generating efficiencies. Their emissions intensities are therefore lower than subcritical plants. Worldwide there are 400 supercritical plants mainly in Japan, Korea, the USA, Russia and Europe (more than half of coal capacity in Japan and Korea is supercritical). Supercritical plants are not automatically built by virtue of their higher efficiencies, even in wealthy countries. In the USA, Canada and Australia subcritical plants were still built in the 1990s because of these countries' low coal prices.

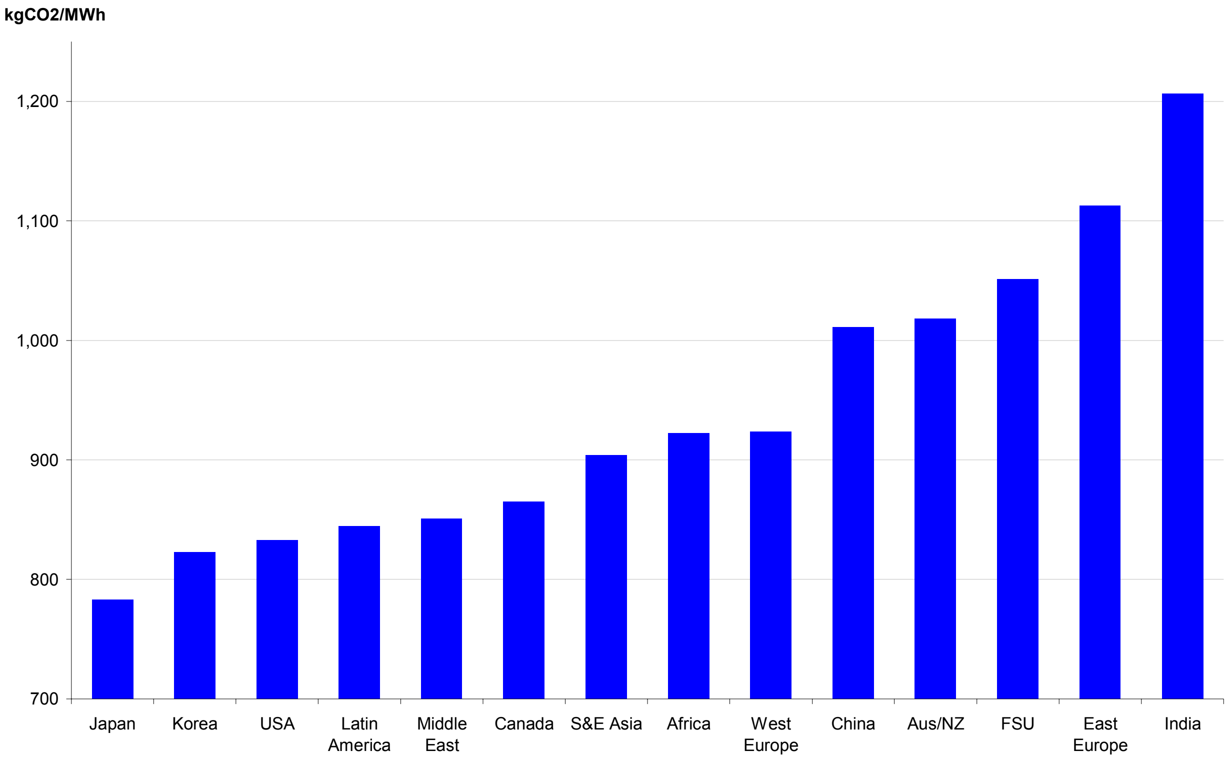
93. There are few fluidized combustion plants. Their competitiveness derives from their environmental performance when using low grade, high ash coals. Integrated gasification combined cycle (IGCC) is a relatively new technology and needs further research and development to reach its full potential. IGCC plants allow high efficiencies to be attained even when using low grade coals. There is scope in all three technologies for further efficiency improvements, with efficiencies up to 56% possible for pulverised combustion and gasification.

94. The CO_2 intensity of a region's coal-fired electricity generation (see Figure 4) is primarily driven by plant efficiencies. A one percentage point increase in efficiency leads to around a 2% fall in emissions. The following factors drive higher efficiencies:

- More advanced technology (the most important factor by far).
- Industry structure – smaller plants tend to be less efficient than larger plants.
- Plant maintenance and operating efficiency.
- Coal type – e.g. hard coal contains more energy than brown coal per tonne.
- Coal quality – e.g. low sulphur and low ash content coals produce more heat.
- The extent of coal preparation or washing which cleans coal of impurities raising its heat value.

95. Altering efficiencies beyond business-as-usual would have a significant effect on emissions. For example, emissions from the sector could be reduced by 17% in 2020 if all regions were to achieve the same efficiency level of Japan. World energy-related CO_2 emissions in 2020 would be 4.3% lower.[41] The key barrier to achieving this, however, is the high capital cost of cleaner technologies.

Figure 4 Coal-fired electricity generation CO_2 intensities by region, 2002



Source: Calculated from IEA Statistics.

Negotiating an emissions intensity agreement

96. It is clear that if an emissions intensity target[42] were to be negotiated each country would be starting from very different positions. In general those countries with lower levels of economic development have higher emissions intensities, but this is not a strong relationship. Australia/New Zealand have a high figure while Korea and Latin America are good performers. It would not make sense to adopt a uniform target for each region. It would be more appropriate to adopt a set percentage point reduction based on current levels to take into account initial positions. However, even this encounters some difficulties:

- For a country such as Japan or Korea achieving a 30% reduction on current intensities might be very costly given their already high use of efficient plants, although it would likely stimulate further technological improvements. On the other hand, for a country such as India achieving a 30% reduction (which would still leave its emissions intensity higher than Japan's today) would simply require the adoption of existing efficient technologies and best practice, but this would still be very costly.

- Some countries may find it difficult to achieve higher efficiencies because of their coal endowments. For example, countries with predominant brown coal use (Canada and those in Eastern Europe and Latin America) and/or coal with high ash and sulphur contents such as India might find it more difficult to reduce emissions because these coals contain less energy. Investment costs in new plants may also be higher given their fuel input mix.

- In some countries the phase-out of less efficient plants may be slowed by the lack of alternative energy sources which serve as substitutes to coal, by lack of finance or by rapid growth in demand.

- Many developing countries may not have the skills required to operate high efficiency plants and would need assistance.

97. The above difficulties point to the need for any agreement to be flexible – even a set percentage for each country may not be workable. An alternative to negotiating emissions intensity targets could be to target plant efficiencies through mandating certain technologies that meet a thermal efficiency of, for example 40%. The problem with this is that it would be less flexible than an intensity target because all plants would need to reach the same level whereas with an intensity target efforts would be distributed where they cost the less. Given the scale of the costs involved any agreement to reduce emissions in this sector would almost certainly need government assistance measures, helped by multilateral funds or mechanisms such as a sectoral CDM. However, this may push more investment into coal-fired generation at the expense of cleaner energy sources such as natural gas.

98. Partial equilibrium econometric modelling work commissioned by the Round Table indicates the following for a scenario where all countries reduce the CO_2 intensity of their coal-fired electricity sector by 30% for each 15-year period beginning 2005 until 2095:

- CO_2 concentration levels would be reduced by 3.9% in 2050 and 7.9%, relative to BAU (the BAU concentration levels are 525 ppmv in 2050 and 739 ppmv in 2095).

- Total emissions would be reduced by 2 064 Mt in 2050 and 2 489 Mt in 2095, relative to BAU.

- Electricity emissions fall by a little less than 50% in 2050 and by 60% in 2095 due to the improved emissions performance of coal plants and second-order effects (falls in coal generation, rises in gas generation, a five-fold increase in sequestration, and an overall reduction in electricity generation by about 8–10%, relative to BAU).

- Global cost is USD 198 billion in 2050 and USD 297 billion in 2095. Australia/New Zealand consistently have the highest costs relative to GDP with India, the USA and the Former Soviet Union following.

99. An agreement that targeted coal-fired electricity generation would appear to be a more effective way of reducing emissions than an agreement targeting the whole of the electricity sector. If the 30% intensity target were applied to the entire electricity sector rather than just coal generation, emission reductions would be up to 250% lower. The impact on CO_2 concentration levels would be around half that of targeting coal. The intensity target only applied to coal significantly lowers coal-fired electricity generation, increases the production of electricity from natural gas and increases coal sequestration. The cost, however, of targeting the coal sector and achieving greater emission reductions is higher, although it does lower over time: it is three times higher in 2050 and 30% higher in 2095.

100. At first glance this is a somewhat surprising result. There are, however, two reasons for the results. The first is that emissions intensity for the electricity sector as a whole would decrease regardless of a carbon policy. This is due to increased use of less carbon intensive electricity sources in the BAU scenario. Even with less optimistic technology assumptions in the BAU scenario, the electricity-wide target still results in fewer emissions reductions, but to a lesser extent. Business as usual activities thus allow for the electricity sector to meet the target partially but not completely. The second is that when coal is singled out

coal options are limited to a mix of higher cost capacity and higher cost carbon capture. This disadvantages coal in the competition with other sources and thus drives its use down.

101. An important consideration for any proposed emissions intensity coal-fired electricity agreement would be the treatment of combined heat and power (CHP) plants. It is very difficult at the moment to compare their efficiencies and CO_2 intensities with electricity-only plants because CHP plants have two outputs – heat and electricity. At present it is not clear how to allocate the inputs and CO_2 between the heat and electricity. If CHP plants were excluded from an agreement this would have significant implications for regions such as the Former Soviet Union and Eastern Europe where the majority of electricity comes from CHP plants.

Negotiating an R&D agreement

102. There is significant potential for R&D agreements in this sector. All current technology types have potential to improve efficiencies. This is heavily dependent on the further development of advanced materials such as new alloys. Beyond these incremental improvements, carbon capture and storage offers an option to significantly reduce emissions. At this stage, however, the costs of installing a plant with CO_2 capture in 2010 are expected to be 28% to 78% higher than a plant without capture. Efficiency losses are expected to be 6–12 percentage points due to additional fuel requirements.

103. Large-scale uptake of capture and storage technologies is probably ten years off. Some major technical and cost challenges need to be addressed before retrofit (or new build) of capture systems become an effective mitigation option. A key to achieving lower capture costs lies in the production of a more concentrated, pressurised stream of CO_2. CO_2 capture needs to be combined with high efficiency plants. New types of power plants such as IGCC plants allow the use of much more efficient technology because of their higher pressure and higher CO_2 concentration. Capture equipment costs are also subject to economies of scale. The existing IEA Greenhouse Gas R&D programme, set up in 1991, already provides an institutional framework which could be built on. The Carbon Sequestration Leadership Forum,[43] set up in 2003, increases awareness of sequestration issues among high-level policymakers.

Automotive transport – Light duty vehicles (refer Annex E)

104. Light-duty vehicles – cars, sport utility vehicles, small passenger vans and personal-use pickup trucks – account for 90% of automotive transport production and 59% of automotive transport emissions. In 2000, light-duty vehicles (LDVs) consumed 980 billion litres of fuel and emitted 2 800 Mt of CO_2 equivalent. This accounted for 6.7% of total anthropogenic GHG emissions. In 2000, 82% of LDV sector emissions came from developed regions with more than half of this from North America. If current trends continue, annual GHG emissions from LDVs will increase by 110% over 2000–2050, but the share of the OECD will fall to 48% of emissions by 2050. By 2050, North America is expected to still be the top emitter. US emissions will be more than double that of China, which will have overtaken Western Europe in the 2040s to become the second largest emitter.

105. In 2003, around 55 million LDVs were produced worldwide. Production is heavily concentrated in developed countries, although the share in developing countries, in particular China, is increasing due to their high demand growth. Production is concentrated in a dozen or so firms. In 2003, the five largest manufacturers accounted for 50% of production, the ten largest 74% and the 15 largest for 87%. Trade is significant in the LDV sector with $435 billion worth of automobiles traded in 2003. Japan was the largest net exporter at $65 billion followed by Western Europe at $30 billion. The USA is by far the largest net importer with net imports totalling $100 billion.

106. Around 90% of emissions in the LDV sector take place during the use of the vehicle. When looking at vehicle use there are two factors to look at: the number of LDVs and the number of kilometres travelled. On both of these measures OECD countries are dominant, accounting for around 80% each of worldwide LDVs and kilometres travelled. The total number of LDVs in use worldwide is expected to grow from around 700 million to just over 2 000 million in 2050. In 2050, 20% of all operating vehicles are expected to be in North America, followed by 17% in China, 13% in Western Europe, 10% in Latin America and 8% in India. In 2050, North America is expected to account for 27% of world passenger travel, followed by China at 15% and Western Europe at 13%.

107. Consumption patterns are determined by a complex mix of human behaviour, geography, economic growth and public policy. Higher average household incomes tend to lead to higher rates of personal vehicle ownership and longer and more frequent trips. On the other hand, higher acquisition and ownership costs, provided they are large enough, can significantly lower LDV consumption. Fuel costs are the largest element in the variable cost of driving and impact significantly on LDV use. Among IEA member countries, gasoline prices at the end of 2004 ranged from USD 0.50/litre in the USA to USD 1.55/litre in the Netherlands with a similar range for diesel.

108. Better availability, higher quality and lower cost public transport can significantly lower LDV ownership and use, but this is a relationship that cannot be easily disentangled from the spatial organisation of urban areas and different lifestyle factors. For example, poor parking availability and high parking costs can increase public transport use. Similarly, dense settlement and congestion caused by lack of roading space can make public transport more attractive in particular settings. The extent to which spatial planning tools can successfully be deployed to achieve lower emissions is the subject of significant debate.

109. The level of LDV ownership and their use explains a part of total emissions. The other part of the emissions equation is the emissions intensity or energy use of the fleet. Energy use is determined by energy intensity (fuel economy) and by the type of energy consumed (fuel mix). The most important factors bearing on fuel economy are power train efficiency, vehicle size, weight and performance. Important considerations for these are the materials used, aerodynamic drag, rolling resistance and technical innovations in engine design which enable more efficient fuel use.

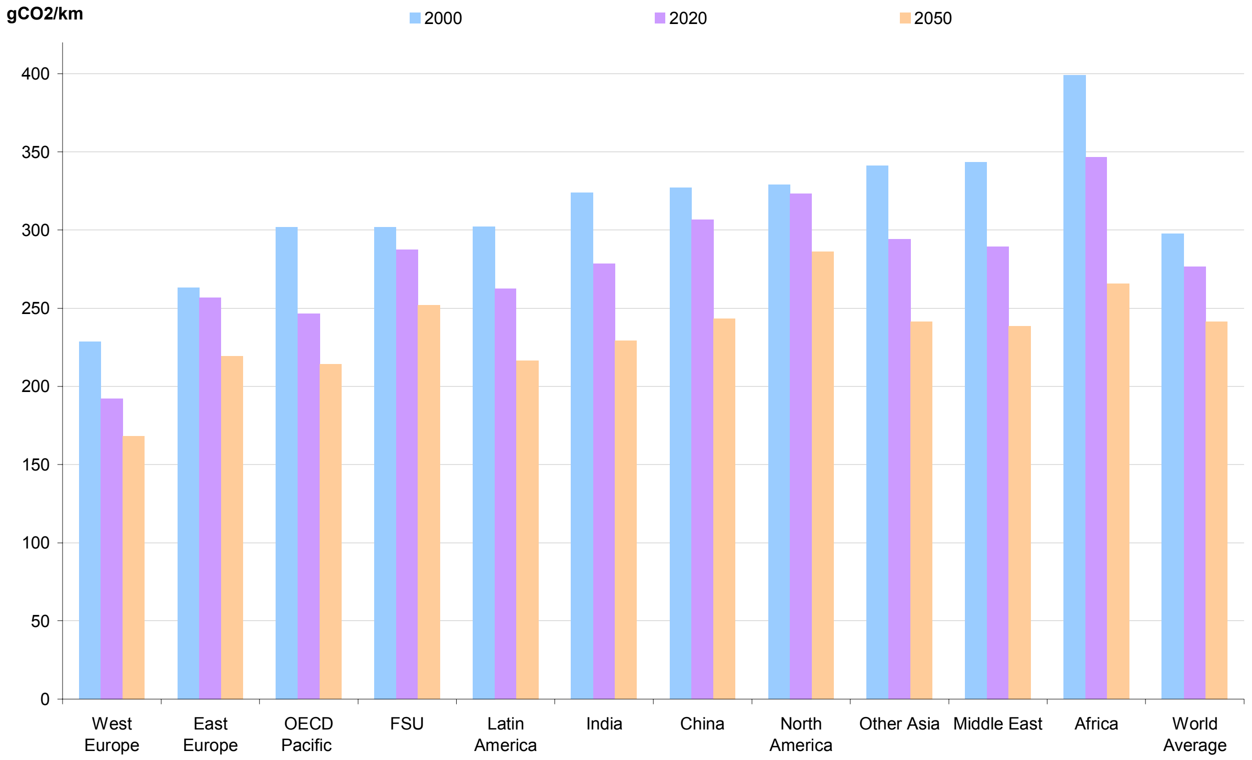
110. Fuel economy varies significantly across regions. Estimates in 2000 for fleet LDV fuel consumption averaged 10.3 litre/100km worldwide ranging from 23% lower in Western Europe to 35% higher in Africa. If present trends continue, worldwide fleet LDV fuel consumption will decline to 9.6 litre/100km in 2020 and 8.4 litre/100 km in 2050. Regional differences among developed regions will not only persist, they will grow. Fleet LDV fuel consumption in 2050 is projected to be 5.9 litre/100km for Western Europe, 7.5 litre/100km for OECD Pacific and 10.0 litre/100km for North America.

111. Fuel mix is predominantly fossil fuel based. Government policies, in particular the level of taxes on types of fuel, are the most important factor in explaining different fuel mixes across regions. In 2000, gasoline was used in 82% of the new LDVs sold worldwide. The principal alternative to gasoline is diesel, used in 16% of new LDVs sold in 2000. Diesel accounts for 9% of automotive fuel use worldwide, but a quarter of the fuel use in Western and Eastern Europe and India. Diesel engines consume 18% less fuel and emit 12% less CO_2 per km than gasoline internal combustion engines. New LDVs are over 85% dependent on gasoline in all regions except for Western Europe (58% gasoline) and Eastern Europe (78% gasoline).

112. Figure 5 shows emissions intensity by region. There is no clear relationship between intensity and economic development, although Western Europe is the best performer. Its low intensity figure is in large part due to its high level of dieselisation (40% of new LDVs are diesel powered) and higher fuel taxes. Higher fuel prices encourage more efficient use of fuel through incentivising consumers to purchase smaller, lighter, lower performing and/or more efficient cars, and to a lesser extent through more fuel

conserving driving styles. Spatial factors such as small parking spaces also play a part. The high emissions levels for North America are explained by its larger and heavier fleet and by the higher use of gasoline. The geographic expanse of North America and the spatial organisation of its cities and towns may also be important factors. Arguably, another important factor is the US CAFE Program which may have favoured the consumption of pick-up trucks relative to other LDVs, thus raising the size and weight of the US fleet.

Figure 5 Well-to-wheel GHG emissions intensity of automobile stock by region, 2000, 2020 and 2050



Source: WBCSD (2004).

Negotiating any agreement

113. The industry is very compact with the largest 15 companies accounting for 87% of global production and the share of developing country emissions is small at 20%. Even though this figure will rise over time, the economic development impacts on developing countries of a carbon-constraining agreement are perhaps less of a significant concern than for other sectors. This is partly due to the fact that the renewal of a country's automobile fleet often occurs much faster than the upgrading of production facilities.

114. However, with trade in excess of $400 billion per year and a significant degree of product differentiation, the LDV sector exhibits very strong competition globally. This high degree of competition and the economic value of the sector would likely make it very difficult to negotiate a sectoral agreement, not least because governments have used their regulatory regimes, in particular through the setting of standards, to attempt to confer competitive advantage on their firms. Evidence of both the possibilities for and barriers to a sectoral approach may be found in the report of the *Sustainable Mobility Project*, an industry study on which this paper has relied for significant amounts of data. The SMP was a collaborative project that brought together eight of the largest automobile manufacturers in the world together with some key associated energy and component companies. The report provides the most comprehensive industry

analysis of the challenges facing LDVs ever published and is something of a milestone in long term, sectoral thinking. However, while the report provides a detailed and thoroughly researched analysis of the problems caused by growing motorisation, it has little to say about the policy framework that would be needed to achieve some of the sustainability goals the report outlined. This is not surprising since changes in the overall regulatory environment go to the core of the competitive strategies of individual companies. It does however underline the difficulties that any sectoral agreement would face.

Negotiating an emission intensity agreement

115. There is a significant divergence in regional emissions intensities and this range is not expected to narrow. One striking projection is that the difference in intensity between Western Europe and North America is expected to become even wider in the future with Western Europe's intensity expected to be 40% lower than North America's in 2050. These differences have existed for some time and are entrenched in a complex web of factors, including government policy and mobility patterns. For these reasons a uniform target would be likely to be unworkable.

116. The major automobile manufacturers have concentrated their production and marketing on three major markets – the USA, the EU and Japan. Each of the markets has different policy settings that influence fuel economy, fuel taxation, car ownership costs, road infrastructure and public transport. Over many years these regulatory policies have shaped company behaviour, production strategies and consumer demand. Measurement of compliance differs considerably across regions with authorities in each region having developed their own tests. An agreement would need to establish common assessment methodologies or mutual recognition standards before any target could be implemented. The spatial organisation in towns and cities also varies considerably across all three markets. Local, state and national government policies have influenced this, but geography and the availability of land have also been major influencers.

117. The interplay among all of these elements is extremely complex. Negotiating an emissions intensity agreement would therefore be very difficult as it is hard to know the degree to which any one of these factors has affected the differences in variability. That said, even though the causes are complex, what is clear is that there is room for improvement. Given that government policies appear to have had a significant impact on shaping current emissions intensities, there is no reason in theory why they should not be able to influence fuel economy and emissions intensity in the future. In reality, however, governments are constrained by public expectations about access to mobility. Both consumers and governments will need to want change before emissions intensities can be significantly lowered.

118. Partial equilibrium econometric modelling work commissioned by the Round Table indicates that targeting the transport sector is not a cost-effective approach to reducing emissions. The scenario modelled envisaged all new passenger cars and trucks emitting no more than 140gCO_2/km for 2005–2020; in subsequent periods the standard is lowered 30%. Results show that this would result in a fall in emissions by 8% in 2050 and 11% in 2095, relative to BAU. CO_2 concentration levels would fall by 5% in 2050 and 14% in 2095, relative to BAU. The cost of achieving these reductions is, however, significant. The model predicts global costs of USD 2 462 billion in 2050 and USD 3 854 billion in 2095. The cost of *each unit* of emission reduction is around ten times higher in 2050 than targeting the coal-fired electricity generation sector and around eight times higher in 2095. The first reason is that sequestration is not a possible technology as it is in other sectors and alternatives to fossil fuels such as hydrogen and biomass are undeveloped and are not expected to be cost-competitive on a very large scale. The second is that transport demand is more insensitive to price than other sectors.

Negotiating an R&D agreement

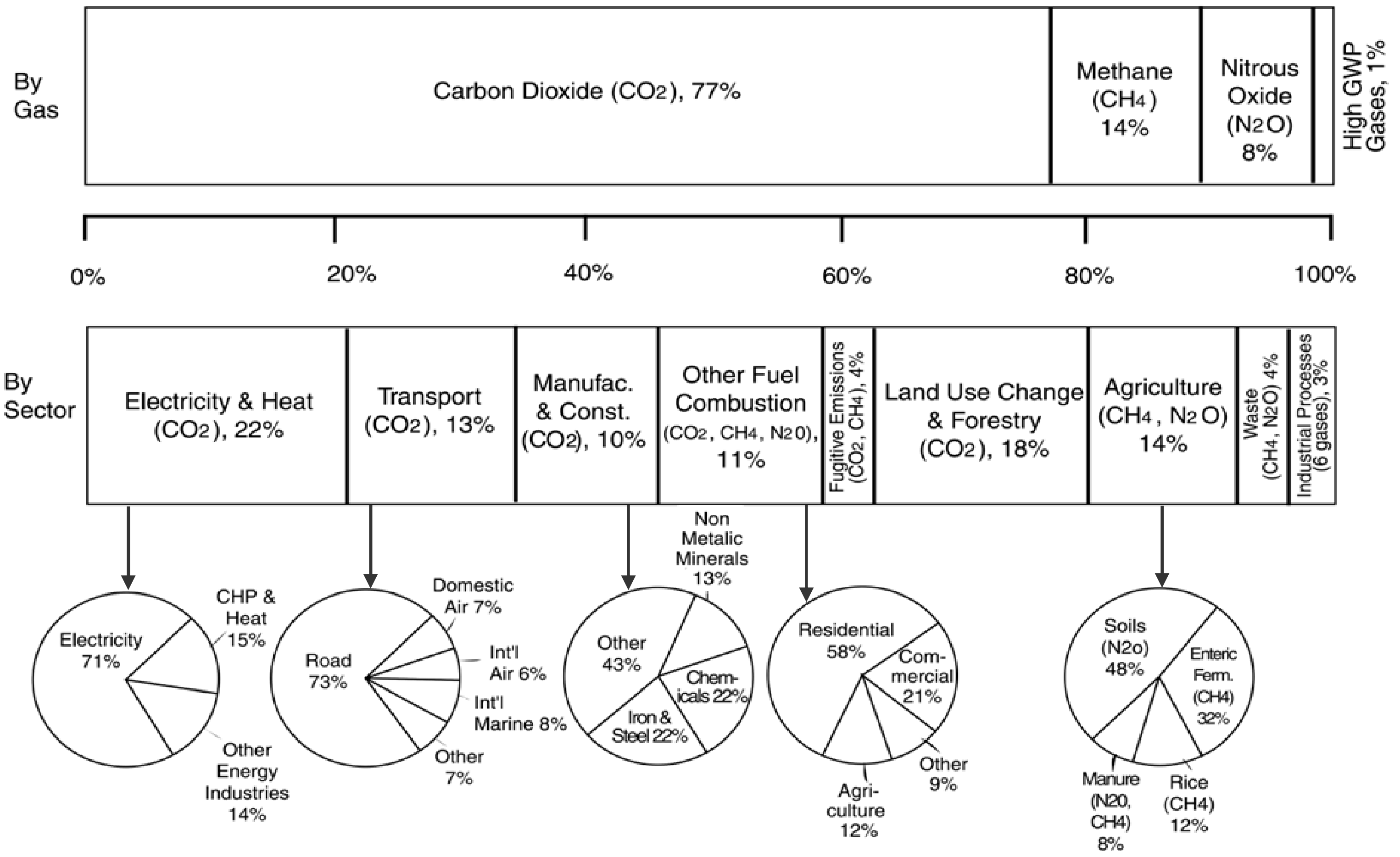
119. The LDV sector is currently dependent on one technology platform, the internal combustion engine. It is an inherently inefficient platform in terms of the fraction of energy consumed actually moving the vehicle and its load. Current gasoline vehicles with automatic transmission can have a well-to-wheel efficiency of less than 15%. Significantly reducing emissions intensity will rely on developing alternative propulsion systems and/or dramatically increasing the use of lower carbon fuels. There is a wide range of possible pathways to reduced emissions. Intensities range from 250gCO_2/km for an internal combustion engine fuelled by liquid hydrogen reformed from natural gas to zero emissions for a fuel cell using compressed gaseous hydrogen derived from water by using electricity which has been produced using renewable energy.

120. Estimates undertaken by the World Business Council for Sustainable Development indicate that "only the use of carbon-neutral hydrogen in fuel cells and advanced biofuels in internal combustion powered vehicles can largely or totally offset the growth in CO_2 emissions produced by the growth in road travel during the period 2000–2050". A range of initiatives exist that governments could build on, for example, the European Council for Automotive R&D, the US Council for Automotive Research and the US-led "International Partnership for the Hydrogen Economy".[44]

Table 1 Sectoral overview

	Aluminium, 2004		Cement, 2004	Steel, 2004		Coal-fired elec, 2002	LDVs, 2000
Production	**aluminium ingot (Mt)**		**cement (Mt)**	**crude steel (Mt)**		**generation (TWh)**	**vehicles (million)**
	Primary	Secondary		Integrated	Elec furnace		
Total Production	30.0	7.7	2186	698	357	6241	55 (2003)
% traded		75%	6%		30%	3%	
Share of 10 largest firms		54%(primary)	55%		28%	20%	74%
Emissions	**(Mt CO_2 eq.)**		**(Mt CO_2 eq.)**	**(Mt CO_2 eq.)**		**(Mt CO_2 eq.)**	**(Mt CO_2 eq.)**
	Primary	Secondary		Integrated	Elec furnace		
	386	5		1952	214		
Total Emissions		391	1930		2165	6636	2800
% of total anthropogenic GHG emissions		0.9%	4.6%		5.2%	15.8%	6.7%
Emissions intensity	**(t CO_2/t)**		**(t CO_2/t)**	**(t CO_2/t)**		**(kg CO_2/MWh)**	**(g CO_2/km)**
	Primary	Secondary		Integrated	Elec furnace		
Electricity	6.1	0.1	0.0	0.1	0.4		
Fossil fuel	2.6	0.5	0.4		0.2	1063	297
Process	Anode effect and anode consumption 4.0		Limestone calcination 0.4	Fossil fuel combustion & iron ore reduction 2.7			
Total Emissions Intensity	12.7	0.6	0.9	2.8	0.6	1063	297
Emissions reduction potentials							
Reductions using existing or near-term technologies	• point feeder prebakes		• dry rotary kilns with preheaters • alternative fuels • increased additives (~30–35% combined)	• continuous casting • furnace gas recovery • coke dry quenching • top-pressure recovery turbines (~2% combined)		• higher efficiency plants such as supercritical plants (17% in 2020 if all regions achieve level of Japan) • CHP plants (≤35%)	• diesels (18%) • hybrid gasoline-electric vehicles (30%) • diesel hybrids (36%)
Mid term possible technologies	• wetted drained cathodes (25%) • inert anode and wetted drained cathode (40%)		• combined electricity and cement plants (5–10%)	• CCF (≤45%), Circored (≤45%), Circofer (≤20%)		• further efficiency improvements and higher use of IGCC plants (≤30%)	• fuel cells based on fossil fuels (30–50%)
Long term possible technologies	• carbothermic reduction (6%) • kaolinite reduction (2%)		• alternative binders (≤80%) • carbon capture and storage (≤90%)	• carbon capture and storage (≤90%) • alternative reductants such as H_2 (50–60%)		• hybrid combined cycles • hydrogen (from coal) fuel cells; • carbon capture and storage (≤90%)	• fuel cells based on H_2 from renewable energy (≤100%) • advanced biofuels (≤80)

Figure 6 Global GHG emissions by gas and sector, 2000



Source: Baumert *et al.* (2005). Underlying data sources are International Energy Agency, U.S. Environmental Protection Agency, U.S. Energy Information Administration, Carbon Dioxide Information Analysis Center

VI DISCUSSION

121. The paper has aimed to shed light on the question of whether transnational sectoral agreements could help reduce greenhouse gas emissions. In limiting itself to an analysis of five key illustrative sectors, the paper has highlighted some of the possibilities and the difficulties of a sectoral approach, paying particular attention to emissions intensity based agreements and R&D agreements. It has not sought to provide any conclusions on the overall merits of a sectoral approach to reducing GHG emissions.

122. The sheer scale of the greenhouse gas emissions issue and the limited progress in negotiating instruments thus far make solutions that single out sectors worth looking at. Those sectors with easily monitored point source emissions or widely standardised technologies may offer an attractive option. Juxtaposing the forecast emissions growth in these sectors and the estimated technical potential for reducing them as summarised in Table 1 highlights what could be achieved if all new investment in each sector was at the current technical leading edge. It also shows how much more progress would be made if it were possible to bring forward more distant and speculative technologies.

123. What would be needed for sectoral agreements to bridge that gap? Two broad observations need to be made at the outset. In the first place, negotiating or mandating sectoral improvements would require clear and unequivocal government support and well defined relationships between any such agreements and existing or likely future emissions reduction policies. Business enterprises cannot be expected to commit significant resources to novel, stringent transnational and pan-sectoral agreements in the absence of strong political commitment and policy certainty. There will also be a need for solid support in the form of specialised data, enforcement and dispute resolution institutions.

124. Secondly, it has to be underlined that the issues in each sector are different and that an agreement would need to be tailor-made.

- **Aluminium** has very high levels of trade and electricity use accounts for 50% of emissions on average. Recycling of aluminium is growing and this is much less energy and emissions intensive. All new smelting investment in this sector uses the cleanest technology. Globally aluminium is now a well organised sector with the International Aluminium Institute encompassing 99% of global aluminium capacity and the top ten companies have a large share of the market at 51%.

- **Cement** has very low levels of trade and electricity accounts for only around 5% of emissions. The difference in emissions intensities is considerable with Japan's being 26% below the USA's. The bulk of emissions are produced as chemical byproducts in the production of clinker and as long as cement is dependent on clinker for its binding agent it will be challenging for the cement industry to reduce emissions in the absence of blending additives. The top ten cement producers account for 55% of global capacity, but there is a very large number of small players and there is, as yet, no global cement institute.

- **Steel** is the largest energy consuming manufacturing sector in the world. The difference in intensities is significant with North America's being 63% lower than China's. The use of coke as a fuel and chemical reactant in the production of iron accounts for 90% of steel emissions. There are two well developed production processes with the much cleaner secondary production based on scrap gradually expected to continue increasing its share. Plant efficiencies vary considerably across countries and economies of scale are significant. It is historically a politically sensitive industry and the industry remains fragmented with the top ten producers accounting for only 28% of crude steel production. The International Iron and Steel Institute covers only 30–40% of world capacity, but its membership includes nearly all of the world's major steel producers drawn from over 50 countries.

- **Coal-fired electricity generation** accounts for the bulk of electricity and heat generation emissions at 70%. The difference in emissions intensities is significant with Japan's being 35% lower than India's. It is overwhelmingly a domestic industry and unlike the other sectors, governments often have a large stake in production capacity. Coal endowments vary significantly across the world. Some countries have no coal resources, some have poor quality coal, while others have large quantities of very high quality coal. Capital investment in new, efficient technologies is very expensive and most investment in the next 25 years will be in India and China where the average plant efficiency is expected to fall well short of those available using the best available technologies.

- The **automobile** industry is dominated by a dozen or so large multinational companies. Unlike the other sectors, 90% of emissions are emitted during the use of automobiles, rather than their production. The emissions intensity (fuel economy) of an average car differs significantly across regions with Western Europe's level 43% below Africa's. Government policies on fuel efficiency, fuel taxation and car ownership costs significantly affect emissions as does spatial organisation and the quality and cost of public transport alternatives. The drivers behind lower emissions intensity are lighter, smaller and higher performance vehicles and higher use of non-gasoline fuels. Reducing emissions in this sector appear to be very costly because demand for mobility is insensitive to price and because alternative fuels such as hydrogen and biomass are not expected to be cost-competitive on a very large scale.

125. Notwithstanding these differences a number of provisional conclusions on both intensity agreements and R&D agreements can be advanced.

(a) Intensity agreements

126. Any discussion of intensity-based sectoral agreements takes place in the face of some unpromising realities. The divide between developed countries and developing countries is stark, with many developing country economies having rapidly expanding requirements for aluminium, cement, steel, electricity, automobiles and other emissions-intensive products. So long as capital costs for installing the most efficient technologies remain high, developing countries will struggle to reduce their emissions intensities to the level of those in the OECD.

127. Meanwhile, per capita emissions in developed countries remain significantly higher than those for developing countries and their total emissions as a whole continue to climb. Even the migration of manufacturing production to countries with lower labour costs, whether as a result of environmental regulations or other factors, is not altering emissions trends in developed countries. So long as some developed countries stand outside carbon-constraining global instruments, developing countries will have little motivation to join.

128. With this in mind it is to state the obvious to note that uniform global targets are likely to be unworkable for all of the sectors examined. There is significant variation between each country/region both with respect to current emissions intensities (although this appears to be less so in aluminium) and the estimated emission reduction potentials. This variation is due to differences in the supply of raw materials, existing technology stock, industry structure, consumer preferences and regulations. Some of these factors

are often beyond a government's control, in particular resource endowments and consumer preferences. More efficient technology – very often the main factor in reducing emissions – is nearly always associated with higher capital costs, but not necessarily higher operating costs. Developing countries would struggle to gather the required capital for these investments in the absence of multilateral funds or a mechanism such as a sectoral CDM.

129. Depending on the sector, a set percentage point reduction from current intensities could be workable, but it would depend on the estimated emission reduction potential. For a sector where the key levers to reduce emissions are beyond government and business control, even a set percentage may be unworkable. For example, in coal-fired electricity generation a country with poor quality coal resources, low levels of economic development, and small power plants would find it difficult to reduce its emissions by the same percentage as a developed country with high quality coal reserves and a more modern infrastructure. On the other hand, those countries with already low emissions intensities might face significant cost to reduce their emissions by a set percentage.

130. An emissions intensity agreement could be incentivised by allowing for emissions trading within the sector. The existence of a trading scheme would provide financial incentive to firms to reduce emissions and would reduce economic costs associated with the agreement. Even a non-binding agreement could incorporate trading to deliver incentives for exceeding a target while not punishing firms that did not meet the target.[45] The possibility of linking a sectoral trading scheme to trading schemes operating within national emissions caps would need to be further developed. Both governments and the private sector have roles to play in mitigating GHG emissions. Only markets can mobilise capital and technological development required whilst strategic direction must come from government.[46]

131. If transnational sectoral agreements were to have something close to global coverage, they would need to be attractive to developing countries. This would require incentives for investing in potentially expensive clean technologies – technologies that might not in the ordinary course of events be taken up in those countries. The principal vehicle currently available to incentivise mitigating Annex I country emissions through investments in non-Annex I countries is the Clean Development Mechanism under the Kyoto Protocol. The CDM has only been recently established. Many of the problems encountered at this stage appear to relate to the project-based nature of the mechanism. Establishing baselines against which real additionality of emissions reductions can be measured is a time-consuming and costly process on a project-by-project basis. Even where there is an existing baseline against which a project can be assessed, the procedure is still time-consuming and resource-intensive.

132. One means of overcoming these shortcomings would be to extend the CDM to accommodate whole sectors rather than single projects. The advantages of this approach would rest in the development of methodologies for establishing baselines on a pan-sector basis against which investments entailing emissions reductions possibilities could be more swiftly and reliably assessed using common information agreements. The CDM Executive Board has already approved three consolidated baseline methodologies. These could be a starting point for constructing sectoral baselines. A further development of consolidated methodologies could be a sector-wide emissions intensity level based on Best Available Technology. Any new investments that met or exceeded the sectoral baseline could be eligible to generate CDM credits. More ambitious baselines would reduce the risk of free-riding.[47] With regard to additionality, a sectoral approach can create incentives to invest in large projects and sell emissions reduction credits.[48]

133. Data problems faced by the current CDM are part of a wider issue facing any attempts to constrain future emissions growth. There are data difficulties with all of the sectors examined in this paper. We identified the following problems:

- Data is not always complete. For example, process emissions intensities for aluminium are not publicly available by smelter, country or region, although they may be able to be worked up with industry co-operation.

- Recent data is not always available. For example, the steel industry's emissions intensities in this paper are ten years old and were taken from a sample of firms from a proprietary database.

- Much data on industry costs and technologies is proprietary and cannot be published. While government could purchase the necessary data and use them in negotiations, the inability to publish such basic details would undermine the credibility of agreements. Furthermore, the data would be very costly to obtain and maintain on a regular basis.

- Developing country data on emissions and, to a lesser extent, industrial production is not entirely dependable.

- Data lags at the country level of two or more years could pose problems for monitoring sectoral agreements.

- Though firms' abilities to measure emissions are improving, through programmes such as the Greenhouse Gas Protocol Initiative, many firms, particularly small ones and those in developing countries, do not measure emissions all that accurately.

- Sub-sectoral classification difficulties between countries would become a problem if an agreement targeted a particular part of the sector (such as a type of cement).

- To the extent that data requirement include commercially sensitive information, data may need to be collected, compiled and monitored by third parties such as industry associations or commercial auditing firms. Firms are often hesitant to release sensitive information directly to governments.

134. Solving some if not all of these data problems would be an essential first step in any attempt to construct a transnational sectoral agreement in which governments could place confidence. A sectoral agreement simply to furnish information on emissions on a common global basis would be a minimal first step of considerable value in its own right. Assembling data in a timely and accurate fashion could well be a necessary first step in building the necessary confidence to consider some form of agreement with differentiated intensity targets. Governments could work with sectors to develop sectoral emissions reporting agreements without prejudice to their formal negotiating positions under the Framework Convention.

(b) R&D agreements

135. The paper has shown that all sectors have potential transformation technologies as well as incremental improvements to existing technologies that could significantly lower emissions. Sectoral R&D agreements could be used to further the development and implementation of emissions-reducing technologies. There are a number of existing initiatives that transnational agreements could build on such as the IEA Greenhouse Gas R&D programme. R&D agreements could be designed to be standalone programmes or as complements to intensity agreements. An intensity agreement could provide the regulatory incentives to develop new technologies by setting the intensity target(s) below that achieved by the current best available technology.

136. Collaborative R&D between companies is currently constrained by fears of antitrust lawsuits. The aluminium industry has, for example, indicated that this is the single largest barrier to firms in the industry collaborating on developing transformational technologies. Industry also appears reluctant to fund long term R&D with governments as governments cannot guarantee that they will meet their end of the bargain over a long time period such as 15 years. Governments will be concerned also with preventing free-riding by firms wherein firms have little incentive to invest in technology development if they can reap the benefits of the R&D anyway.

137. An agreement would need to clearly identify ownership: Once a new technology has been developed, who owns it? This would need to be clearly defined in order to maximise upfront participation and the technology's diffusion. Negotiation of this would clearly be much more difficult where the industry had a large number of players, but this is not always the case. An industry such as automobiles with as few as a dozen or so key multinational companies exhibits fierce competition. Collaborative R&D to accelerate the development of technological breakthroughs would be very hard to bring about, but clear ownership of property rights could help.

Trade

138. Finally, governments and trade diplomats have invested more than 50 years in crafting rules to govern trade flows in the expectation that the gains from freer and more predictable trade would improve living standards. A sectoral agreement aiming to reduce GHG emissions would need to be consistent with the two overriding trade principles of most-favoured-nation (treat trading partners equally) and national treatment (treat foreigners and locals equally). International institutions to address environmental problems are of even more recent origin than trade institutions. In the absence of a settled understanding of the relationship between multilateral environmental agreements and trade rules, participants in sectoral agreements would have to work hard to attain widespread participation and ensure that, in an effort to engage domestic industries, they did not resort to trade restricting measures such as non-tariff barriers.

VII CONCLUSIONS

139. There is nothing "obvious" that commends sectoral agreements as a way to reduce GHG emissions. But the characteristics of some sectors may make them more plausible candidates. The discussion of the five sectors above suggests that concentration of ownership, high levels of trade and significant scope to reduce emissions through known technologies are likely to be factors in favour of a sectoral approach. On the other hand, significant regional differences, widely dispersed ownership, differential regulatory settings and competitive pressures in specific markets will all pose potential barriers to the elaboration of agreements. To complicate matters, positive and negative characteristics exist side by side in the same sector.

140. Three general points commend themselves to any parties considering sectoral agreements. Firstly, a careful examination would need to be made by both governments and industries of whether the potential merits of initiating a sectoral approach were sufficient to justify the significant claims they would make on the attention of managers and officials. These judgments are beyond the scope of this paper and would have to be the subject of further work.

141. Secondly, a foundational element for any sectoral agreement will be the ability to generate high quality information on emissions. Since this applies to almost any imaginable emissions reduction regime,

a sectoral agreement to encourage the universal reporting of emissions would hold value even if it did not lead to any more ambitious undertakings.

142. Finally, given the significant investment in processes and institutions under the Convention (most notably emissions trading and the Clean Development Mechanism) it would be important at an early stage to consider the relationship between any proposed agreement and the existing architecture for addressing GHG emissions. More generally, sectoral agreements should only be attempted if they were to enhance the prospects of more broadly based emission reduction efforts.

143. If this seems a cautious assessment of the possibilities, it must be acknowledged that the potential exists to reduce significantly the rate of emissions growth – at least in the sectors examined here. Their contribution to reducing GHG emissions will depend on the extent to which their coverage approaches a global or near global level.

REFERENCES

Ahmad, N. and A. Wyckoff (2003), *Carbon Dioxide Emissions Embodied in International Trade of Goods*, OECD, Paris.

Barrett, S. (2003), *Environment and Statecraft: The strategy of environmental treaty-making*, Oxford University Press, New York.

Baumert, K., T. Herzog, and J. Pershing (2005), *Climate Data: A sectoral perspective*, World Resources Institute, Washington, http://www.pewclimate.org/docUploads/Sectoral%20Data%2Epdf, draft.

Bodansky, D. with contributions from S. Chou and C. Jorge-Tresolini (2004), *International Climate Efforts Beyond 2012: A Survey of Approaches*, Pew Center on Global Climate Change.

Bodansky, D., *et al.* (2004), *Strawman Elements: Possible approaches to advancing international climate change efforts*, Pew Center on Global Climate Change, prepared for the Climate Dialogue at Pocantico, http://www.pewclimate.org/docUploads/Strawman%20Elements.pdfSTRAWMAN%20ELEMENTS.

Bosi, M. and J. Ellis (2005), *Exploring Options for "Sectoral Crediting Mechanisms"*, OECD/IEA Project for the Annex I Expert Group on the UNFCCC, Paris, draft.

Bosi, M. and A. Laurence (2002), *Road-testing Baselines for Greenhouse Gas Mitigation Projects in the Electric Power Sector*, Information Paper for the Annex I Expert Group on the UNFCCC, OECD/IEA, Paris.

Bygrave, S. and J. Ellis (2003), *Policies to Reduce Greenhouse Gas Emissions in Industry: Successful approaches and lessons learned: Workshop report*, Information Paper for the Annex I Expert Group on the UNFCCC, OECD/IEA, Paris.

Grubb, M. and J. Wilde (2004), *The European Emissions Trading Scheme: Implications for industrial competitiveness*, Carbon Trust, London.

Ellerman, A. D. and I. S. Wing (2003), "Absolute versus intensity-based emissions caps", *Climate Policy* 3S2 (2003) S7-S20.

den Elzen, M. G. J. and M. M. Berk (2004), *Bottom-up approaches for defining future climate mitigation commitments*, RIVM report 728001029, Bilthoven, the Netherlands.

Herold, A. (2003), *Current Status of National Inventory Preparation in Annex I Parties and non-Annex I Parties*, OECD, Paris.

Humphreys, K. and M. Mahasenan with contributions from Placet, M. and K. Fowler (2002), *Toward a Sustainable Cement Industry: Substudy 8: Climate Change*, commissioned by the World Business Council for Sustainable Development, Battelle, http://www.wbcsdcement.org/pdf/final_report8.pdf.

IEA (2004), *World Energy Outlook 2004*, OECD/IEA, Paris.

IEA (2002), *Beyond Kyoto: Energy dynamics and climate stabilisation*, OECD/IEA, Paris.

Industrial Structure Council (2004), *Sustainable Future Framework on Climate Change*, Special Committee on a Future Framework for Addressing Climate Change, Global Environmental Sub-Committee, Industrial Structure Council, Japan.

International Aluminium Statistics (2005), International Aluminium Institute statistics, http://www.world-aluminium.org/iai/stats/index.asp, accessed March 2005.

IPAI (2000), *Aluminium Applications and Society, Life Cycle Inventory of the Worldwide Aluminium Industry with Regard to Energy Consumption and Emissions of Greenhouse Gases*, International Primary Aluminum Institute, Paper 1 – Automotive.

International Iron and Steel Institute (2004a), *Steel Statistical Yearbook 2004*, International Iron and Steel Institute, Brussels.

Jordan, A., *et al.* (2002), "The Innovation and Diffusion of 'New' Environmental Policy Instruments (NEPIs) in the European Union and its Members States" in Biermann *et al.* (eds.), *Proceedings of the 2001 Berlin Conference on the Human Dimensions of Global Environmental Change "Global Environmental Change and the Nation State"*, Potsdam Institute for Climate Impact Research, pp. 149–159.

Mæstad, Dr. O. (2003), *Environmental Policy in the Steel Industry: Using economic instruments*, OECD, Paris.

Mæstad, O. (2000), *Data For a Steel Industry Model*, Foundation for Research in Economics and Business Administration (SNF) working paper no. 86/00, Bergen, Norway.

Neuhoff, K. (2004), *Large Scale Deployment of Renewables for Electricity Generation*, Round Table on Sustainable Development, OECD, Paris.

Ninomiya, Y. (2003), "Prospects for Energy Efficiency Improvement through an International Agreement" in National Institute for Environmental Studies and Institute for Global Environmental Strategies (NIES/IGES) *Climate Regime Beyond 2012: Incentives for Global Participation*, Japan, pp. 16–19, http://www.nies.go.jp/social/post2012/pub/jrr2003-1.pdf.

OECD (2004), *Renewable Energy: Market and Policy Trends in IEA Countries*, OECD/IEA, Paris.

OECD (2003), *Voluntary Approaches for Environmental Policy: Effectiveness, efficiency and usage in policy mixes*, Paris.

OECD/IEA (2000), *Emission Baseline – Estimating the unknown*, OECD/IEA, Paris.

Philibert, C. (2003), *Technology Innovation, Development and Diffusion*, Information Paper for the Annex I Expert Group on the UNFCCC, Paris.

Philibert, C. and J. Pershing (2001), "Considering the Options: Climate targets for all countries", *Climate Policy* 1 (2001) pp. 211–227.

Philibert, C., *et al.* (2003), *Evolution of Mitigation Commitments: Some key issues*, Information Paper for the Annex I Expert Group on the UNFCCC, OECD/IEA, Paris.

Samaniego and Figueres (2002), "Evolving to a Sector-based Clean Development Mechanism", in Baumert *et al.* (eds.), *Building on the Kyoto Protocol: Options for protecting the climate*, World Resources Institute, Washington.

Schmidt, J., K. Lawson and J. Lee (2004), *Sector-Based Greenhouse Gas Emissions Reduction Approach for Developing Countries: Some options*, Center for Clean Air Policy, Working Paper prepared for the Dialogues on Future International Actions to Address Global Climate Change.

Tanaka, K. and H. Kudo (2005), *Sectoral Evaluation of the Utilization Potential of Energy Efficient Technology*, The Institute of Energy Economics, Japan.

United States Geological Survey (2003), *Minerals Yearbook (Volume I: Metals and Minerals)*, http://minerals.usgs.gov/minerals/pubs/commodity/myb/.

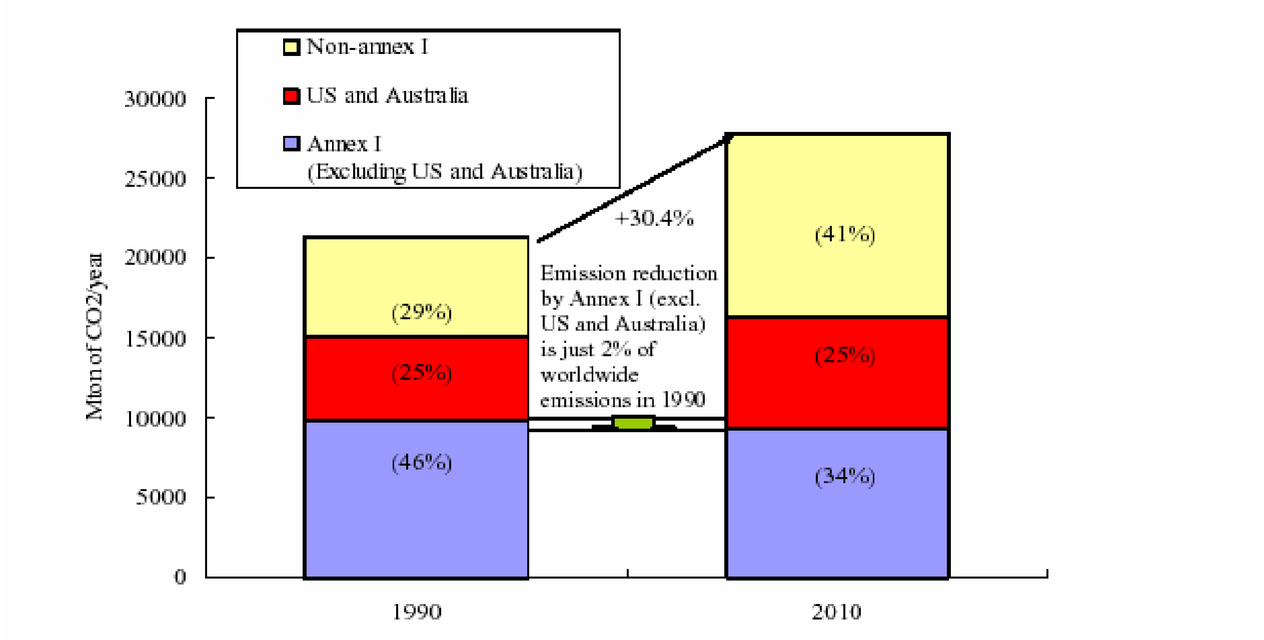
WBCSD (2004), *Supporting IEA/SMP Transport Model documentation and reference case projections*, The Sustainable Mobility Project, World Business Council for Sustainable Development, http://www.wbcsd.org/templates/TemplateWBCSD5/layout.asp?type=p&MenuId=ODE&doOpen=1&ClickMen.

ENDNOTES

[1] Unpublished results of econometric modelling performed by the Joint Global Change Research Institute, University of Maryland, for the Pew Center on Global Climate Change's Climate Dialogue at Pocantico. According to the runs commissioned, an economy-wide absolute emissions target with emissions trading would result in a reduction in global emissions of 34% in 2050 and a 66% reduction in 2095 compared to BAU. The resulting concentration level would be 567 ppmv in 2095, 23% below the reference case. This would come at a global cost of 0.3% of GDP in 2050 and 1.1% in 2095. To reduce one million tonnes of carbon comes at a cost of $511 million (USD 2003) in 2050 and $1 981 million in 2095. The policy scenario was: (1) for 2005–2020, the USA and Australia stabilise emissions at 2005 levels, other developed countries reduce 10% from 2005 levels; (2) all developed countries reduce emissions by 15% for each subsequent 15-year period until 2095; (3) developing countries enter when GDP per capita is at the low end of developed countries' GDP per capita; (4) for 2005–2020 and 2020–2035 developing countries stabilise at 2020 levels; and (5) for subsequent periods developing countries reduce emissions 15% each period.

A GHG emissions standard for new passenger cars and trucks would result in a reduction in global emissions of 23% in 2050 and 37% in 2095. The resulting concentration level would be 635 ppmv in 2095, 14% below the reference case. This would come at a global cost of 1.7% of GDP in 2050 and 1.4% in 2095. To reduce one million tonne of carbon comes at a cost of $3 330 million (USD 2003) in 2050 and $1 704 million in 2095. Therefore, compared to the absolute emissions target the unit emission reduction cost is 6.5 times higher in 2050 for an automotive standard, but is 15% *less* in 2095. A comparison of per unit emission reduction cost in 2030 shows that the cost is 19 times; in 2080 it has fallen to 1.45 times greater. Over time the per unit emission reduction cost gradually falls for automotive standards, but increases for absolute emissions targets. The policy scenario for the automotive standard was: (1) for 2005–2020 all new passenger cars and trucks emit no more than 140gCO_2/km (the EU standard in 2008); and (2) in each 15-year period until 2095, the standard is lowered 30% each period.

[2] The effect of the Kyoto Protocol is represented graphically below. The graph is sourced from Industrial Structure Council (2004). The source data is the US Department of Energy's 2004 *International Energy Outlook*.



[3] Article 3(9) of the Kyoto Protocol states "Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol… The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period…". The first commitment period is 2008–2012.

[4] IPCC (2001) *Climate Change 2001 – Mitigation* cited in Bosi and Ellis (2005) notes that responses to climate change can be more cost effective if deployed as a portfolio of policy instruments.

[5] A number of papers discuss advantages and disadvantages of a sectoral approach to reducing emissions. See, for example, Bosi and Ellis (2005); Schmidt *et al* (2004); Bodansky *et al.* (2004); den Elzen and Berk (2004); Philibert *et al* (2003); and Philibert and Pershing (2001).

[6] IEA (2004). See Annex D for further information.

[7] Current energy consumption in OECD countries averages 3.2 tonnes of oil equivalent per person. Energy consumption in the USA and Canada is significantly above the OECD average at 5.4 tonnes of oil equivalent per person. For non-OECD countries the figure is 0.7 tonnes of oil equivalent per person. Figures calculated from IEA (2004).

[8] If the effect of the Kyoto Protocol or any enhanced version of it were to displace carbon-intensive activity to countries not bound by the protocol, developing countries might receive a 'development' dividend. Global emissions, however, would be unaffected or even increased if the displaced activity was then undertaken using more carbon intensive energy sources and less efficient technologies. Meanwhile, unless the demand for carbon intensive products is reduced, the consumption of countries that have shed emissions intensive industries will continue to fuel those emissions through imports. A consumption-based approach to measuring emissions would more appropriately focus on the demand for products rather than on the supply of them. In many cases up until now, the major demand has been from developed countries and their responsibility for continuing high levels of emissions at a global level is masked by the approach under the Convention which has been from the outset to assess emissions where they are produced. An important distinction has to be made between growth in carbon emissions by non-Annex I countries resulting from increasing economic activity to meet local demand, and growth caused by meeting the demand of Annex I countries arising from those countries curbing production, but not demand. There is at least a prospect that the current system has an in-built tendency over time to transfer emissions to non-Kyoto countries.

Identifying the influence of the Kyoto Protocol on emissions and trade flows requires an empirically based behavioural model. Ahmad and Wyckoff (2003) state that "Equilibrium models such as the OECD's GREEN model have attempted to establish the possible size of changes in global (CO_2) emissions that might occur in response to policy or price changes, and these have tended to suggest that this was not likely to be significant. However, these models require a number of behavioural assumptions that can restrict the confidence with which conclusions can be drawn." (p. 12).

[9] In the manufacturing and construction sector fossil fuel combustion accounts for 10% of global anthropogenic emissions. The sector's use of electricity accounts for 10% of global anthropogenic emissions (this is included in the 22% figure for electricity and heat emissions). The sector's process emissions account for the remaining 3%.

[10] For example, Japan and France both have a target of a 75% reduction in CO_2 emissions by 2050. The UK and Sweden have a target of 60% by 2050. Germany and the Netherlands have 2020 targets of 40% and 30% respectively.

[11] See Bosi and Ellis (2005).

[12] For a more comprehensive list of possible instruments and approaches and for further discussion we refer the interested reader to Bodansky (2004), Philibert *et al* (2003), IEA (2002), and Philibert and Pershing (2001). Philibert (2003) provides more in-depth discussion on technology options.

[13] Developing business-as-usual emission projections and baselines for specific sectors and projects against which to measure emission reductions is difficult and full of uncertainty. It has been described as 'estimating the unknown' given the inherent uncertainty of establishing an emission level corresponding to what would otherwise happen (OECD/IEA (2000)). Bosi and Laurence (2002) examines the electricity sectors in Brazil, Chile and South Africa. Two key findings are that: (1) the types of data and data availability vary between countries; and (2) calculating an emission rate in countries with very little recent capacity additions is challenging because it is difficult to assess what and/or when new facilities will be built.

[14] These targets are also called relative or indexed targets.

[15] Ellerman and Wing (2003) argue that both absolute and intensity-based caps have the same effects in a world where future emissions and economic output are known with certainty. Outcomes for marginal costs, abatement, emissions and welfare diverge only because of the variance of actual future GDP relative to its forecast expectation. If GDP growth is greater than expected, an absolute cap will require more abatement and incur higher cost than an intensity cap; however, if GDP growth is lower than expected, it is the intensity cap that will require greater abatement and incur higher cost. Intensity limits result in less variation of abatement costs and welfare than do absolute limits.

[16] Ellerman and Wing (2003).

[17] The 1998 Protocol to the 1979 Convention on Long-range Transboundary Air Pollution concerning the Control of Emissions of Nitrogen Oxides contained fixed absolute country targets. In addition the Protocol required Parties to apply national emission standards to major new stationary sources (i.e. sources with a thermal input of at least 50 MW such as electricity and heat plants and commercial combustion plants) and new motor vehicles. A Technical Annex provides guidance on what these standards might be. Included in that advice are emissions intensities for the various sources based on the use of best available technology and practices. The text of the Protocol is available at http://www.unece.org/env/lrtap/full%20text/1988.NOX.e.pdf.

[18] See Philibert (2003) for further discussion.

[19] Ninomiya (2003) notes that the OECD and four major developing countries (Brazil, China, India and Russia) account for 77% of global primary energy consumption. Other countries will tend to follow their standards to ensure market access and economies of scale in production. Barrett (2003) states that "[i]f enough countries adopt a standard, it may become irresistible for others to follow, whether because of network effects, cost considerations (as determined by scale economies), or lock-in" (p.395).

[20] For example, Barrett (2003) notes that California shapes US automobile standards. The USA in turn plays a significant role in shaping automobile standards across the globe. "…the US market is too large for foreign manufacturers to ignore. This means that a large number of foreign manufacturers tool up to satisfy US regulations. But having already incurred this cost, these companies can supply cars satisfying the US standards in their home markets at very low cost. Domestic regulators in these countries will therefore have little to gain and much to lose by setting a different standard at home. Even countries that do not export to the United States have an incentive to adopt the same standards – or if not the same current standards than standards used previously by the United States. For example, Brazil adopted the 1975 US standards in 1992, the 1981 US standards in 1997, and the 1994–96 standards in 2000" (Barrett (2003), p.99).

[21] For example, the United Nations Economic Commission for Europe has extended the EU's harmonisation of automobile standards to much of Europe. The United States, Canada and Mexico are in the process of harmonising vehicle emission standards under the North American Free Trade Agreement. See Barrett (2003).

[22] See den Elzen and Berk (2004) for a more in-depth discussion of strengths and weaknesses associated with technology-based standards.

[23] Philibert (2003).

[24] The focus should be on both breakthrough and emerging technologies. A focus solely on breakthrough technologies may result in the neglecting of emerging, lower-cost technologies closer to being cost-competitive.

Total government energy research, development and demonstration (RD&D) budgets increased sharply after the oil price shocks in the 1970s. Budgets declined to about half of their peak levels by 1987 and remained relatively stable to 2002. See IEA (2004). Margolis and Kammen (1999) *Underinvestment: the Energy Technology and R&D Policy Challenge* cited in Neuhoff (2004) show that total investment in R&D in the US increased from USD 100 billion in 1976 to USD 200 billion in 1996, while US energy R&D in the US decreased from USD 7.6 billion to USD 4.3 billion. Private R&D in the energy sector is extremely low. In the USA, for example, 0.5% of sales revenue in the electricity sector is devoted to R&D, compared to 3.3% in the car industry, 8% in electronics and 15% in pharmaceuticals. See Neuhoff (2004).

[25] Bodansky *et al.* (2004).

[26] Under the UNFCCC, Annex I Parties are requested to provide annually an inventory submission of essential inventory data and background information on data and methodologies. Non-Annex I Parties need to provide national communications, which include national inventories, less frequently under the UNFCCC. Herold (2003) found that:

(i) During recent years Annex I Parties had considerably improved on the availability and timeliness of inventory submissions.

(ii) 104 non-Annex I Parties had provided initial national communications. However, none of the significant Parties such as China, India or Brazil had officially submitted a national communication.

(iii) Non-Annex I Parties usually had more incomplete and less transparent, consistent and accurate inventories than Annex I Parties. One particular problem was the non-availability in many sectors of activity data collected on a continuous basis.

A range of initiatives is underway to improve the consistency and accounting of emissions. For example, the Greenhouse Gas Protocol Initiative is a broad coalition of businesses, NGOs, government and inter-governmental organisations whose objective is to develop internationally accepted accounting and reporting standards for GHG emissions and promote their use in companies and other organisations. The GHG Protocol operates under the umbrella of the World Business Council for Sustainable Development and the World Resources Institute. For further information see http://www.ghgprotocol.org. An example of a sectoral inventory protocol is cement. Ten major cement companies have developed the Cement Industry CO_2 Inventory Protocol and are promoting its adoption by small and large companies around the globe. A copy of this is available at http://www.wbcsdcement.org/pdf/co2-protocol.pdf.

[27] OECD (2003) and Bygrave and Ellis (2003). Voluntary agreements are particularly common in Europe. For example, estimates for the number of voluntary agreements in Germany in 2001 were 130. In the Netherlands more than 100 voluntary agreements exist. Austria has around 30 and the UK had between 10 and 20 by the late 1990s. By 2001, there were nine EU-wide voluntary agreements. See Jordan *et al* (2002).

[28] See OECD (2003) for an in-depth analysis on the effectiveness of voluntary approaches.

[29] Philibert (2003).

[30] Bosi and Ellis (2005).

[31] Philibert (2003).

[32] Even if representatives could be assembled for all relevant countries, these representatives would need to consult with all their constituent members and come to an agreed internal position before entering negotiations with other representatives. They would also need to consult all members on negotiation proceedings and seek further agreement on new positions. This would be very costly and make negotiations slow and cumbersome. In addition, there is a significant risk of representatives being limited by their 'lowest common denominator' and therefore negotiating very weak targets.

[33] Each sector's emissions were calculated using production figures and emissions intensity estimates. The sector shares of total anthropogenic GHG emissions, except for automotive transport, are slightly overestimated for two reasons. The first is that they were based on 2002 or 2004 sectoral emissions and 2000 total anthropogenic emissions. The second is that sectoral emissions were calculated using emissions intensity estimates from 1995 for steel, 1998 and 2003 for aluminium and 2000 for cement.

[34] There is a range of opinion as to the readiness of existing technologies to reduce emissions. The IPCC, in their third assessment report completed in 2001, conclude that known technological options could achieve atmospheric stabilisation levels, such as 550 ppm, 450 ppm or below over the next 100 years or more. More recent publications, however, conclude that there is a need to intensify research on breakthrough technologies. See Philibert (2003). For this paper we assume that both improved technology diffusion of existing technologies and further technology development are important to solving the climate change problem.

[35] See Philibert *et al* (2003) pp.10–11 for further discussion.

[36] Canada, United States, Latin America, Africa, Western Europe, Eastern Europe, the Former Soviet Union, Middle East, India, China, Korea, Japan, South and East Asia, and Australia/New Zealand.

[37] These figures are calculated from (1) electricity consumption data by source reported by aluminium producers to the International Aluminium Institute, (2) electricity emissions factors from the IEA, and (3) a world average of 6.7 tCO_{2eq}/tAl of fossil fuel and process-related emissions, which was obtained from the IPAI (2000).

[38] Note that the combined region of Australia/New Zealand is misleading. Coal accounts for 78% of electricity generation in Australia. In New Zealand hydroelectricity accounts for 61%, natural gas 25% and coal 4%. The combined region Australia/New Zealand reflects the electricity generation of Australia because Australian electricity generation is five and half times larger than New Zealand's. Data was drawn from IEA Statistics (Energy Balances of OECD Countries).

[39] The emissions figure is calculated from (1) regional emissions intensities (Humphreys and Mahasenan (2002)); and (2) regional cement production data in 2002 (United States Geological Survey (2003)).

[40] See Mæstad (2003) for a discussion on the characteristics of the steel market. Modelling undertaken in Mæstad (2003) suggests that carbon leakage is a potential issue in the steel sector. The study estimates that an OECD-wide carbon tax would reduce OECD steel production by an estimated 9%. The reduction is much greater for integrated steel mills (12%) than for scrap-based secondary plants (2%). Non-OECD production would increase by almost 5%, implying a fall in world steel production of 2%. The carbon tax would induce some substitution from the use of pig iron towards more intensive use of scrap in integrated steel making. Scrap prices would then rise, thus weakening the competitiveness of secondary scrap-based production. The tax would reduce OECD steel CO_2 emissions by 19%. Global emissions from the sector would decline by 4.6%, twice the reduction in global steel production due to substitution towards a cleaner input mix and cleaner processes in the OECD. On the other hand, Grubb and Wilde (2004) suggests that the steel sector would not be significantly affected in the short and medium terms, but could suffer in the longer term. The paper looked at the impact of the EU emissions trading scheme and focused on the effect of higher electricity prices.

[41] IEA (2004) predictions for energy-related CO_2 emissions are 33 226 Mt in 2020. The CO_2 reductions arising from the hypothetical worldwide adoption of Japan's efficiency level is estimated to be 1 419 Mt in 2020.

[42] The intensity target could be based on CO_2 per unit of electricity produced as discussed or it could be based on CO_2 per output of the entire country (i.e. GDP). An intensity target indexed to GDP would have the effect of making greater end-use efficiency a way to achieve the target.

[43] The objectives of the CSLF are to:

- facilitate the development of improved cost-effective technologies for the separation and capture of CO_2 for its transport and long-term storage;
- make these technologies broadly available internationally; and
- identify and address wider issues relating to carbon capture and storage, including promoting the appropriate technical, political and regulatory environments for the development of such technology.

In 2004, one of the key outcomes was the presentation and endorsement of several projects such as the CSLF Technology Roadmap and the establishment of three Technical Group task forces. This includes projects involving research and development, information exchange and networking, facilitation of collaboration, public perception and outreach, support to policy formulation and institutional, regulatory and legal constraints and issues.

Member countries of the Carbon Sequestration Leadership Forum (CSLF) are Australia, Brazil, Canada, China, Colombia, the EC, France, Germany, India, Italy, Japan, Mexico, Norway, Russia, South Africa, the UK and the USA. The US Department of Energy acts as the Secretariat to a policy group and a technical group. More information is available at http://www.cslforum.org/index.htm.

[44] Further information on the "International Partnership for the Hydrogen Economy" can be found at http://www.iphe.net/defaultb.htm.

[45] Bosi and Ellis (2005).

[46] Diringer in Aldy *et al* (2003), *Beyond Kyoto – Advancing the international effort against climate change* cited in Bosi and Ellis (2005).

[47] Bosi and Ellis (2005).

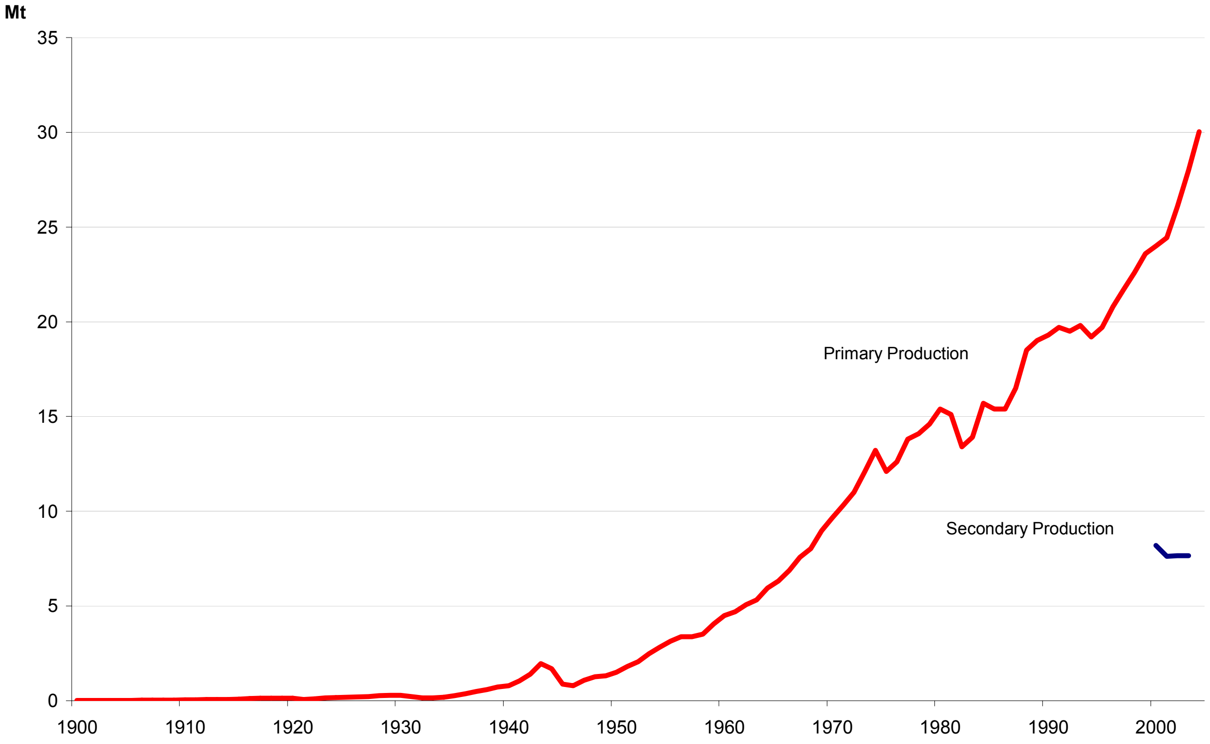
[48] Samaniego and Figueres (2002).

ANNEX A – ALUMINIUM

PRODUCTION

In 2004, world primary aluminium production was 30.0 million tonnes (Mt), 20 times the 1.5 Mt produced in 1950 (see Figure A1). The average annual growth rate since 1990 has been 3.2%. In 2003, secondary production based on recycling used aluminium was estimated at 7.7 Mt.

Figure A1 World aluminium production, 1900–2004

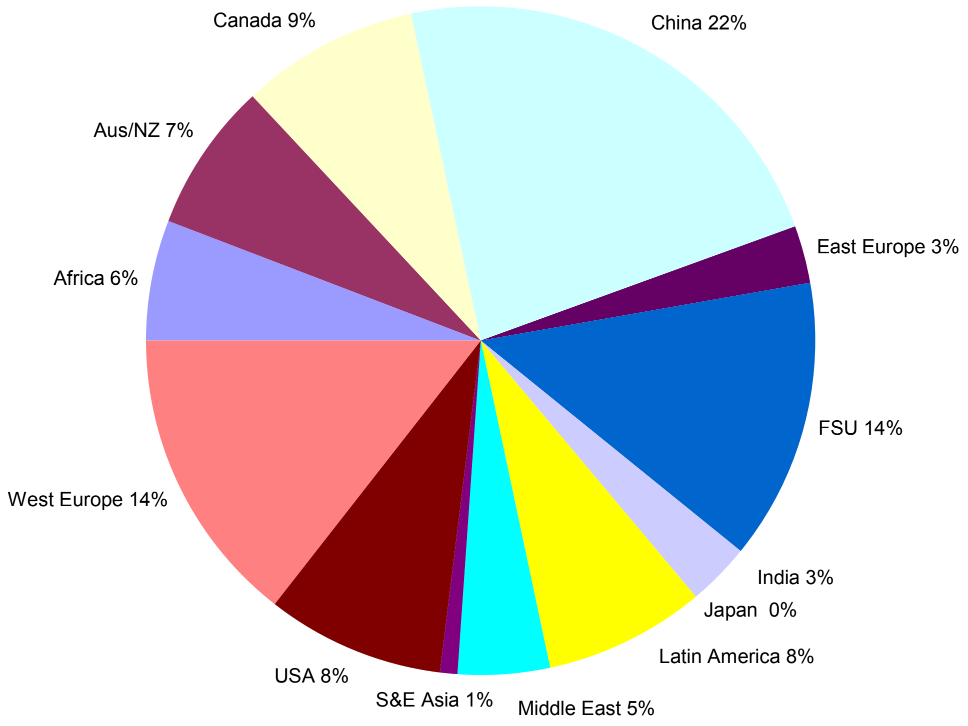


Sources: United States Geological Survey (2003) and World Bureau of Metal Statistics (2005).

Primary aluminium production comprises three stages: bauxite mining, alumina refining and aluminium smelting. Typically, these stages are geographically distinct from each other – different regions are dominant at each of the stages. Mining takes place where the primary raw material, bauxite is located. Smelting takes places where the power required is most reliable and least expensive (see Figure A2). Refining, the intermediate stage, takes place near the smelters in some regions of the world and near the mines in others. Australia and Latin America are now the largest mining and refining regions, while China and North America are the largest smelting regions. The Former Soviet Union is the third largest refining and smelting region. It should also be noted that during the last 30 years, a new group of "vertically integrated" producers – Australia, Brazil, China and the Former Soviet Union – active in all three stages, has emerged.

Secondary aluminium production involves the re-melting and casting of used aluminium. Its location is determined by the availability of scrap aluminium. Data on secondary production is poor, but it is believed that most (perhaps 90%) occurs in OECD countries where aluminium has been used intensively for many years and where used aluminium is more readily available, making recycling economically viable.

Figure A2 World primary aluminium production by region, 2004



Source: World Bureau of Metal Statistics (2005).

The industry has undergone significant restructuring in the past 40 years. In the late 1960s, the six major companies – Alcoa, Alcan, Pechiney, Reynolds, Kaiser and Alusuisse – controlled approximately 80% of total capacity of bauxite, alumina and aluminium. The number of players increased to more than 20 towards the end of the 1970s as many steel, base metal, energy and engineering firms adopted a strategy of horizontal integration and moved into aluminium. Since then, there has been a reconsolidation. In 2004, the top five companies represented 41% of world production and the top ten 54%.[1] Most aluminium companies are single metal companies, and only 20% are involved with other metals. Large vertically integrated companies, active in both recycling and bauxite mining, represent over half the world's production.[2]

CONSUMPTION

Aluminium consumption is driven primarily by growth in the construction, transportation and packaging sectors. Western Europe, China and the USA are the world's largest consumers of aluminium, each accounting for around a fifth of global consumption (see Figure A3). The uncertainty regarding growth rates in China (see Table A1) greatly affects any global consumption projections. Based on a simple ordinary least squares regression of consumption over 1994–2004 shows that world consumption will rise to 42 Mt by 2020. Regional shares are shown in Table A1.

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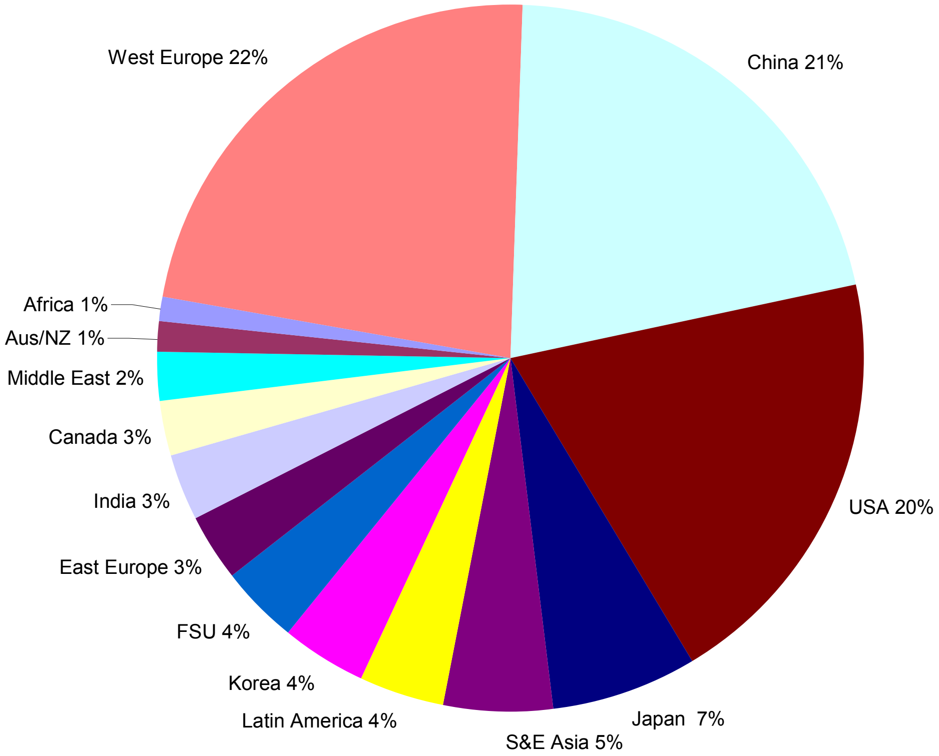
[1] Correspondence with Alcan May 2005.

[2] Bergsdal *et al*. (2004).

Figure A3 World primary aluminium consumption by region, 2004



Source: World Bureau of Metal Statistics (2005).

Table A1 Primary aluminium consumption growth and projections by region

	Average annual growth 1994–2004 (%)	Projected consumption shares in 2020 (%)
China	14.1	27.8
East Europe	8.6	4.2
Africa	7.5	1.4
FSU	6.5	3.8
Korea	6.2	4.2
Middle East	6.0	2.6
India	5.4	2.5
S&East Asia	4.3	4.7
Latin America	4.1	3.7
Canada	3.5	2.7
West Europe	2.8	22.4
USA	0.5	14.8
Aus/NZ	0.4	1.0
Japan	-0.3	4.0
WORLD	4.0	

Source: Calculations based on ordinary least squares regression of data from World Bureau of Metal Statistics (2005).

TRADE

Trade plays a major role at all stages of the aluminium production process. Of total world aluminium production (primary and secondary), 77% is traded across borders and 28% of world production is traded across the 14 regions shown in Table A2. The Former Soviet Union, (3.5 Mt), Canada (2.2 Mt), Australia/New Zealand (1.8 Mt) and Latin America (1.7 Mt) are the largest net exporters. The USA, Japan and Western Europe are easily the largest net importers.

Table A2 Aluminium trade (100 000 tonnes), 2003

Importing: *Exporting:*	Africa	Aus/NZ	Canada	China	East Europe	FSU	India	Japan	Korea	Latin America	Middle East	S&E Asia	USA	West Europe	Total exports	Extra-reg. exports	Net exports
Africa	2.1	0.0	0.0	0.4	0.0	0.0	0.1	2.1	0.8	0.1	0.1	0.8	0.5	0.5	7.9	5.8	4.1
Aus/NZ	0.0	0.4	0.0	1.9	0.0	0.0	0.1	7.9	2.4	0.0	0.1	3.5	0.8	0.3	19.3	18.9	17.7
Canada	0.0	0.0	-	0.0	0.0	0.0	0.0	1.2	0.8	0.5	0.1	0.0	24.3	2.0	28.9	28.9	21.7
China	0.1	0.4	0.2	6.1	0.0	0.1	0.0	2.9	5.1	0.1	0.2	1.3	0.3	0.3	18.0	11.8	3.6
East Europe	0.0	0.0	0.0	0.0	2.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	8.9	11.5	9.3	2.8
FSU	0.0	0.0	0.0	1.1	2.0	0.7	0.0	9.9	0.5	0.2	0.2	0.2	9.7	11.5	36.6	35.9	34.5
India	0.2	0.0	0.0	0.1	0.0	0.0	-	0.0	0.0	0.0	0.2	1.0	0.0	0.1	1.8	1.8	-0.4
Japan	0.0	0.0	0.0	1.1	0.0	0.0	0.0	-	0.3	0.0	0.2	1.0	0.1	0.1	3.5	3.5	-26.1
Korea	0.0	0.1	0.0	1.6	0.0	0.0	0.0	0.5	-	0.0	0.0	0.8	0.1	0.0	3.5	3.5	7.2
Latin America	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.1	3.6	0.1	0.0	10.8	5.6	24.8	21.2	16.6
Middle East	0.3	0.1	0.0	0.0	0.0	0.0	0.3	0.4	0.2	0.0	2.4	0.5	0.0	0.5	5.9	3.5	0.7
S&E Asia	0.0	0.2	0.0	1.1	0.0	0.0	1.4	0.2	0.0	0.1	0.1	3.9	0.1	0.1	7.6	3.6	-5.9
USA	0.0	0.0	6.7	0.3	0.0	0.0	0.0	0.1	0.2	3.0	0.2	0.1	-	0.5	11.3	11.3	-37.6
West Europe	0.8	0.2	0.2	0.5	4.4	1.1	0.1	0.3	0.3	0.7	1.3	0.4	2.0	75.3	88.6	13.3	-17.1
Total imports	3.7	1.6	7.2	14.4	8.7	2.1	2.2	29.6	10.7	8.2	5.2	13.5	48.9	105.6	269†		
Extra-reg. imports	1.6	1.2	7.2	8.3	6.4	1.4	2.2	29.6	10.7	4.6	2.8	9.5	48.9	30.3		172†	

Source: UN Comtrade.
Boxed fields: intra-regional trade. “0.0”: indicates trade of less than 5 000 tonnes between respective regions. “–”: indicates no trade between respective regions. Extra-regional exports = total exports less intraregional exports. Net exports = trade balance = total exports less total imports (negative values indicate net imports). †: Exports and extra-regional exports shown in the chart do not necessarily add to the total figure shown because of unspecified items in the raw data.

COSTS

The process of smelting consumes an average of 15 000 kWh of electricity per tonne of aluminium. This is a reduction of 6% compared to 1990 and more than 50% compared to the beginning of the century. Electricity costs average about one-quarter of primary aluminium production operating costs worldwide, although they may be more than 35%.[3] They represent a key to cost competitiveness, and are highly variable from producer to producer.

The electricity costs of secondary aluminium recycling plants are much lower as these plants require only about 5% of the electricity per tonne of aluminium compared to primary plants. Secondary plants are more sensitive to the prices, availability and quality of scrap aluminium.

In terms of investment costs, secondary plants cost much less than primary production plants. Primary plants involve capital investment of $1.5–2.0 billion for a plant of 500 000 tonnes of capacity.[4]

TECHNOLOGY

Aluminium is produced by two methods – primary based on ore and secondary based on recycling used aluminium. Primary production, which currently accounts for about 80% of world production, involves four principal steps.

1. mining to extract bauxite.
2. refining bauxite to produce alumina by the Bayer process.
3. smelting to produce aluminium by the Hall-Héroult process with ancillary anode production.
4. ingot casting to produce ingots for later fabrication into end-use products.

Secondary production involves:

1. collection of used aluminium.
2. re-melting of used aluminium to produce aluminium – usually in a natural gas-fired furnace.
3. ingot casting.

Smelting, the core of the process, is an electrolytic process that pulls the oxygen from alumina (Al_2O_3) to produce elemental aluminium (Al). It is an energy-intensive process because it takes a great deal of power to break the chemical bond between aluminium and oxygen. There are two major electrolytic technologies and each has several configurations:

- Söderberg technology: Vertical Stud Söderberg, Horizontal Stud Söderberg.
- Prebake technology: Point Feeder Prebake, Center Work Prebake, Side Work Prebake.

The Söderberg technology is typically older, smaller and less efficient (see Table A3). They account for 27% of world production, but represent a majority of capacity in the Former Soviet Union. In China there are more Söderberg plants by number than Prebake, but Prebake plants account for the majority of capacity given their larger size.[5] Recent information indicates that Söderberg capacity in China has been reduced to

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[3] Grubb and Wilde (2004). For example, costs in China are 38% of operating costs (Alcan (2004)).

[4] Correspondence with Alcan 18 May 2005.

[5] Bergsdal *et al*. (2004).

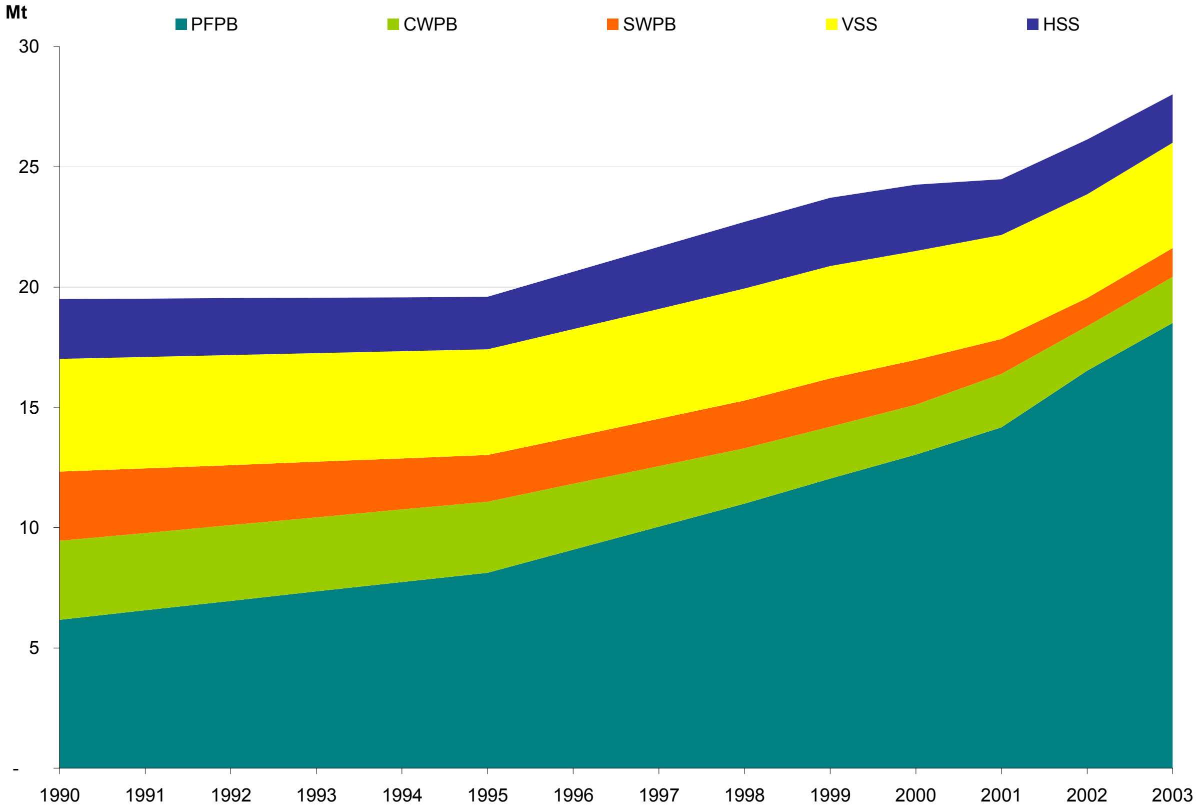
just 3% of total capacity.[6] New construction, regardless of location, is in the most efficient point feeder prebake technology.[7]

Table A3 Electricity consumption and CF_4 emissions in aluminium smelting, by technology

Technology	MWh / t Al	Median CF_4 emissions kg CF_4 / t Al[8]
Söderberg	16.6	0.58 Vertical Stud 0.30 Horizontal Stud
Center Work Prebake	15.5	0.19
Side Work Prebake	14.6	1.39
Point Feeder Prebake	14.4	0.08
All existing plants 1995	**15.5**	
Point Feeder Prebake (upgrade / brownfield expansion)	13.8	
Point Feeder Prebake (greenfield expansion)	13.3	

Source: Schwarz et *et al.* (2000), *Future carbon dioxide emissions in the global material flow of primary aluminium* cited in Bergsdal *et al*. (2004). CF_4 emissions from World Bank (2005).

Figure A4 Global primary aluminium production by technology type, 1990–2002



Source: International Aluminium Institute (2005b). Note: HSS = Horizontal Stud Söderberg; VSS = Vertical Stud Söderberg; SWPB = Side Work Prebake; CWPB = Center Work Prebake; Point Feeder Prebake.

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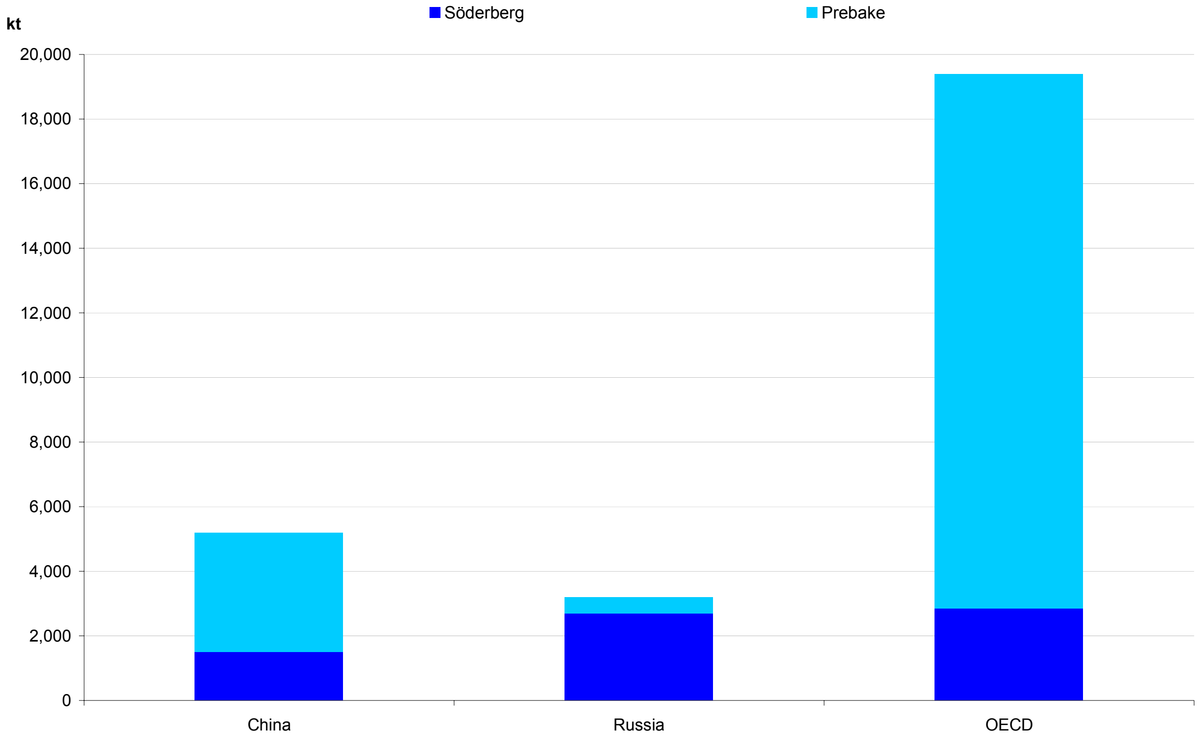
[6] Correspondence with Alcan 13 May 2005.
[7] Meeting with Alcan 30 March 2005.
[8] These CF_4 figures are for 2000. They are currently under review with the International Panel on Climate Change.

Figure A5 China, Russia and OECD aluminium smelter capacity by technology, 2003



Source: Alcan (2004).

Energy savings have been and are still actively pursued by aluminium producers since electricity costs constitute a high percentage of total production costs. The continuous improvement in smelting efficiencies that has occurred throughout the history of commercial aluminium production has come from relatively minor changes to the electrolytic process and from changes to cell configurations and from improved operating procedures. The basics of the Hall-Héroult smelting process remain fundamentally unchanged from the technology's inception in the late 1880s.

Additional improvements of both productivity and environmental performance are still possible. There are ongoing efficiency improvements in the Hall-Héroult process because of continued adoption of improved cell designs, improved feeding systems, improved bath composition, improved control systems, and other technical and practice advancements. This trend has resulted in a gradual decline in energy consumption in the range of 0.2–0.5% per year.

A large number of technological and engineering improvement options still exist and are being adopted by industry. Some examples include:

- Point feeders, which enable more precise, incremental alumina feeding for better cell operation.
- Improved process controls, which reduce the frequency of anode effects and control operational variables, so that cells remain at their optimal conditions.[9]

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[9] Choate and Green (2003).

One possible near-term innovations for improving smelter energy efficiency is the **wetted drained cathode**. This technology can be retrofitted into existing smelting potlines and supporting infrastructure with cell modifications. Wetted cathodes are anticipated to lower energy consumption of a Hall-Héroult cell by 10% when compared to a modern Hall-Héroult cell.

Two longer term alternative technologies to the Hall-Héroult process are the **carbothermic reduction** and **kaolinite reduction** processes:

> *"Both processes could potentially change where and how the industry operates, while lowering energy consumption. These alternatives consume more carbon and have higher onsite carbon emissions than the Hall-Héroult process. However, their electrical demands are lower which results in lower overall (utility-to-metal)* CO_2 *emissions. The carbothermic process, the subject of extensive research for more than forty years, is the only non-electrochemical process that has shown potential for aluminium production. It is anticipated to save 20% in energy and be economical at a much smaller scale than Hall-Héroult facilities. Kaolinite reduction – involving alumina conversion to aluminium chloride and reduction to aluminium -- was demonstrated in the late 1970s, but it was not commercialised because of problems with product purity and projected high capital and operating costs. New construction materials, improved thermodynamic understanding, and the potential to use low-cost alumina containing clays, rather than bauxite, have maintained the interest in the technology. The kaolinite reduction process is anticipated to save about 11% of the energy required for a modern Hall-Héroult system. However, the kaolinite reduction process is commercially interesting because of its lower on-site energy demands, use of non-bauxite ores, and lower-cost raw materials." (Choate and Green, 2003)*

EMISSIONS

Estimated GHG emissions of the aluminium sector are shown in Table A4. Current emissions are estimated to be 391 Mt of CO_2 per year, about 0.9% of total anthropogenic emissions.[10] About 60% of these emissions are estimated to be from primary plants in non-OECD countries, due to their large amount of primary production and their slightly higher than average electricity emissions intensities. Process emissions of smelters in developing countries can be as low as smelters in OECD countries. Another 39% of emissions come from primary plants in OECD countries. The remaining 1% of emissions are from secondary plants.

The primary and secondary aluminium processes have vastly different energy and environmental characteristics. Primary plants use 193.5 GJ per tonne of aluminium while secondary plants use 10.3 GJ per tonne. Primary plants emit 12.7 tonnes of CO_2 equivalent per tonne of aluminium compared to 0.6 for secondary plants.[11]

The energy used and GHGs emitted during primary aluminium production are shown in Table A5. Overall, for primary production from mining through to ingot casting:

- Anode production and aluminium smelting uses 75% of energy and 97% of electricity of the primary production route, and accounts for 80% of GHG emissions.
- Electricity accounts for 81% of energy used in the anode production and aluminium smelting stages.

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[10] The emissions figure for the aluminium sector is based on 1998 process emission intensity figures, 2003 electricity emissions intensity and 2004 production data. Aluminium's share of total emissions is likely to be a slight overestimate because the 2000 total anthropogenic GHG emissions figure was used as the denominator.

[11] IPAI (2000).

- Anode feedstock (coke) accounts for 13% of the energy used.

Table A4 World aluminium GHG emissions profile, 2004 estimate

	OECD	Non-OECD	Total
Production	**(Mt)**	**(Mt)**	**(Mt)**
Primary	12.0	18.1	30.0
Secondary	7.0	0.6	7.7
Total production	19.0	18.7	37.7
Apparent consumption	**(Mt)**	**(Mt)**	**(Mt)**
Total primary consumption	17.3	12.2	29.5
Emissions intensity	**(t CO_2/t)**	**(t CO_2/t)**	**(t CO_2/t)**
Primary			
Electricity	5.9*	6.4*	6.1*
Fossil fuel	2.6**	2.6**	2.6**
Process	4.0**	4.0**	4.0**
Total	12.6	13.0	12.7
Secondary			
Electricity	0.1**	0.1**	0.1**
Fossil fuel	0.5**	0.5**	0.5**
Process	--	--	--
Total	0.6**	0.6**	0.6**
Weighted average emissions intensity	8.2	12.6	10.3
Emissions	**(Mt CO_2)**	**(Mt CO_2)**	**(Mt CO_2)**
Primary	151	235	386
Secondary	4	0	5
Total emissions	155	236	391

Sources: World Bureau of Metal Statistics (2005) and IPAI (2000). *2003 data. **Estimated using global average based on 1998 data. Considerable variation exists among plants due to installed technologies and operating performance.

There are five major sources of GHG emissions in anode production and aluminium smelting:[12]

1. CO_2 from the production of **electricity** used in electrolysis. On average this accounts for 57% of smelter emissions. There is significant regional variation depending on the fuel source.
2. CO_2 from **fuel use**. On average this accounts for 2% of smelter emissions.
3. CO_2 process emissions from **carbon anode oxidation** during electrolysis. On average this accounts for 16% of smelter emissions.
4. **Perfluorocarbons** (PFCs) process emissions produced intermittently during brief process upset periods in electrolysis known as anode effects. On average this accounts for 22% of smelter emissions. There is significant regional variation depending on the type of technology used and plant performance. Through the International Aluminium Institute sustainability initiative, primary smelters are reporting PFC emissions on an ongoing basis.
5. CO_2 **miscellaneous process emissions** such as coke calcinations and anode baking. On average this accounts for 3% of smelter emissions.

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[12] Some sites may also emit small amounts of sulphur hexafluoride (SF6) where the gas is used as an inert cover gas in electrical equipment.

Table A5 Energy use and emissions profile of primary aluminium production

	Bauxite mining	Alumina refining	Anode production	Aluminum smelting	Ingot production	Total
Energy	(%)	(%)	(%)	(%)	(%)	(%)
Electricity	0.0	1.0	0.3	60.4	0.8	62.4
Fossil Fuel	0.7	14.6	0.6	1.4	1.7	19.0
Transport	0.6	0.4	0.0	0.0	0.4	1.4
Ancillary		5.0	12.1			17.1
Total	1.3	21.0	13.1	61.8	2.9	100.0
GHG emissions						
Process			1.4	12.8		14.2
Electricity		0.9	0.2	45.7	0.6	47.4
Fossil Fuel	0.6	12.0	0.5	1.0	1.2	15.4
Transport	1.3	0.9	0.0	0.0	1.1	3.3
Ancillary		1.3	0.9			2.2
PFC				17.5		17.5
Total	1.9	15.1	3.0	77.1	2.9	100.0

Source: IPAI (2000). Greenhouse gas emissions related to electricity production and consumption for aluminium smelting were estimated from: (1) actual electricity consumed by smelting locations including transmission losses; (2) country specific power plant production characteristics (efficiency factors, technologies) as estimated by the OECD; (3) country specific CO_2 emission factors from fuels (tonne of CO_2 per tonne of fuel) from the IPCC and OECD.

Much of the regional variation in aluminium GHG emissions is due to differences in the sources of the electricity used in the smelters (see Figure A6). Smelters in Latin America are based almost entirely on hydroelectricity. Those in Australia/New Zealand and Africa use coal-based electricity for three quarters of their needs. Natural gas accounts for more than half of the electricity in Asia. In Europe, there is a greater range of electricity sources, including 18% of nuclear electricity.

Figure A7 shows how these variations in electricity play out for aluminium smelters. The blue bars show the average electricity used by smelters in each region. There is little variation in the average regional efficiencies of plants, indicating that the regional average efficiency of plants is similar. The red bar shows the differences in electricity emissions intensities resulting from the profiles in Figure A6. The tan bars show how the two previous factors combine to give smelter emissions. The range of electricity-based emissions is wide – from 0.3 tonnes CO_2 per tonne of aluminium (tCO_2/tAl) in Latin America to 11.9 tCO_2/tAl in Australia/New Zealand. When added to the world average 6.7 tCO_2/tAl in process and fossil fuel emissions, average regional smelter emissions intensities were found to range from 7.0 to 18.5 tCO_2/tAl. The world wide average was 12.7 tCO_2/tAl. Data was not available to calculate regional variations in process emissions. PFC emissions, which account for an average of 55% of process emissions, are known to vary considerably by smelter.[13]

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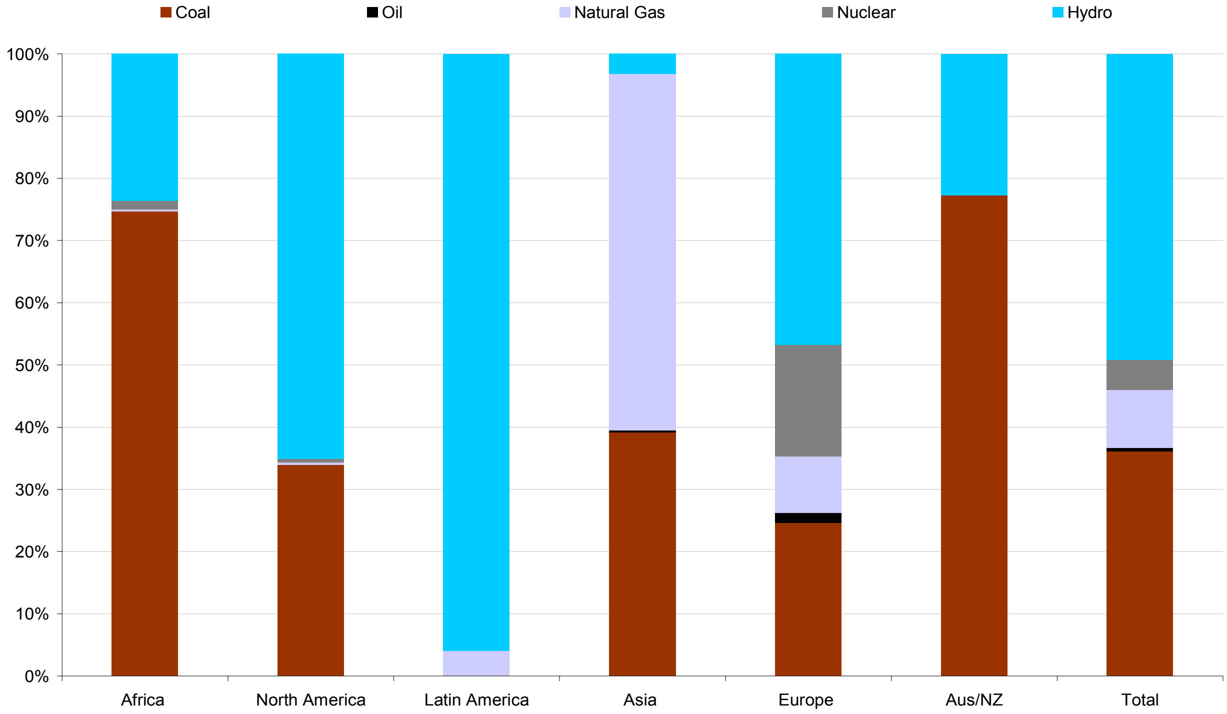
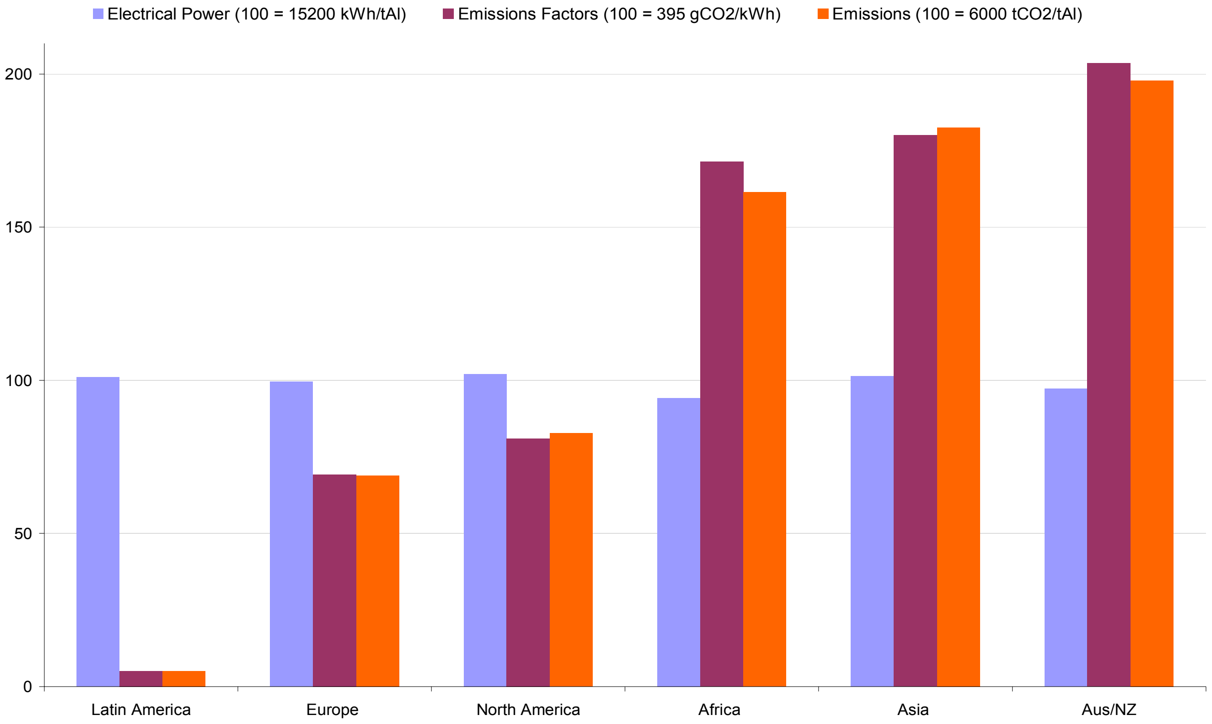
[13] International Aluminium Institute (n.d.) and IPAI (2000). International Aluminium Institute (2005b) contains a listing of PFC emissions by plant. The figures are based on a 2003 survey in which plants representing 62% of global primary aluminium participated. The range for point feeder prebake plants was 0.018 – 3.71 $tCO_2eq./tAl$; for center work prebake the range was 0.215 – 2.421 $tCO_2eq./tAl$; for side work prebake the range was 2.83 – 24.50 $tCO_2eq./tAl$; for vertical stud Söderberg the range was 0.15 – 4.93 $tCO_2eq./tAl$; and for horizontal stud Söderberg the range was 1.31 – 9.20 $tCO_2eq./tAl$. Most point feeder center work prebake plants (the majority of plants) had figures less than 1 $tCO_2eq./tAl$.

Figure A6 Sources of electric power used in primary aluminium production by region, 2003



Source: International Aluminium Statistics (2005).

Figure A7 Primary aluminium electricity-based emissions intensities by region, 2003



Sources: International Aluminium Statistics (2005) and IEA Statistics. Note: the emissions factors do not account for the land use effects of hydroelectricity generation.

CLIMATE POLICIES

A 1999 survey found that "as of November 1998, ten countries had undertaken industry-government initiatives to reduce PFC emissions from primary aluminium production: Australia, Bahrain, Brazil, Canada, France, Germany, New Zealand, Norway, the UK and the USA. Eight of the countries, representing over 50% of world-wide production, had voluntary reduction programmes. New Zealand and the UK had regulatory programmes".[14]

Table A6 Industry-government aluminium initiatives, 1998

Country	Programme description
Australia	The Australian aluminium industry signed a voluntary "Framework Agreement" and joined the Greenhouse Challenge, an industry-government partnership, in 1995.
Bahrain	Bahrain's sole aluminium producer has entered into a voluntary agreement to reduce GHG emissions with Bahrain's Ministry of housing, Municipalities and Environment.
Brazil	The Brazilian Aluminum Association signed a voluntary agreement with Brazil's Ministry of Science and Technology to reduce GHG emissions.
Canada	Canada's Aluminum Industry Association participated in the voluntary Challenge and Registry Program initiated by the Canadian Government and the voluntary Canadian Industry Program for Energy Conservation.
France	Aluminum Pechiney (now part of Alcan) made a voluntary commitment to reduce its GHG emissions to the French government.
Germany	The Germany Aluminum Industry pledged to reduce GHG emissions under a voluntary agreement with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and under the Voluntary Declaration German Industry.
New Zealand	PFC emissions from New Zealand's sole aluminium smelter are regulated under the 1991 Resource Management Act. NZAS also participates in a voluntary agreement with the Minister of Energy to reduce its CO_2 emissions.
Norway	The Norwegian aluminium industry began negotiations with the Ministry of the Environment in 1996 to develop a voluntary programme aimed at reducing PFC emissions and increasing energy efficiency.
United Kingdom	PFC emissions from the aluminium industry are regulated in the UK under the Integrated Pollution Control (IPC) regime, under the 1990 Environmental Protection Act. Much of the effort to reduce GHG emissions has been undertaken voluntarily by the industry in agreement with regulatory authorities.
United States	In 1995, 11 of 12 (now 18 of 19) primary aluminium producers joined with the US Environmental Protection Agency (EPA) to form the Voluntary Aluminum Industrial Partnership to Reduce PFC Emissions.

"The framework and requirements of the voluntary programmes vary, but certain characteristics are common to all. Typically, stakeholders set emission reduction targets, either company-specific or industry-wide. Once the targets are set, a process to monitor and track progress toward achieving these reductions is established. Methods include monitoring programmes and periodic reporting by industry. The government is responsible for improving the diffusion of relevant science and technology research and practices. In addition, the government may highlight the accomplishments of the programme and publicly recognise participating companies."

The scope of emissions reduction activities found in the 1999 survey varied from country to country. In some countries, such as the USA, the programmes were restricted to PFC emissions from primary aluminium production. Other countries, such as Australia, Canada and France, included all GHGs covering the entire primary aluminium industry, including alumina refineries and semi-fabrication facilities. In these countries, the programmes covered energy consumption related CO_2 emissions and direct CO_2 and PFC emissions.

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[14] United States Environmental Protection Agency (1999).

While the scope of the programmes varies across countries, the emission reduction activities undertaken at the company level are similar: ... best management practices, technical initiatives and research initiatives."[15]

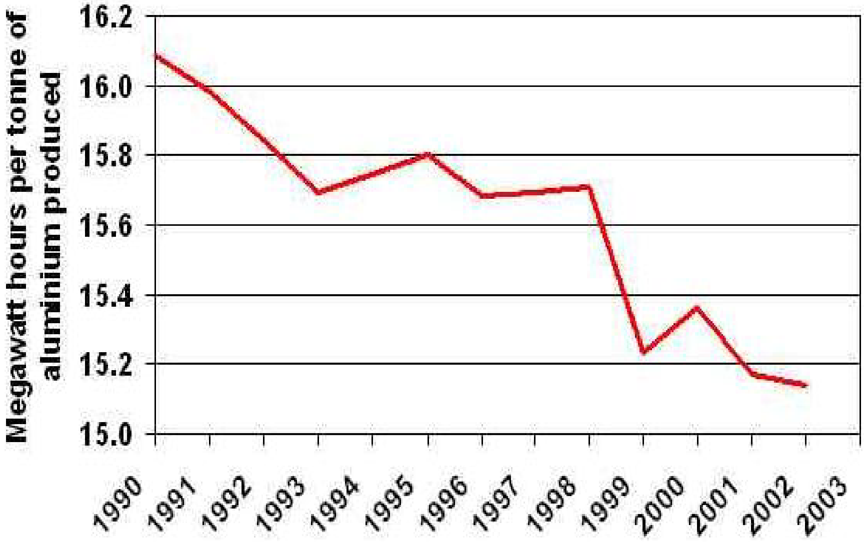
INDUSTRY INITIATIVES

The International Aluminium Institute (IAI) has undertaken the *Aluminium for Future Generations Sustainable Development Programme*.[16] Launched in 2003, the programme comprises eight voluntary objectives and twenty two performance indicators designed to encourage a continual improvement in performance by the industry. To assist companies to achieve these voluntary objectives the IAI has available a team of consultants made up of leading technical experts. They provide advice and training on good practice from around the world. Two voluntary objectives pertain directly to climate change issues:

1. An 80% reduction in PFC greenhouse gas emissions for the industry as a whole per tonne of aluminium produced by 2010 versus 1990. Note that PFC specific emissions, per tonne of aluminium, were reduced by 73% from 1990–2003.[17] This represents a reduction equivalent to around three tonnes of CO_2 per tonne of aluminium produced since 1990. Voluntary agreements between government and industry have played a significant role.

2. A 10% reduction in smelting energy usage for the Industry as a whole per tonne of aluminium produced by 2010 versus 1990. Figure A8 shows that since 1990 the average amount of electricity used for electrolysis has been cut by 6%.

Figure A8 Global electric energy used for electrolysis, 1990–2002



Source: International Aluminium Institute (2005a).

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[15] United States Environmental Protection Agency (1999).

[16] International Aluminium Institute (2005a).

[17] *Ibid.*

REFERENCES

Alcan (2004), *China's Aluminum Industry, Setting the Record Straight*, Industry Analysis Department, Alcan Inc. http://www.alcan.com/web/publishing.nsf/AttachmentsByTitle/Investors-OtherPublications/$file/Broch_Chine_AN_v8a.pdf.

Bergsdal, H., A. Strømman, E. Hertwich (2004), *The Aluminium Industry, Environment, Technology and Production*, Norwegian University of Science and Technology (NTNU), Industrial Ecology Programme report no. 8/2004.

Grubb, M. and J. Wilde (2004), *The European Emissions Trading Scheme: Implications for industrial competitiveness*, Carbon Trust, London.

International Aluminium Institute (2005a), *Aluminium for Future Generations – Sustainability update* 2004, London http://www.world-aluminium.org/iai/publications/sustainable.html, accessed April 2005.

International Aluminium Institute (2005b), *The International Aluminium Institute's Report on the Aluminium Industry's Global Perfluorocarbon Gas Emissions Reduction Programme: Results of the 2003 Anode Effect Survey*, International Aluminium Institute, London, http://www.world-aluminium.org/iai/publications/documents/aes_pfc_2003.pdf.

International Aluminium Institute (n.d.), *The Aluminium Industry's Sustainable Development Report*, London http://www.world-aluminium.org/iai/publications/documents/sustainable_summary.pdf, accessed April 2005.

International Aluminium Statistics (2005), International Aluminium Institute statistics, http://www.world-aluminium.org/iai/stats/index.asp, accessed March 2005.

IEA Statistics: International Energy Agency statistics.

IPAI (2000), *Aluminium Applications and Society, Life Cycle Inventory of the Worldwide Aluminium Industry with Regard to Energy Consumption and Emissions of Greenhouse Gases*, International Primary Aluminum Institute, Paper 1 – Automotive.

UN Comtrade: *United Nations Commodity Trade Statistics Database*, UN Statistics Division, http://unstats.un.org/unsd/comtrade, accessed March 2005.

United States Environmental Protection Agency (1999), *International Efforts to Reduced Perfluorocarbon (PFC) Emissions from Primary Aluminum Production*, EPA 430-R-99-001.

United States Geological Survey (2003), *Minerals Yearbook, Aluminium*, 2003 edition, Washington, DC http://minerals.usgs.gov/minerals/pubs/commodity/myb/.

World Bureau of Metal Statistics (2005), *World Metal Statistics Yearbook*, Hertfordshire.

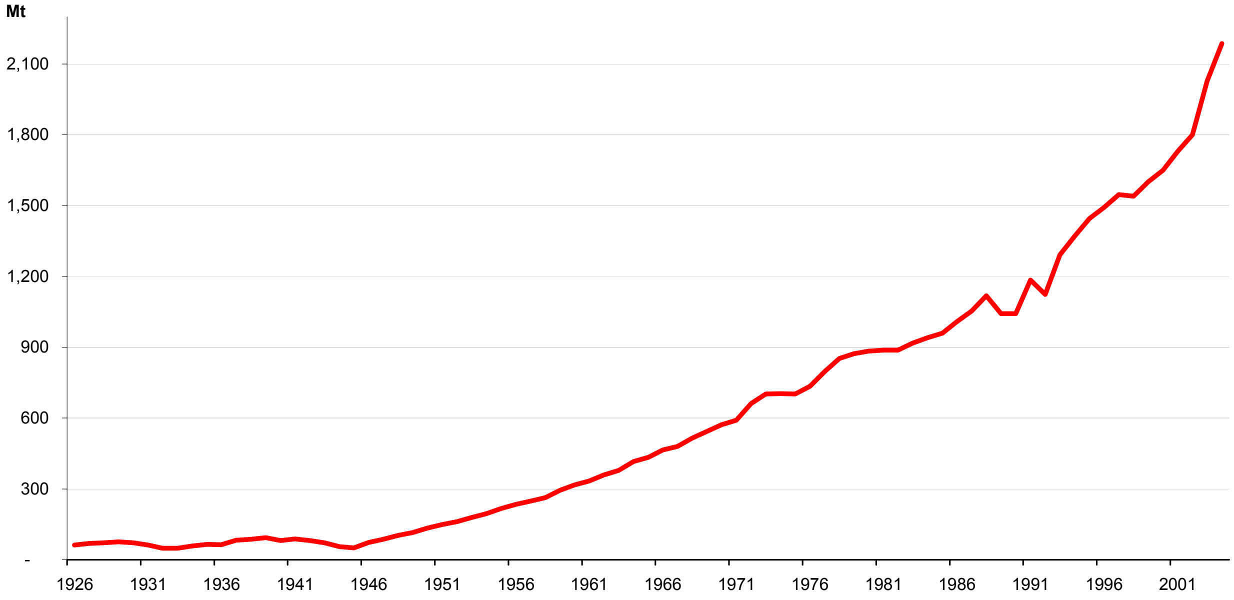
World Bank (2005), *Opportunity for Reduction of Per-fluorinated Carbons (PFCs) from the Aluminum Industry*, presentation 15 April 2005, World Bank.

ANNEX B – CEMENT

PRODUCTION

Since 1945 cement production increased by a factor of 44 from 50 million tonnes (Mt) to 2 186 Mt in 2004. In the last ten years the average annual growth rate was 4.8%, higher than the previous decade's 4.1%, but well below the 10% for 1945–1973. The high growth in the last decade is significant given that the amount of cement production now is more than double that of 20 years ago.

Figure B1 World cement production, 1926–2004



Sources: United States Geological Survey (2003) and Hargreaves (2005).

China has been the world's largest cement producer since 1985.[1] In 2004, China accounted for 44% of world production (Figure B2). China's cement production alone was more than the next 27 largest cement producers combined. Western Europe is a distant second with a world production share of 11% followed by South and East Asia at 8%.

The cement industry has undergone significant consolidation over the past decade through mergers and acquisitions. As recently as 1988, the market share of the world's top five cement companies was just 9% of the global market (excluding China).[2] By 2003, this figure had increased to 42%.[3] The capacity of the top ten cement producers represents 55% of global capacity.[4]

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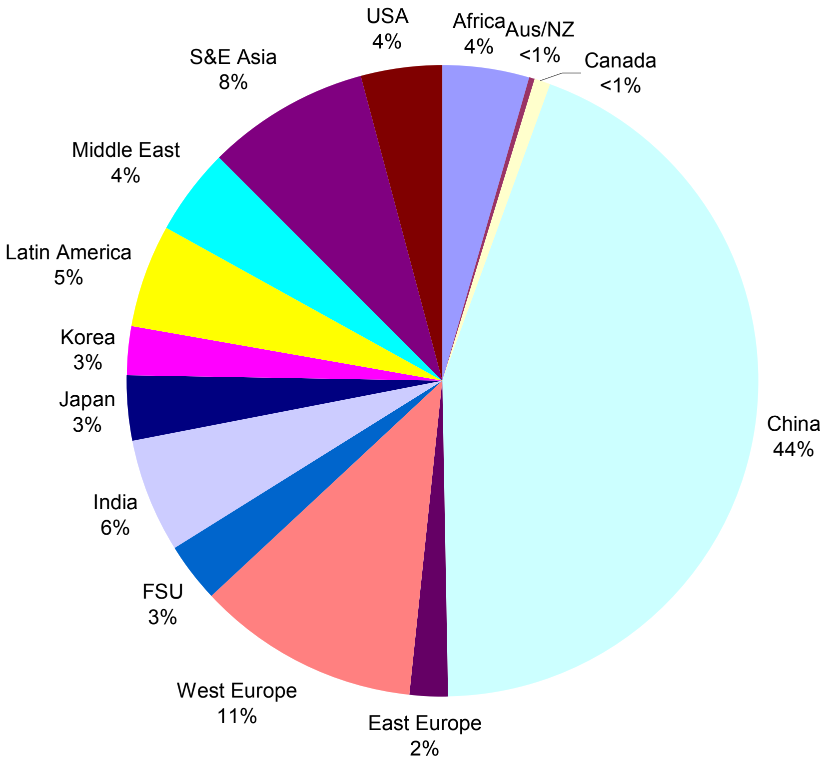
[1] Soule *et al*. (2002).

[2] World Cement (2005).

[3] Schmidt *et al.* (2004).

[4] Individual company shares, as a percentage of global cement capacity are: Lafarge 12, Holcim 11, Heidelberger 7, Cemex 7, Italcementi 5, Taiheiyo 5, Siam Cement 2, Dyckerhoff 2, RMC 2, and Votorantim 2.

Figure B2 Cement production by region, 2004



Source: Hargreaves (2005).

In some countries such as Brazil, the UK, South Africa and Thailand the top five cement producers (by capacity) have more than 80% of the market. In other countries the figure is much lower: 49% in the USA, 42% in India and 10% in Russia. China has a very low ratio at 3%. This is not surprising given that there are around 8 000 to 9 300 cement plants in China, most of which are very small[5] (this compares with 320 plants for the whole of the European Union[6]). The share of the major cement internationals[7] ranges from around 70–80% in North America, Australia/New Zealand, Latin America, Western Europe and Africa to 27% in Asia and 6% in the Middle East.[8]

Foreign ownership is high in the USA at 89% and the UK at 77%. India and China have only 3% and 1% foreign ownership of their industries. The major Indian companies such as Grasim and L & T and Chinese Anhui Conch Group are significant players who sell cement to international traders.[9]

CONSUMPTION

In developing countries housing typically accounts for the majority of cement consumption. For example, in Brazil, it accounts for 70% of total cement consumption.[10] However, developing countries' recent high demand growth has been driven by major infrastructure projects. In China, for example, 40% of cement is

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[5] China's average production by plant is 10 times smaller than French plants, 12 times US plants and 14 times German plants. Soule *et al*. (2002).

[6] CEMBUREAU (1999).

[7] International cement majors were defined to include Buzzi Unicem, Cementos Portland, Cemex, Cimpor, CRH, Dyckerhoff, HeidelbergCement, Holcim, Italcementi, Lafarge, RMC, Semapa, Titan and Votorantim.

[8] World Cement (2005) (figures derived from company data, CEMBUREAU and JPMorgan).

[9] World Cement (2005).

[10] Correspondence with Lafarge 18 May 2005.

now used for basic infrastructure construction.[11] In developed countries the demand structure tends to be different with non-residential buildings and infrastructure often more important. For example, in the USA, housing accounts for 30% of total consumption; non-residential buildings and infrastructure each account for 35%. There is a strong positive relationship between cement consumption per capita and GDP per capita until around USD 15 000 when cement consumption tends to reach a plateau.[12]

Cement is generally consumed close to where it is produced. For all regions, world consumption shares mirror production shares. Production and consumption shares differ at most by one percentage point. For example, China's consumption share is 45% and its production share is 44%.[13]

World cement consumption in 2003 was around 1 800 Mt. Cement demand is predicted to rise to 2 800 Mt by 2020 and to 5 800 Mt by 2050.[14] Growth in demand is projected to be faster in those regions with lower per capita income levels and high economic growth. Accordingly, Latin America, the Former Soviet Union and India are expected to see their shares in world demand increase from 16% to 24% by 2020. China's share is expected to fall to 36%, although its absolute growth will still be significant.[15] In contrast, consumption shares for Western Europe and the USA are estimated to drop from 18% to 10% by 2020 with their absolute levels of demand expected to remain at current levels or even decrease slightly.

TRADE

The widespread availability of raw materials combined with high transport costs relative to cement's value result in little cement trade. Ninety-four per cent of global cement production remains within the country of production. Of the 5.8% traded internationally, 39% remains within the region. Only 3.5% of production is traded between regions.[16] More than half of this extra-regional trade is between neighbouring regions, i.e. only 1.7% of production is between distant regions.

Of the net exporters, exports represent a significant portion of domestic production in Canada and Japan. These exports are predominantly destined for neighbouring regions (the USA for Canada, and China and South and East Asia for Japan). The USA is by far the world's largest net importer of cement, importing 20.5 Mt or 18% of consumption.

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[11] Soule *et al*. (2002).

[12] Correspondence with Lafarge 18 May 2005.

[13] Consumption shares were calculated from Hargreaves (2005). Of the 14 regions the USA had the largest difference between consumption and production shares with a consumption share of 5.6% compared to 4.3% for production.

[14] Demand projections are based on IPCC Scenario A1. Predictions beyond 2050 vary considerably. Battelle (2002).

[15] Alternative predictions in World Cement (2005) predict that China will account for 52% of global consumption in 2020.

[16] Note that this representation includes the single-country "regions" Japan, Korea, India, China, the US, and Canada, where all exports and imports appear as "interregional". If these are excluded and only the trade between actual multi-country regions is looked at, the share of interregional trade is only 2.6%.

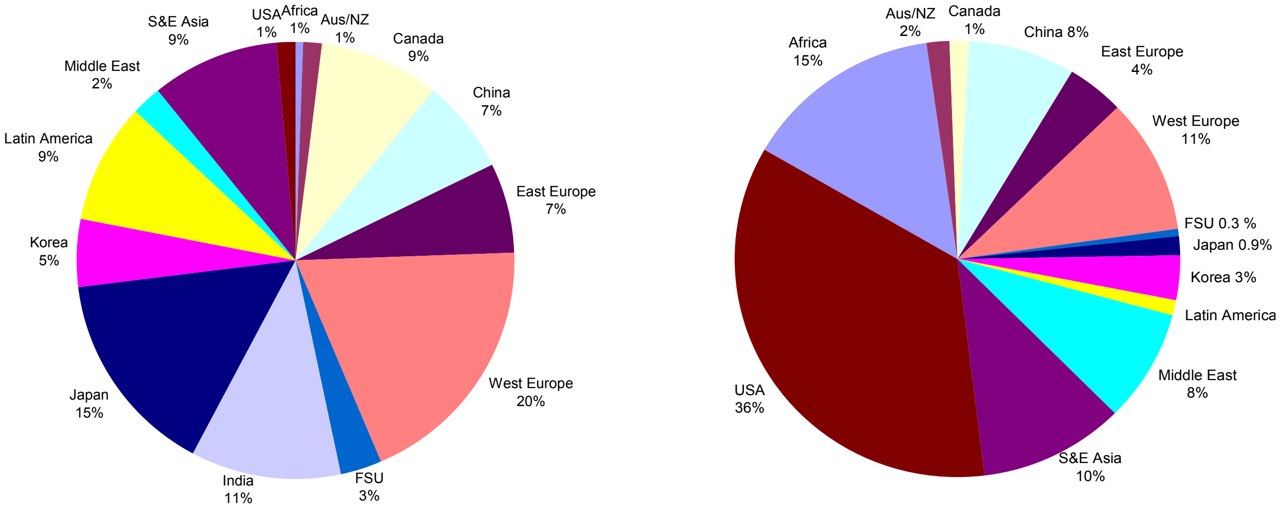
Table B1 Cement trade (Mt), 2003

Exporting: \ *Importing:*	Africa	Aus/NZ	Canada	China	East Europe	West Europe	FSU	India	Japan	Korea	Latin America	Middle East	S&E Asia	USA	Total exports	Extra-reg. exports	Net exports
Africa	1.5	0.0	0.0	0.0	0.0	0.4	-	-	0.0	-	0.0	-	0.0	0.0	1.9	0.4	-8.3
Aus/NZ	0.0	0.0	-	-	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.8	0.0	0.8	0.8	-0.4
Canada	0.0	0.0	-	0.0	0.0	0.0	0.0	-	0.0	-	0.0	0.0	0.0	5.7	5.7	5.7	4.8
China	0.3	0.0	-	1.2	0.0	0.0	0.0	0.0	0.0	1.1	0.1	0.0	0.3	1.9	5.7	4.5	-0.2
East Europe	1.4	0.0	-	-	2.8	2.7	0.0	-		-	0.0	0.0	0.0	0.2	7.0	4.3	1.7
West Europe	3.7	0.0	0.0	0.0	1.8	19.3	0.1	0.0	0.0	0.0	0.0	1.6	0.0	3.3	31.5	12.2	6.2
FSU	0.0	-	-	0.1	0.6	1.3	1.6	-	-	-	-	0.0	0.0	0.0	3.7	2.0	1.7
India	0.3	0.1	-	0.0	0.0	0.6	0.0	-	-	-	0.0	3.3	2.5	0.0	6.9	6.9	6.9
Japan	1.0	0.8	-	4.3	-	0.0	0.0	0.0	0.0	0.9	0.1	-	2.3	0.0	9.7	9.7	8.9
Korea	0.4	0.0	-	0.0	-	0.0	0.0	-	0.8	-	0.0	0.0	0.1	1.7	3.1	3.1	1.2
Latin America	0.0	-	0.0	-	-	0.3	-	-	-	-	2.0	0.0	-	5.3	7.7	5.6	4.8
Middle East	0.4	-	-	-	0.2	0.4	0.2	0.0	-	-	-	2.7	0.2	-	4.2	1.6	-3.4
S&E Asia	1.0	0.2	-	0.2	0.0	0.4	-	0.0	0.0	0.0	0.5	0.1	9.7	3.3	15.6	5.9	-0.3
USA	0.0	0.0	0.8	0.0	0.0	0.0	0.0	-	0.0	0.0	0.1	0.0	0.0	-	0.9	0.9	-20.5
Total imports	10.1	1.2	0.8	5.9	5.3	25.3	1.9	0.0	0.9	1.9	2.9	7.7	15.9	21.4	104†		
Extra-reg. imports	8.6	1.1	0.8	4.7	2.6	6.0	0.3	0.0	0.9	1.9	0.8	5.0	6.3	21.4		64†	

Source: UN Comtrade.[17]

Boxed fields: intra-regional trade. “0.0”: indicates trade of less than 50 000 tonnes between respective regions. “–”: indicates no trade between respective regions. Extra-regional exports = total exports less intraregional exports. Net exports = trade balance = total exports less total imports (negative values indicate net imports). †: Exports and extra-regional exports shown in the chart do not necessarily add to the total figure shown because of unspecified items in the raw data.

Figure B3 Regional shares of extra-regional cement exports and imports, 2003



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[17] HS-2523 (Portland cement, aluminous cement and slag cement).

TECHNOLOGY

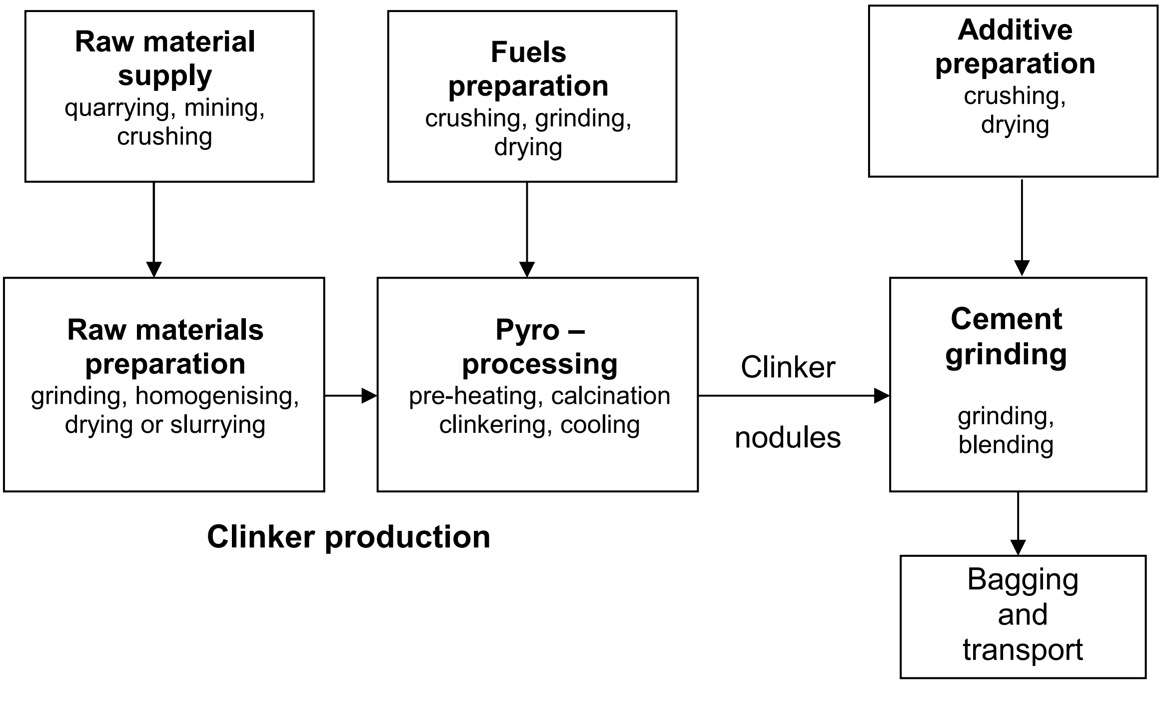
Cement production consists of three main stages:

- **Raw material preparation** where limestone (the primary material), silica, alumina and iron ore are quarried or mined and transported to cement production plants. Here they are crushed, ground (to "meal" in the dry process or to "slurry" in the wet process) and dried. Cement containing less than 5% of additives is called Ordinary Portland Cement; other cement is often called "blended" or "composite" cement.[18]

- **Clinker production** where the raw materials are burnt in intense heat to obtain clinker. Clinker, an intermediate product, is the binding agent of cement. During the production of clinker the burning of limestone creates lime and CO_2; this process is known as calcination or decarbonation.

- **Finish grinding** where clinker is ground to powder and blended with additives such as gypsum and fly ash to become cement.

Figure B4 Cement production process[19]



The clinker production stage is the core of the production process. It is also the most complex and energy intensive stage. Two different types of technologies are used in clinker production:

- **Vertical kilns** where fuel and raw materials are fed to the top of the kiln while air is introduced at the bottom. Vertical kilns are the oldest and least sophisticated technology in use today. They

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[18] Portland cement is cement containing 95% clinker and 5% gypsum. There are 27 different types of cement (Reinaud (2004)). Examples of cement other than Portland are white, mansonry, slag, aluminous and regulated-set.

[19] Ruth, M., E. Worrell and L. Price (2000) *Evaluating Clean Development Mechanism Projects in the Cement Industry Using a Process-Step Benchmarking* Approach cited in Ellis (2001).

are widespread in some developing countries where transport infrastructure to transport raw materials or cement is poor.[20] They are used in small-scale plants, usually in more remote areas where large scale plants are not economically viable.

- **Rotary kilns** enable large-scale cement production, but require substantial investment. They typically operate at 1 500 to 1 600°C and are more efficient than the small-scale vertical kilns. Depending on the addition of water at the grinding stage, four different processes are used in rotary kilns: dry, semi-dry, semi-wet and wet processes.[21] The dry process is the most modern and less energy-intensive process, although the wet and semi-wet process require less pre-processing of raw materials with a moisture content of more than 15%.

Figure B5 shows kiln technology by region in the mid 1990s. Rotary kilns accounted for 91% of cement production capacity worldwide. Only in China were vertical kilns the dominant technology, accounting for 93% of capacity. More recent information, based on production rather than capacity, indicates that the share of rotary kilns has continued to increase. For example, Western Europe no longer uses vertical kilns and in China the share of vertical kilns has fallen to around 75% of Chinese production.[22] This is expected to decline to 50% in 2015.[23]

Use of rotary wet kilns accounts for more than half of capacity in Australia/NZ and the Former Soviet Union. While they are gradually being phased out and replaced by dry kilns, particularly in the faster growing industries of developing Asia, they remain important in the USA, Canada, India, Eastern Europe, Latin America and Africa. Their continuing importance reflects the fact that cement plants have a technical life of more than 50 years.[24] The shares of the most efficient technology – dry rotary kilns – range from 100% in Japan to 5% in China.[25] Most regions have shares of between 50% and 80%. The adoption of the dry process depends in part on the availability of suitable raw materials. Russia and Ukraine, for example, have had difficulties in adopting the dry technology because local limestone has a high moisture content.[26] That said rapid modernisation is possible. Poland and Romania opened their cement industries to capital investment by multinational corporations. Poland reduced its energy intensity dramatically over the last ten years and now has one of the lowest intensities in the EU.[27]

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[20] Worrell *et al*. (2001).

[21] The **dry process** is where dry raw meal is fed to a cyclone preheater or precalciner kiln or, in some cases, to a long dry kiln with internal chain preheater. Preheaters use the waste heat of the kiln. The **semi-dry process** is where dry raw meal is pelletised with water and fed to a travelling grate preheater prior to the rotary kiln or in some cases, to a long kiln equipped with internal cross preheaters. The **semi-wet process** is where raw slurry is first dewatered in filter presses. The resulting filter cake is either extruded into pellets and fed to a travelling grate preheater or fed directly to a filter cake drier for dry raw meal production prior to a preheater kiln. The **wet process** is where the raw slurry is fed either directly to a long rotary kiln equipped with an internal preheating system (conventional wet process) or to a slurry drier prior to a preheater kiln (modern wet process). CEMBUREAU (1999).

[22] Soule *et al*. (2002).

[23] *Ibid.*

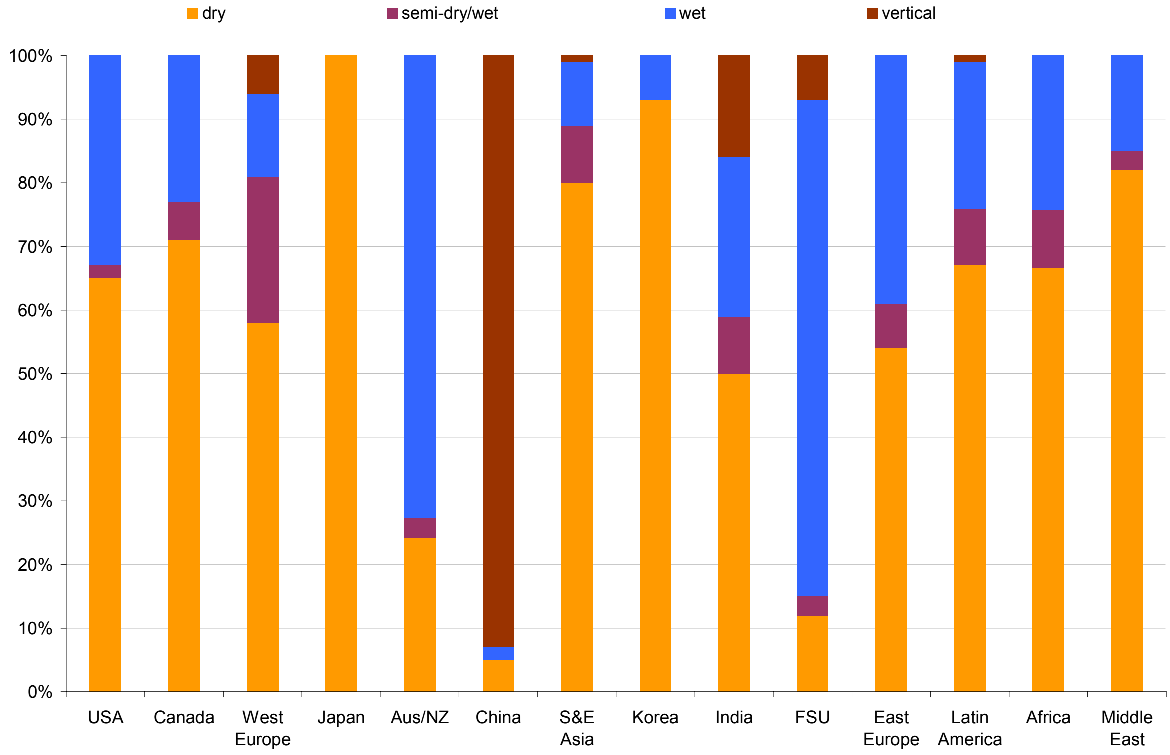
[24] Ellis (2001).

[25] Based on more recent data China's share may be as high as 25%.

[26] World Energy Council (1995). The majority of high moisture limestone is found in Annex I countries. Ruth, M., E. Worrell and L. Price (2000) *Evaluating Clean Development Mechanism Projects in the Cement Industry Using a Process-Step Benchmarking Approach* cited in Schmidt *et al*. (2004).

[27] Correspondence with Ernst Worrell, Ecofys.

Figure B5 Kiln type by region, mid 1990s



Source: Humphreys and Mahasenan (2002).

ENERGY USE

Energy costs in the cement sector account for between 25% and 35% of total direct costs.[28] Total energy use is significant. For example, the Chinese cement industry consumes approximately 6% of China's energy.[29] Energy use per kg of clinker is lowest in Japan at just over 3 MJ/kg and is highest in the USA and the Former Soviet Union at 5.5 MJ/kg.

Variations in energy consumption are explained by three factors: (i) the clinker-to-cement ratio; (ii) the type of kiln used (rotary vs. vertical); and (iii) the share of dry vs. wet production.

Clinker-to-cement ratio: Since clinker production is the most energy-intensive step in cement production, the higher the clinker-to-cement ratio, the higher the energy intensity. Increasing the additives in cement such as blast furnace slags, fly-ash,[30] and volcanic material reduces the amount of clinker needed. However, the availability of suitable additives differs between regions. Clinker-to-cement ratios in 1994 show a range of 80% in Japan to 96% in Korea.

Vertical vs. rotary kiln: Although rotary kilns are more energy efficient than vertical kilns, in some countries, including India and China, vertical kilns are still common because of their small size and easy-to-master technology (see Figure B5). There has been a tendency to move toward larger kiln types to benefit from economies of scale.

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[28] Schmidt *et al*. (2004).

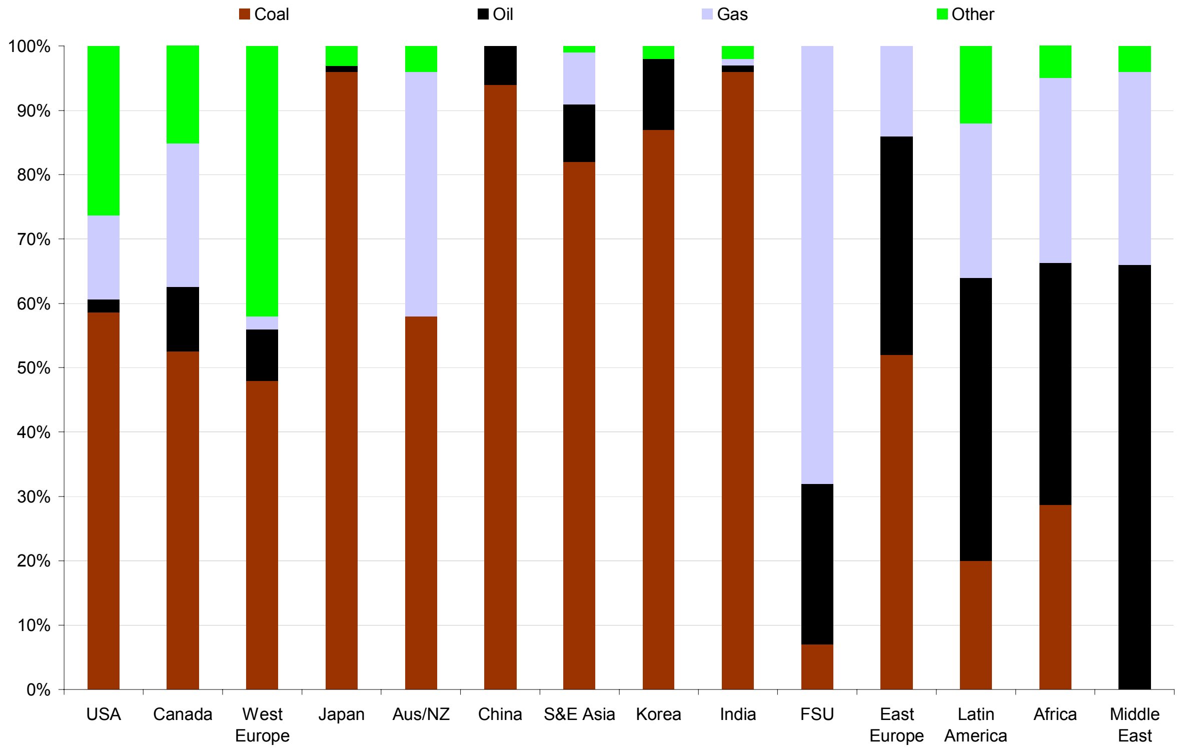
[29] Soule *et al*. (2002).

[30] Blast furnace slags are a residual from the production of pig-iron. Fly ash is produced during the combustion of coal for electricity generation.

Dry vs. wet process: A full conversion from a long-wet kiln to a dry preheater/precalciner kiln can yield fuel savings of 45% or more.[31] In the USA, for example, the dry process typically uses 3.5–4.5 MJ/kg, while the average wet process uses over 5.2 MJ/kg.[32] The advanced dry technologies do not require water evaporation and therefore have fewer losses of waste heat from the kiln.

Figure B6 shows the fuel types used for energy in cement. Coal is the dominant fuel, but the Former Soviet Union has a high share of gas. Oil is a significant share for the Middle East, Africa, Latin America and Eastern Europe.

Figure B6 Fuel mix for cement production by region, mid 1990s



Source: Humphreys and Mahasenan (2002). Note: the "other" category includes alternative fuels and raw materials (inputs to cement production derived from industrial, municipal and agricultural waste streams).

EMISSIONS

Cement production is responsible for an estimated 4.6% of global anthropogenic GHG emissions.[33] Assuming no improvement in unit-based emissions, CO_2 emissions from the cement industry will grow 1.5–2-fold by 2020, and will more than quadruple by 2050.[34]

CO_2 emissions from cement production can be represented as follows:[35]

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[31] Fog, M. H. and K. L. Nadkarni (1983) *Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries*, cited in World Energy Council (1995).

[32] United States Department of Energy (1990) *Industry Profiles – Final Report: Energy Profiles for US Industry* cited in World Energy Council (1995).

[33] Total cement emissions are estimated at 1 930 Mt CO_2 in 2004. This figure was based on 2000 emissions emission intensity figures and 2004 production data. Cement's share of total anthropogenic GHG emissions is likely to be a slight overestimate because the 2000 total anthropogenic GHG emissions figure was used as the denominator.

[34] Humphreys and Mahasenan (2002). Estimates are based on IPCC Scenario A1.

	Process emissions from converting limestone to lime (onsite)	$\geq$ 50%
+	Energy use emissions from combustion of fossil fuels (onsite)	$\geq$ 40%
+	Energy use emissions from generation of electricity consumed	~ 5%
+	Energy use emissions from transport (offsite)	~ 5%
=	Total CO_2 emissions for cement production	

The majority of CO_2 emissions from cement production occur from converting limestone to lime in clinker production and from generating the heat energy required for this. Up to 90% of the emissions resulting from energy generation – both heat onsite and electricity offsite – are released during the clinker production stage. Raw material preparation and finish grinding account for most of the emissions accompanying the remaining energy use in production. The majority of this energy is derived from electricity or kiln exhaust gas.[36]

On average, process emissions account for 52% of overall emissions. Higher process emissions are generally associated with higher clinker-to-cement ratios which are in turn determined by the availability and quality of limestone and additives. Table B2 shows that on a regional basis there is not significant variation in process emission intensity.

Energy use emissions account for the remaining 48% of emissions. Energy use emissions are influenced by: the type of technology, the level of clinker production, plant operating efficiency, the fuels used for combustion, the need for pre-processing of raw materials and the efficiency of the local power generation and distribution system. There is a significant range in energy use intensities across regions. India's is more than double Japan's even though coal accounts for around 95% of Japan's fuel source. This points to the fact that Japan's technology is well advanced and highly efficient, although this does not explain all the difference. Another factor is the type of coal used: Indian coal is generally of poor quality, while Japan imports high quality hard coal.[37]

Table B2 Process and energy use emissions, 1994

	Clinker to cement ratio	Process emissions	Energy use emissions	Process emissions intensity	Energy use emissions intensity
	(%)	(% of total emissions)		(t CO_2/t Cement)	
Africa	87	54	46	0.44	0.38
Aus/NZ	84	56	44	0.41	0.32
Canada	88	52	48	0.45	0.42
China	83	47	53	0.41	0.47
EE/FSU	83	53	47	0.42	0.38
India	89	48	52	0.45	0.48
Japan	80	63	37	0.40	0.23
Korea	96	59	41	0.48	0.33
Latin America	84	58	42	0.42	0.31
Middle East	91	53	47	0.46	0.40
S&E Asia	91	53	47	0.45	0.39
USA	88	49	51	0.44	0.45
West Europe	81	57	43	0.40	0.31
WORLD	85	52	48	0.42	0.39

Source: Calculated from data in Worrell *et al.* (2001).

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[35] *Ibid.*

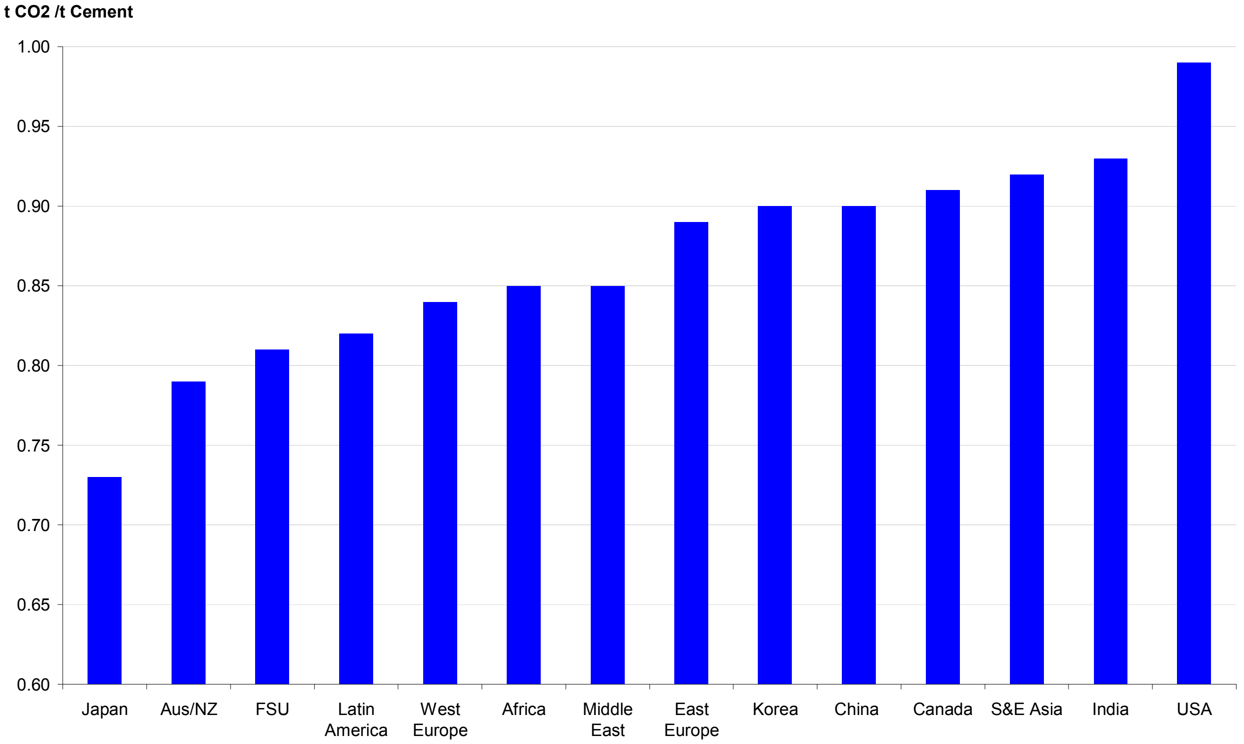
[36] Hendricks, C. A., E. Worrell, D. de Jager, K. Blok and P. Riemer (1999) *Emission Reduction of Greenhouse Gases from the Cement Industry* cited in Schmidt *et al*. (2004).

[37] See Annex D.

Clinker-to-cement ratio figures should be treated with caution due to differences between countries. In some countries such as the USA or Korea, ready-mix producers are allowed to mix cement themselves with slag and fly-ash. This use of slag is, however, not accounted for in clinker-to-cement ratio statistics provided by the local cement industry associations. In other countries, most of the available slag is used by cement producers in the clinker grinding step because regulations forbid ready-mix producers to mix slag and cement at their own ready-mix plants.[38]

Emissions intensities (tonne of CO_2 emitted per tonne of cement produced) have significant regional variation (Figure B7). There is no clear relationship between intensities and level of economic development, although Japan has the lowest emissions intensity. Canada and the USA, for example, have high emissions intensities, while the Former Soviet Union and Latin America have one of the lowest. The low intensity for the Former Soviet Union is explained by its high use of natural gas (see Figure B6).

Figure B7 Cement CO_2 intensities by region, 2000



Source: Humphreys and Mahasenan (2002).

Emission reductions potential

The cement industry can not have a direct influence over emissions generated offsite, although companies can build plants close to quarries and customers to minimise transport-related emissions and purchase electricity from low-emission electricity providers. The cement industry does, however, have direct control over emissions arising on site. Plant operators can reduce the clinker-to-cement ratio through mixing clinker with an increased proportion of additives and through substituting clinker with an alternative binder. Reducing the clinker-to-cement ratio not only reduces process emissions, but it also reduces energy emissions because less heat energy is required in production. Aside from improving operating efficiency,

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[38] Correspondence with Lafarge 18 May 2005.

firms can also replace older kilns with more efficient dry rotary kilns and use alternative fuels to coal and oil.

(1) Reducing the clinker to cement ratio through increased use of additives

Portland cement (containing 95% clinker) still represents about 80% of the global cement production.[39] The CO_2 reduction potential from mixing clinker with a higher proportion of additives over the next 15 years is estimated to be 7% globally.[40] Regional variation was significant, however, because of the availability of additives such as fly ash and blast furnace slag. The USA and Canada were estimated to have the highest reduction potential at more than 34% and Korea was estimated to be able to reduce its emissions by between 26% and 34%. Regions with little or no scope were China, South and East Asia, India, Latin America, Africa and the Middle East.

Research by the German Cement Association demonstrates that it takes about a decade to establish a viable market for blended cement in areas where Portland cement is the trusted material.[41] To facilitate the increased use of blended cement the following measures could be taken:

- promoting information exchange and increasing awareness on the quality of blended cement;
- facilitating investment of necessary process modifications;
- improving the availability of suitable components such as slag and fly ash;
- building the skills required for blended cement production; and
- reviewing regulations, in particular product standards and building regulations, that act as a barrier to the use of blended cement.[42]

(2) Reducing emissions by substituting clinker with alternative binders

The production of CO_2 in producing clinker, the binding agent of cement, is unavoidable. Seeking an alternative binding agent represents a long-term option. Geopolymer binders made from inorganic compounds represent one alternative. Their associated CO_2 emissions are estimated to be up to 80% lower than those resulting from the production of Portland cement, although this estimate is optimistic. Their lower emission intensity is because these binders are produced at lower temperatures and do not use limestone. Geopolymers have not yet successfully been commercialised as a cement replacement on a large scale.[43]

(3) Reducing energy use through more efficient technology

The energy efficiency output of kilns varies greatly. Currently the use of dry kilns with preheaters presents the best available technology.[44] When compared to wet kilns, the precalciner process reduces emissions by 22%. Improving technical efficiency through retrofitting existing plants and phasing out energy-intensive

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[39] World Cement (2003).

[40] Humphreys and Mahasenan (2002).

[41] Afsah (2004).

[42] Tanaka and Kudo (2005), Asfah (2004), Schmidt *et al*. (2004) and Worrell *et al*. (2001).

[43] Humphreys and Mahasenan (2002).

[44] Discussion with Lafarge, April 2005.

manufacturing plants such as wet process plants has been estimated to lower emissions by around 11% by 2020 with up to 15% possible in some regions.[45]

New kiln concepts could in the future reduce emissions. A range of options are being considered such as the introduction of organometallic substances in the kiln, fluidised bed kilns, plasma arc furnaces and microwave technology. In general the new concepts are not cost competitive and there remain technical barriers to overcome. Further R&D is required.[46]

Hybrid energy cement plants represent the cutting edge of plant design. Akin to combined heat and power plants, these are integrated facilities that produce both electricity and cement. One such approach is the Global New Energy Process demonstrated in China and the USA. This process yields virtually zero CO_2 clinker by burning power plant fuel and converting all the fly ash and bottom ash into cement clinker of equal or higher quality than Portland cement. Another approach is the Alstom Combined Power and Cement Process, enabling a 5–10% decrease in CO_2 emissions through use of the coal combustion by-products and all solid waste products.[47]

(4) Reducing emissions through use of lower carbon and alternative fuels

The type of fuel used to generate the heat required in the clinker production stage varies significantly as shown in Figure B6. Fuel switches away from brown coal to hard coal to gas result in a considerable reduction in CO_2 emissions. Overall it is estimated that fuel switching could result in emissions falling by an average of 3% with some regions having the potential to cut emissions as much as 7%.[48]

The use of energy-intensive waste materials for fuel does not reduce CO_2 emissions at the plant, but reduces both the need for fossil fuels and the amount of waste land-filled or incinerated otherwise. Alternative fuels are energy inputs not directly derived from fossil fuel sources. Examples are coal residues, tyres, industrial or household sewage sludge, hazardous sludges such as paint sludge, waste wood, impregnated wood, liquid hazardous wastes, and spent oil and solvents.[49] An aggressive effort to increase the use of alternative fuels has been estimated to reduce emissions by 12% on average with some regions possibly achieving 16%.

The use of waste materials for fuel works well in countries with well-organised waste collection, transportation and storage capacities. The availability of waste fuels such as tyres and solvents and lack of financial means for adequate burners and skilled workers still pose considerable problems in many developing countries.[50] Increased R&D, e.g. in the area of biomass as a fuel source is also important. Use of such fuels can also be incentivised. For example, under the EU ETS, emission allowances are allocated for emission reduction through use of biomass fuel.

Overall estimates

Using currently known technologies and practices could reduce emissions by an estimated 33% on average by 2020: 7% through increasing additives, 11% through improving technical efficiency, 3% through switching from high carbon fossil fuels to lower carbon fossil fuels, and 12% through increasing the use of alternative (non-fossil) fuels. There is significant regional variation with the USA and Canada estimated to be able to reduce their emissions by almost 50%, South and East Asia by around 45%, and Australia/New Zealand by 40%. The Middle East and Africa are lowest at 20–22%.

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[45] Humphreys and Mahasenan (2002).
[46] Placet and Fowler (2002).
[47] Humphreys and Mahasenan (2002).
[48] *Ibid.*
[49] Battelle (2002).
[50] Humphreys and Mahasenan (2002).

Tanaka and Kudo (2005) calculated the effect on emissions if all regions, in 2020, were to achieve the same efficiency level as that of Japan's current efficiency. The study showed that emissions could be reduced by 16% from 3 007 under BAU to 2 523 Mt CO_2.

REFERENCES

Afsah, S. (2004), *CDM Potential in the Cement Sector*, consultant to the Prototype Carbon Fund, World Bank.

Battelle (2002), *Toward a Sustainable Cement Industry*, commissioned by the World Business Council for Sustainable Development, http://www.wbcsd.ch/DocRoot/C4uPdILJR3lJn8COlq3w/batelle-full.pdf.

Cembureau (1999), *"Best available techniques" for the Cement Industry*, the European Cement Association, Brussels.

Ellis, J. (2001), *An Initial View on Methodologies for Emission Baselines: Cement case study*, OECD/IEA Information Paper, OECD/IEA, Paris.

Hargreaves (ed.) (2005), *Global Cement Report (sixth edition)*, Global Cement Statistics 14 year database, International Cement Review, Tradeship Publications Ltd.

Humphreys, K. and M. Mahasenan with contributions from Placet, M. and K. Fowler (2002), *Toward a Sustainable Cement Industry: Substudy 8: Climate Change*, commissioned by the World Business Council for Sustainable Development, Battelle, http://www.wbcsdcement.org/pdf/final_report8.pdf.

Placet, M. and K. Fowler with contributions from Baker, K. *et al.* (2002), *Toward a Sustainable Cement Industry: Substudy 7: How Innovation can Help the Cement Industry Move Toward More Sustainable Practices*, commissioned by the World Business Council for Sustainable Development, Battelle, http://www.wbcsdcement.org/pdf/final_report7.pdf.

Reinaud, J. (2004), *Industrial Competitiveness Under the European Union Emissions Trading Scheme*, IEA Information Paper, IEA, Paris.

Schmidt, J., K. Lawson and J. Lee (2004), *Sector-Based Greenhouse Gas Emissions Reduction Approach for Developing Countries: Some options*, Center for Clean Air Policy, Working Paper prepared for the Dialogues on Future International Actions to Address Global Climate Change.

Soule, M. H., J. S. Logan, and T. A. Stewart with contributions from Ma, F., C. Quinn, and Anataike Information Development Co (2002), *Toward a Sustainable Cement Industry: Trends, Challenges, and Opportunities in China's Cement Industry*, commissioned by the World Business Council for Sustainable Development, Battelle, http://www.wbcsdcement.org/pdf/china_country_analysis.pdf.

Tanaka, K. and H. Kudo (2005), *Sectoral Evaluation of the Utilization Potential of Energy Efficient Technology*, The Institute of Energy Economics, Japan.

UN Comtrade: *United Nations Commodity Trade Statistics Database*, UN Statistics Division, http://unstats.un.org/unsd/comtrade, accessed March 2005.

United States Geological Survey (2003), *Minerals Yearbook, Cement*, 2003 edition, Washington, DC http://minerals.usgs.gov/minerals/pubs/commodity/myb/.

World Cement (2005), *World Cement Production*, http://www.palladian-publications.com/Cement/WC_regional_review_july04.htm, accessed April 2005.

World Energy Council (1995), *Energy Efficiency Improvement Utilising High Technology: An Assessment of Energy Use in Industry and Buildings*, London.

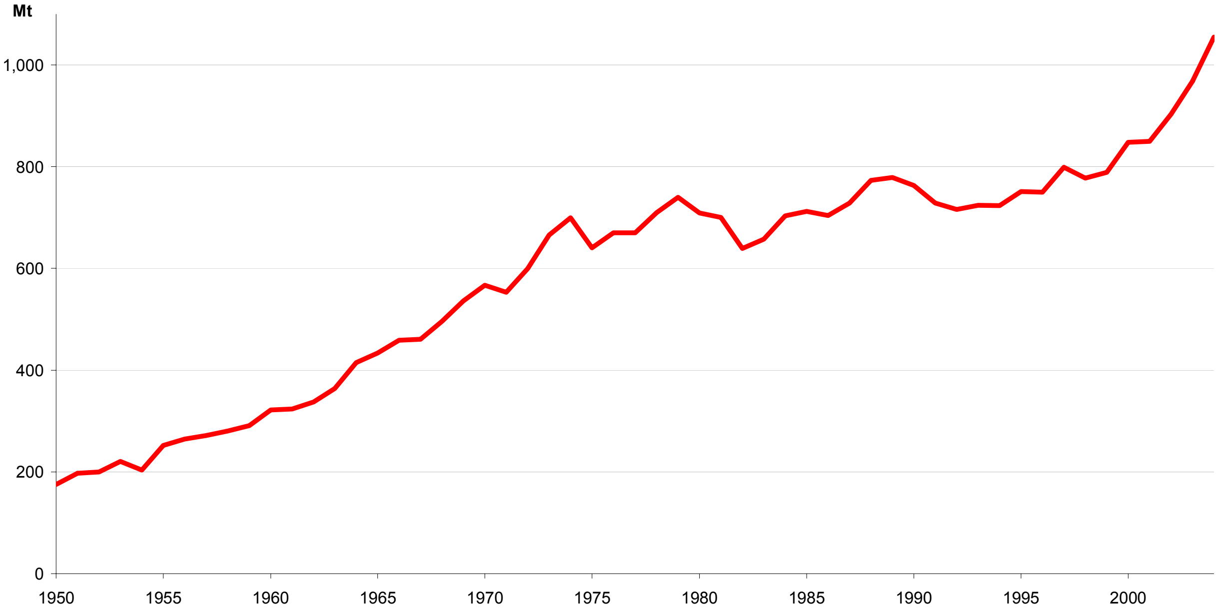
Worrell, E., *et al.* (2001), “Carbon Dioxide Emissions from the Global Cement Industry” in *Annual Review of Energy and the Environment* 26:303–29.

ANNEX C – STEEL

PRODUCTION

World crude steel production[1] grew significantly in the second half of the 20th century. Between 1950 and 1974 annual production increased four fold from 175 million tonnes (Mt) to about 700 Mt, and from 1974 to 2004 it increased 50% to over 1 000 Mt (see Figure C1). The average annual growth rate during 1970 to 2002 was 1.3%. In the last five years production has soared by 34%, driven by strong demand in China.

Figure C1 World crude steel production, 1950–2004



Source: IISI (2004a) and IISI (2005).

In 1974, 70% of steel production was in countries that are currently members of the OECD. In 2004, about half of steel production was in OECD countries (see Figure C2). China is now the world's largest steel producer, accounting for 26% of world production. In 2002, it surpassed Western Europe, which now accounts for 16% of the world steel market. Next largest producers are Japan, the Former Soviet Union and the USA, each with roughly 10% of the world market.

The steel industry has undergone considerable restructuring and consolidation in the past several decades, but remains highly fragmented. The ten largest companies account for 28% of crude steel production,[2] and the next largest ten account for an additional 8%. Mittal, recently formed by the merger of the LNM Group and ISG, has been the largest steel producer since early 2005.

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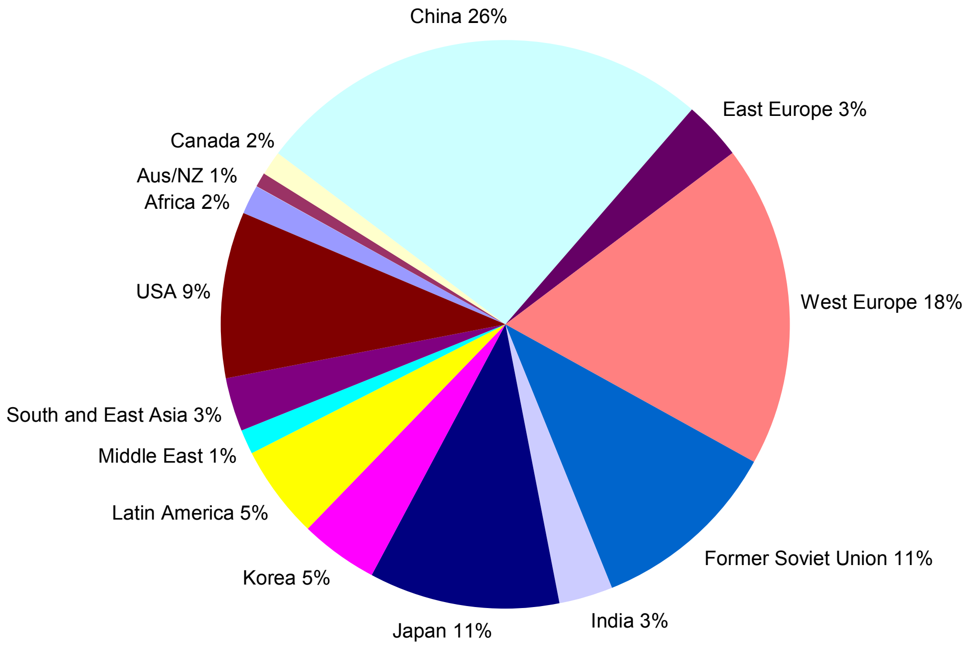
[1] Crude steel is the product produced by a continuous caster or ingot caster. Finished steel is the product produced at the end of the rolling and other finishing processes.

[2] This compares with the ten largest producers accounting for 29% of world production in 1970 and 20% in 1990. Further industry consolidation is generally expected. By 2008–2010, consolidation could result in the ten largest firms accounting for 30–35% of world production (OECD (2004)). In 2003, individual company shares, expressed as a percentage of global production, were: Mittal 5, Arcelor 4, Nippon Steel 3, JFE 3, POSCO 3, Shanghai Baosteel 3, Corus Group 2, US Steel 2, Thyssen Krupp 2, Nucor 2. IISI (2004b).

Figure C2 World crude steel production by region, 2004



Source: IISI (2005).

In some countries the sector is dominated by a small number of large producers. For example, in Australia there are five steel plants with the largest accounting for 66% of Australian steel capacity.[3] In Korea one company Posco dominates steelmaking accounting for all integrated steel, more than half of total Korean steel production.[4] In others, such as China, it is characterised by a large number of small producers,[5] although a number of very large efficient firms have emerged in recent years.[6]

CONSUMPTION

China is the world's largest consumer of steel, accounting for 26% of world consumption in 2003. Western Europe is the next largest at 18%, followed by the USA at 11% and Japan at 8% (see Figure C3). Demand for steel is linked to demand in construction and for automobiles.[7] Confidential medium-term forecasts suggest Brazil, Russia, India, China, Eastern Europe and Turkey will have the highest expected growth of 273 Mt until 2015. Western Europe and North America will have steady growth.

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[3] Department of Industry, Tourism and Resources (2004) *The Australian Steel Industry in 2003* cited in Heaney *et al.* (2005).

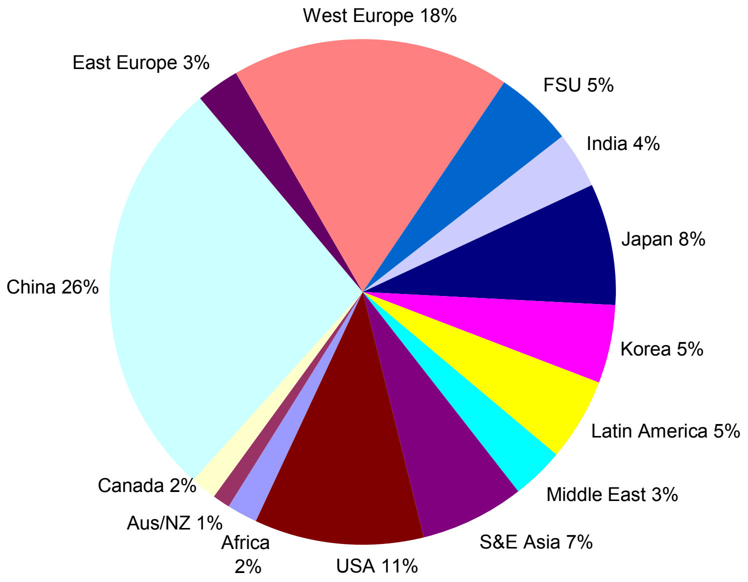
[4] IISI (2004) *Steel Statistical Yearbook 2003* cited in Heaney *et al*. (2005).

[5] Baumert (2005).

[6] In 2003, China's ten largest steel firms produced more than a third of Chinese steel, with the top four firms producing more than 20% (Heaney *et al*. (2005)).

[7] OECD/IEA (2001).

Figure C3 World crude steel apparent consumption by region, 2003



Source: IISI (2004a).

TRADE

Trade plays a major role in the steel market. About 30% of world production is traded across borders and 18% of world production is traded across the 14 regions shown in Table C1. Japan (30.8 Mt), the Former Soviet Union (27.1 Mt) and Latin America (18.0 Mt) are the largest net exporters. China (23.5 Mt), South and East Asia (19.5 Mt), the USA (19.1 Mt) and the Middle East (16.0 Mt) are the largest net importers. A significant proportion of trade is between neighbouring regions. For example, 88% of Canadian exports and 53% of Latin American extra-regional exports are to the USA. Half of Japanese exports head to Korea and China.

Table C1 Steel trade (Mt), 2003

Importing: *Exporting:*	Africa	Aus/NZ	Canada	China	East Europe	West Europe	FSU	India	Japan	Korea	Latin America	Middle East	S&E Asia	USA	Total exports	Extra-reg. exports	Net exports
Africa	1.6	0.1	0.0	0.6	0.0	1.9	0.0	0.0	0.0	0.3	0.2	0.3	0.9	0.4	6.8	5.2	-2.1
Aus/NZ	0.0	0.4	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	1.4	1.0	-0.9
Canada	0.0	0.0	-	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.1	5.0	5.7	5.7	-0.8
China	0.3	0.1	0.1	4.8	0.0	0.5	0.0	0.1	0.3	1.8	0.0	0.3	1.9	0.6	11.4	6.6	-23.5
East Europe	0.4	0.0	0.1	1.1	5.4	9.1	0.2	0.1	0.0	0.2	0.3	1.2	0.3	0.6	19.2	13.8	7.5
West Europe	3.9	0.2	0.8	3.8	5.6	88.3	0.7	0.6	0.1	0.5	1.6	6.7	2.2	4.3	121.2	32.9	7.3
FSU	1.1	0.0	0.0	5.3	0.6	8.5	3.4	0.4	0.0	0.8	0.4	4.7	3.7	0.5	32.3	28.9	27.1
India	0.4	0.0	0.0	1.2	0.0	0.5	0.0	-	0.0	0.2	0.0	0.7	1.4	0.4	5.0	5.0	2.6
Japan	0.4	0.7	0.1	7.5	0.0	0.4	0.2	0.4	-	8.8	1.0	1.2	8.7	0.9	33.4	33.4	30.8
Korea	0.1	0.3	0.2	5.5	0.0	0.6	0.0	0.2	1.9	-	0.3	0.9	2.2	1.2	13.9	13.9	0.1
Latin America	0.5	0.0	0.9	2.8	0.0	2.9	0.0	0.0	0.2	1.2	3.8	0.3	1.0	12.6	27.5	23.7	18.0
Middle East	0.0	0.0	0.0	0.1	-	0.2	0.0	0.0	0.0	0.0	-	0.3	0.1	0.0	0.7	0.4	-16.0
S&E Asia	0.1	0.6	0.0	1.2	0.0	0.2	0.4	0.4	0.1	0.0	0.0	0.2	3.4	0.3	7.1	3.7	-19.5
USA	0.1	0.0	4.1	0.8	0.0	0.7	0.1	0.1	0.0	0.0	1.6	0.1	0.2	-	7.7	7.7	-19.1
Total imports	8.9	2.4	6.5	34.9	11.7	113.9	5.2	2.3	2.7	13.8	9.6	16.7	26.6	26.8	293[†]		
Extra-reg. imports	7.4	2.0	6.5	30.1	6.3	25.6	1.8	2.3	2.7	13.8	5.8	16.4	23.2	26.8		185[†]	

Source: UN Comtrade.[8]

Boxed fields: intra-regional trade. "0.0": indicates trade of less than 50 000 tonnes between respective regions. "–": indicates no trade between respective regions. Extra-regional exports = total exports less intraregional exports. Net exports = trade balance = total exports less total imports (negative values indicate net imports). †: Exports and extra-regional exports shown in the chart do not necessarily add to the total figure shown because of unspecified items in the raw data.

COSTS

In 2003, the costs of producing steel slabs in integrated facilities varied between 141 to 221 €/tonne in (see Figure C4). The highest variability is in raw material and labour costs. Labour costs, for example, range from 3% of the total cost in China to around 20% in North America and Japan. Energy costs typically account for 15–20% of the costs of steel production.[9]

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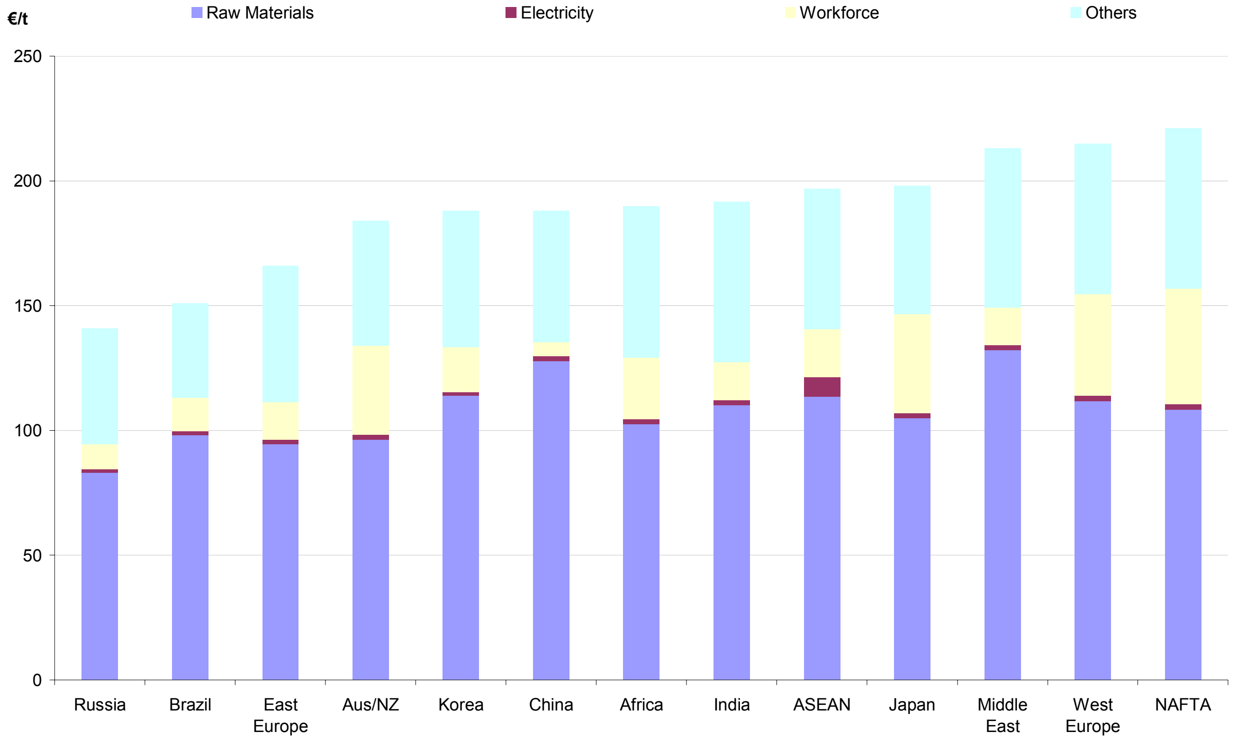
[8] HS-7206 through to HS-7229 and HS-7303 through to HS-7306.

[9] OECD/IEA (2000).

Figure C4 Costs of producing steel slabs at integrated facilities, 2003



Source: World Steel Dynamics – Roland Berger analysis cited in Arcelor (2005).

TECHNOLOGY

Steel is produced by two methods – integrated and electric furnace steelmaking. In 2004, integrated steel plants accounted for 66% of production and electric furnace the remainder.

Integrated steelmaking uses iron ore for most of its material feedstock.[10] The process, which can involve capital investment of between $2 200 and $2 500 million for a four million tonne capacity plant[11], encompasses five stages after the iron ore is mined:[12]

1. treatment of raw materials – ore preparation and cokemaking.[13]

2. iron reduction – usually pig iron production in a blast furnace, but occasionally sponge iron production in a direct reduction vessel.

3. steel refining – usually in a basic oxygen converter,[14] though a few open hearth furnaces still remain (see Figure C5 showing the reduction in open hearth furnaces since 1965 and the growth in basic oxygen conversion technology since 1960).

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[10] Typically, 68% to 72% of the iron units in crude steel made by the integrated process come from pig iron which is derived from iron ore. The remaining 28% to 32% of the iron comes from scrap.

[11] Source: Arcelor. Figures are in US dollars for a flat carbon, hot phase plant.

[12] Power generation (based on process off gases) and oxygen making are common auxiliary processes.

[13] Coke is an upgraded form of coal.

[14] Basic oxygen convertors are also called basic oxygen furnaces.

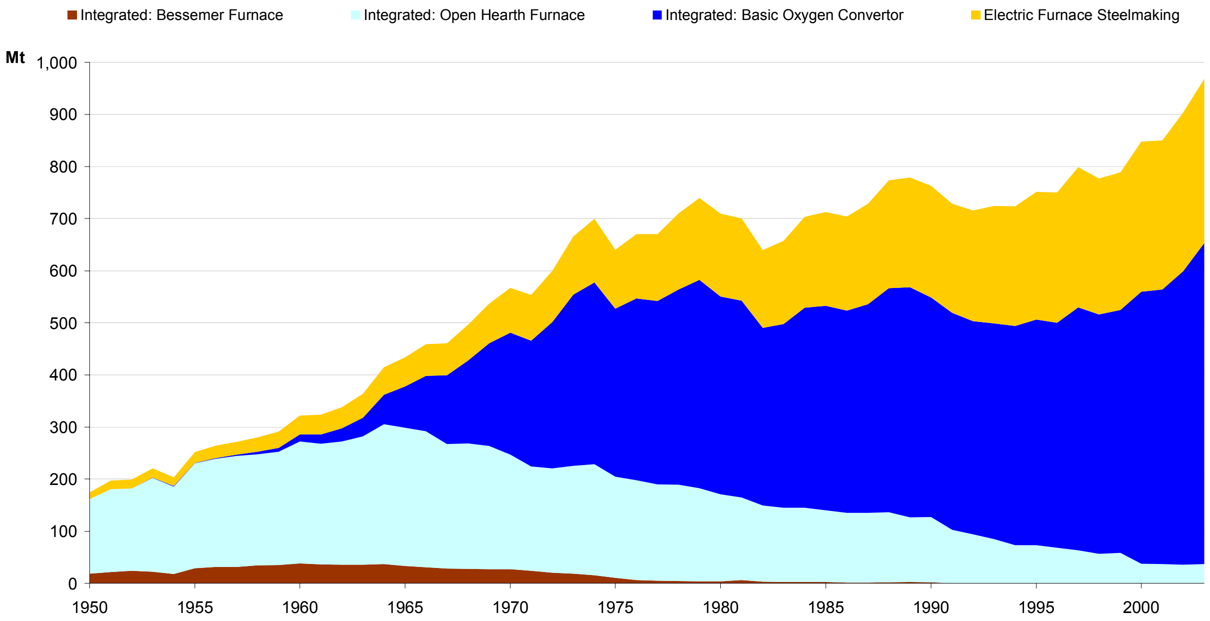
4. casting of crude steel – usually by continuous casting, but some ingot casting still takes place.[15, 16]

5. rolling and finishing.

Electric furnace steelmaking is based mostly on scrap for its iron units. As such it requires a dependable supply of good quality scrap.[17] In general, electric furnace plants are smaller than integrated plants and require less output to be profitable. They are thus frequently called “minimills”, even though their average capacity has been growing and many are of considerable size. The production process, which can involve capital investment of $150–200 million for a one million tonne capacity plant[18], encompasses three stages after the scrap is collected:

1. steel refining or scrap melting in an electric arc furnace.
2. casting of crude steel – almost always by continuous casting.[19]
3. rolling and finishing.

Figure C5 World crude steel production by process, 1950–2003



Source: IISI (2004a).

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[15] Continuous casting is a process whereby molten steel is continuously solidified into semi-finished slabs for subsequent rolling in finishing mills. The alternative, ingot casting, involves pouring the molten steel into large box-like ingot moulds on a batch basis. After the ingots solidify, they are reheated (if needed) and forged into semi-finished shapes for further processing in finishing mills. See Table C2 for a regional breakdown of continuous casting for all steel production.

[16] Some additional refining can also be done in the ladle between stages four and five.

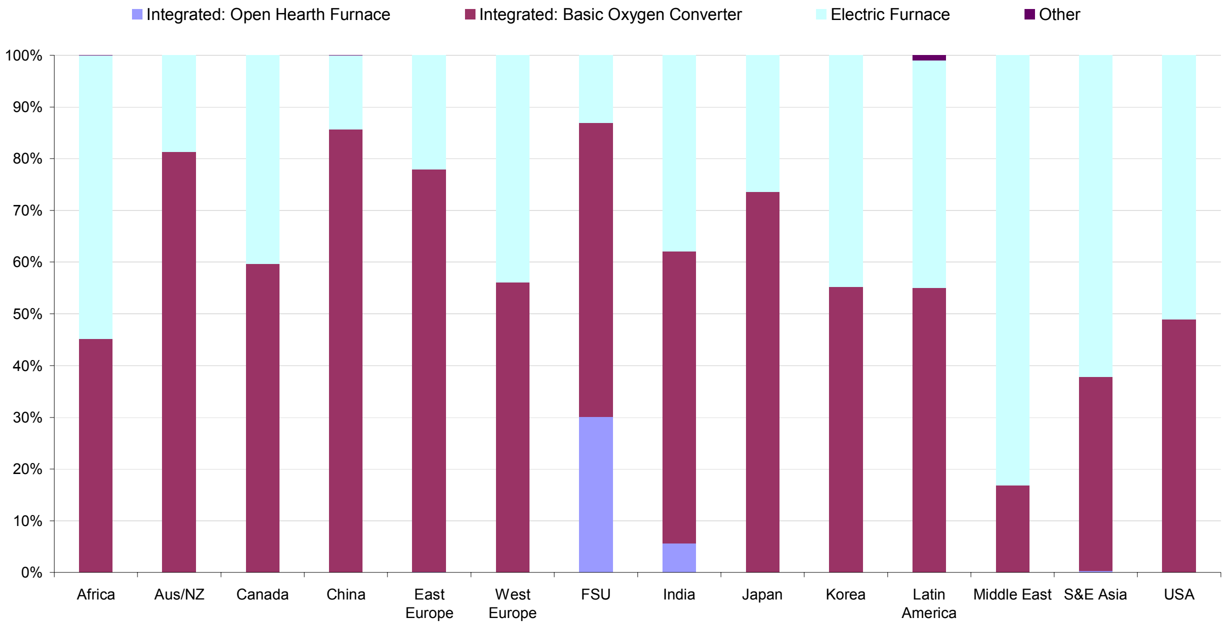
[17] Direct Reduced Iron (DRI), iron ore reduced with natural gas, is used as a scrap substitute in electric furnace steelmaking at some locations where there are difficulties with scrap availability or quality and where natural gas is inexpensive. In 2003, DRI production was 46 Mt with most of this used in electric furnace steelmaking. DRI accounted for about 5% of all iron inputs into integrated and electric furnace steelmaking in 2002.

[18] Source: Arcelor. Figures are in US dollars for a flat carbon, hot phase plant with continuous casting.

[19] On average, 88% of world production by both integrated and electric furnace production uses continuous casting. The production share of continuous casting is above 85% for all regions of the world, except for Eastern Europe and the Former Soviet Union which have a share of 53%. See Table C2.

Use of the two processes varies considerably across regions from 86% integrated steelmaking in China and the Former Soviet Union to 17% in the Middle East (see Figure C6). Only the Former Soviet Union and India now operate plants with open hearth technology.

Figure C6 Regional crude steel production by process, 2003



Source: IISI (2004a).

The development of sintered ore in the 1950s[20] and the replacement of open hearth furnaces with basic oxygen converters and ingot casters with continuous casters have been three key technological developments to improve plant efficiency. Basic oxygen convertors and continuous casters have been taken up on a widespread basis during the last 20 to 40 years, to the point where in 2003 95% of world integrated production was produced by basic oxygen converters (see Figure C5) and 88% world crude steel production was continuously cast. The only places where open hearth furnaces and ingot castings still see significant use are the Former Soviet Union, India and Eastern Europe (for ingot castings).

Other incremental improvements for improving efficiency are the use of Coke Dry Quenching, Top-Pressure Recovery Turbines and furnace gas recovery facilities.[21] The use of these technologies could be increased, but they rely on many factors such as high blast furnace pressures and they are less attractive where electricity prices are low.[22]

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[20] This allowed for a significant decrease in the consumption of coke per tonne of steel from 1 000 kg to 600 kg. Correspondence with Arcelor 13 May 2005.

[21] **Coke Dry Quenching** is a large-scale exhaust heat recovery facility, in which the red-hot coke is not quenched with water but with nitrogen gas after dry distillation. **Top-Pressure Recovery Turbine** is a facility in which the top-pressure of a blast furnace is controlled by a turbine and the unused energy recovered as electric power. **Furnace gas recovery** is a facility in which the heat of the blast furnace is recovered and utilised. Tanaka and Kudo (2005).

[22] Correspondence with Arcelor 13 May 2005.

ENERGY USE AND EMISSIONS

The iron and steel industry is the largest energy consuming manufacturing sector in the world.[23] GHG emissions from iron and steel production are caused by the combustion of fossil fuels, the use of electrical energy and the use of coal and lime as feedstock. The emissions are predominantly CO_2, although very small amounts of CH_4 and N_2O may also be emitted.[24] Taking into account all onsite emissions and the indirect emissions from electricity use, iron and steel production accounts for an estimated 5.2% of total world GHG emissions at 2 165 Mt CO_2.[25]

The **integrated** process is on average around 4.5 times more emissions intensive than the electric process (see Table C2). The blast furnace is the core of the integrated process in terms of energy use and GHG emissions. Coke is both the principal chemical reactant and fuel of the blast furnace. The carbon in the coke reduces the iron ore (Fe_2O_3) to make pig iron (Fe). This process requires a large amount of heat energy, supplied by the combustion of coke, to proceed sufficiently quickly. Coke's reaction with the iron ore and its combustion produces CO_2. The other production stages consume less energy and result in fewer direct CO_2 emissions. To the extent that the processes are more efficient (i.e. yield losses are low), CO_2 emissions per tonne of finished steel output are reduced. The use of continuous casting is particularly important in this regard. Continuous casting yields are typically 96–99%, compared with ingot casting yields of 85–89%.[26]

Electric steelmaking uses much less energy and emits much less CO_2 than the integrated process because the iron in the scrap used for production does not need to be reduced. The steel is simply remelted and re-refined. However, this advantage is partially offset by the fact that this process requires almost three times as much electricity as the integrated process per tonne of steel produced.

Current emissions of the steel industry are shown in Table C2. Fifty-nine per cent of all emissions come from integrated plants in non-OECD countries, significantly higher than their share of production at 38%. Another 31% of total steel emissions come from integrated plants in OECD countries. Electric steel plants emit the remaining 10%.

There are large regional differences in the energy efficiency and environmental performance of steel making according to estimated emissions intensity figures based on 1995 emissions intensity data (see Table C3). The fossil fuel emissions of integrated plants vary from 1.89 (in North America) to 3.65 (in China) tonnes of CO_2 per tonne of crude steel, with a world average of 2.62. In general less developing regions have higher emissions intensities, but the relationship is not strong. The regional differences are due to technology used, plant operating efficiency, plant maintenance, the fuel mix and the quality of coal[27] and iron ore.

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[23] OECD/IEA (2001).

[24] *Ibid.*

[25] Total steel emissions are based on 1995 emissions emission intensity figures and 2004 production data. Steel's share of total anthropogenic GHG emissions is likely to be a slight overestimate because the 2000 total anthropogenic GHG emissions was used as the denominator.

[26] Correspondence with Arcelor 19 and 20 May 2005. Continuous casting yields for flat steel are 96% and 98–99.5% for long steel depending on steel specificities and the length of the sequences. Ingot casting yields are 85% for flat steel and 85–91% for long steel depending on steel specificities.

[27] For example, using high sulphur and/or high ash content coal increasing energy consumption of the process.

Table C2 World steel CO_2 emissions profile, 2004

	OECD	Non-OECD	Total
Production	**(Mt)**	**(Mt)**	**(Mt)**
Integrated	301	397	698
Electric	213	144	357
Total production	514	541	1055
Consumption (2003)	**(Mt)**	**(Mt)**	**(Mt)**
Total consumption	467	503	970
Emissions intensity	**(t CO_2/t)**	**(t CO_2/t)**	**(t CO_2/t)**
Integrated			
Electricity	0.1	0.2	0.1
Fossil fuel	2.1	3.1	2.7
Process			
Total Emissions Intensity	2.2	3.2	2.8
Electric			
Electricity	0.3	0.5	0.4
Fossil fuel	0.2	0.2	0.2
Total Emissions Intensity	0.5	0.7	0.6
Weighted average	1.5	2.6	2.1
Emissions	**(Mt CO_2)**	**(Mt CO_2)**	**(Mt CO_2)**
Integrated	668	1282	1951
Electric	113	100	214
Total Emissions	782	1383	2165

Sources: IISI (2005), IISI (2004) and Mæstad (2000).

Table C3 Estimated steel CO_2 emissions intensities by region, 1995[28]

	Integrated Steel				Electric Steel				Cont. Casting	Total
	Prod. Share (%)	Emissions Intensity (t CO_2 / t crude steel)			Prod. Share (%)	Emissions Intensity (t CO_2 / t crude steel)			Prod. Share (%)	Emissions Intensity. (tCO_2 /t steel)
		Fossil	Elec.	Total		Fossil	Elec.	Total		
USA, Canada, Mexico	48	1.9	0.1	2.0	52	0.2	0.4	0.6	98	1.3
Africa and Middle East	32	2.7	0.1	2.8	68	0.2	0.4	0.6	99	1.3
EU	59	2.0	0.1	2.1	41	0.2	0.3	0.5	97	1.4
Rest of West Europe	73	2.0	0.0	2.0	27	0.2	0.1	0.2	86	1.5
Rest of Asia	51	2.3	0.1	2.4	48	0.2	0.5	0.7	89	1.6
Latin America[29]	63	2.5	0.0	2.5	35	0.2	0.1	0.3	93	1.7
Japan[30]	74	2.4	0.1	2.5	26	0.2	0.2	0.4	98	1.9
East Europe and FSU	53	2.2	0.2	2.4	21	0.2	0.5	0.8	53	2.0
Aus/NZ	81	2.4	0.2	2.6	19	0.2	0.5	0.7	99	2.2
China	86	3.7	0.2	3.9	14	0.2	0.7	0.9	91	3.4
Total World	64	2.6	0.1	2.7	33	0.2	0.4	0.6	88	2.0

Sources: IISI (2004a) and Mæstad (2000). Note: EU excludes Finland and Sweden. Turkey is included in Eastern Europe and FSU.

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[28] Emission intensity figures are from Mæstad (2000). This study used data on materials and energy inputs and production outputs from a sample of 73 production plants around the world representing 10% of total steel production. The data, drawn from a CRU database, was used along with IEA data and IPCC guidelines to calculate carbon emission intensities for each region by production process.

[29] Correspondence with Arcelor on 13 May 2005 suggests that the Latin America integrated figures are higher than is actually the case as are the figures for Japan.

[30] Mæstad (2003) note the following: "Some commentators have indicated that the Japanese emission coefficient in BOF steel production is high relative to the emission coefficients in other industrialised countries. Errors in the relative emission coefficients may be a result of sample biases. Note, however, that a study by Gielen and Moriguchi (2002) on emissions in the Japanese steel industry provide empirical support for the emission coefficient used in this report." Statistics from the Japan Iron and Steel Federation show that the CO_2 emissions intensity for all crude steel production in Japan was 1.69 Mt CO_2 per tonne of steel in 2000.

Potential emissions reductions

The various stages of steel production generate numerous fuel and heat byproduct streams. The extent to which these streams are utilised (and displace the CO_2 emissions from using additional fuels in processes directly or in generating additional heat or electricity, both inside and outside the plant) greatly affects steel plant emissions. There is a variety of process integration and heat recovery technologies that can reduce emissions by better use of these byproduct streams. Technologies that improve process control and increase plant efficiencies are also major potential sources of emissions reductions.[31] Coke dry quenching, top-pressure recovery turbines, continuous casting and furnace gas recovery facilities are some options. The potential emissions reductions from widespread adoption of these technologies are shown in Table C4. The economics of adopting these technologies to better manage byproduct streams depends in large measure on the particular configurations of steel plants and on local markets for fuels, heat and electricity.

Table C4 Steel emissions reduction potentials by region, 2020

	Coke Dry Quenching	Top-pressure Recovery Turbine	Furnace gas recovery facility	Continuous casting	Total
Current diffusion level (%)					
North America	0	2	10	97	
Europe	30	20	10	92	
FSU	30	20	10	42	
Korea	50	100	25	99	
Developing countries	10	2	5	91	
Japan	90	97	100	98	
Target diffusion level (%)					
	90	97	98	100	
CO_2 Emissions Reductions, 2020 (Mt CO_2)					
North America	3	3	0	11	17
Europe	4	3	2	21	29
FSU	4	1	11	13	28
Korea	1	0	0	4	4
Developing countries	18	14	5	58	95
World	30	21	18	107	173

Source: Tanaka and Kudo (2005).

There are many new technologies under various stages of development and early commercialisation that could potentially affect the CO_2 emissions of the steel making process in the medium term. One notable process integration technology is near net shape casting, which refers to the direct casting of the metal into, or near to, the final shape. In conventional steelmaking, with or without continuous casting, steel is first cast and stored. The cast steel is reheated and treated in the rolling mills to be reshaped. Near net shape casting integrates casting and the first rolling steps. The current status of this technology is called ‘thin slab casting’. Instead of slabs of 120–300 mm thickness produced in a continuous caster, slabs of 30–60 mm thickness are cast. The cast thin slabs are reheated in a coupled furnace, and then directly rolled in a simplified hot strip mill. The current state-of-the-art technology is at the prototype stage prior to demonstration. It is expected that deployment will be initially confined to the EU and the USA by the year 2010.[32]

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[31] Worrell *et al.* (1999).

[32] EU ATLAS (1997).

Also of interest in the medium and longer terms are various smelt reduction technologies that have been under development for many years. With further development these might replace blast furnaces or DRI processes at some sites. Among these technologies are the COREX©, the Cyclone Converter Furnace (CCF), AISI, DIOS, HISmelt and FINEX process as alternatives to the blast furnace. The Circored©, Circofer©, SL/RN, Fastmet, HYLI, HYLIII , FIOR and the iron carbide processes represent alternatives to the Midrex DRI process.

These processes are not, however, universal substitutes for blast furnaces or DRI processes. In certain cases, they entail higher emissions than current blast furnaces. Their applicability depends on capacity size requirements, the availability, prices and quality of iron-bearing materials (including scrap), and the relative prices of metallurgical coal, lower grades of coals, natural gas and electricity. Their economic potential to reduce CO_2 emissions depends heavily on site-specific factors such as the availability of CO_2 storage capacity, the emissions factor ($kgCO_2/MWh$) of the power generation sector and the stringency of emission policies.[33]

Daniels (2002) modelled the effects of these three factors on the relative economic attractiveness and CO_2 reduction potential of the major smelt reduction technologies and found the following.

- **Blast furnace** based production will probably remain the most important primary production route for a long time to come in the absence of strong GHG policies, CCF and restrictive legislation on the coke oven.

- **Cyclone Converter Furnace (CCF)** is the only new process that is capable of displacing the blast furnace without GHG policies. However, its development has been halted and it is not likely to be available in the near future.

- **COREX** is a likely successor of the blast furnace when restrictive legislation on coke oven rebuilding proves too big a burden for the blast furnace. However, COREX generates great quantities of CO_2 and the implementation of even moderate GHG policies would favour other processes.

- **Midrex** and **Circored** are likely candidates in the case of stringent GHG policies and the absence of CO_2 storage possibilities. Circored appears to be the more attractive because of its lower investment costs and its ability to use cheaper fine ore. However, it is a much newer process and its characteristics may prove less favourable than currently seems. High natural gas prices are inhibiting the wider adoption of both processes.

- **Circofer** is an attractive candidate, were CCF unavailable, in the case of stringent GHG policies combined with the possibility of CO_2 removal.

No technology has the lowest emissions in all circumstances. Daniels (2002) assessed the emissions reduction potential as follows:

> *In the absence of CO_2 storage capacity, natural gas based production technologies such as Midrex and Circored allow the maximum potential of roughly 30% reduction for high power generation emission factors and 60% for low emission factors. In the presence of CO_2 storage capacity, low power generation emission factors allow reductions between 85 and 90% by all included new production routes. At high power generation emission factors, only the two pig iron based new production routes (Corex and CCF) realise reductions of about 80%. Generally, CO_2 storage*

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[33] Daniels (2002).

allows specific emissions of primary production that are in the same range as those of scrap based production. (Daniels, 2002)

Overall, in the long term carbon capture and storage and process technologies based on hydrogen reduction of ore and electrolysis using electricity generated from carbon-neutral biomass sources offer the lowest emissions.

In North America, the steel industry is engaged in the "CO_2 Breakthrough Program" to discover, pilot and ultimately demonstrate new steelmaking technologies that will greatly reduce the industry's energy intensity. The industry has expressed particular interest advancing the concepts of geological sequestration, closed-cycle biomass techniques, advanced scrap recycling (removing unwanted elements) and scrap processing (smaller sizes, including powder, for melt efficiency), and alternative reducing agents.[34]

CLIMATE POLICIES

Governments are using three main policies to encourage the steel industry and other energy-intensive industries to reduce their energy use and CO_2 emissions:

- **Voluntary approaches:** these are the most widely used of the three policies – 13 OECD countries have voluntary agreements with their steel industries. While voluntary approaches are useful in engaging industry and heightening awareness of emissions mitigation, their effect on steel industry energy use and emissions is at best mixed. In some countries, these instruments represent unilateral statements of intent by industry to cut emissions, but involve no independent evaluation of such proposed cuts in relation to baseline emissions trends, and no penalties for failure to meet targets. Elsewhere, in particular the Netherlands and the United Kingdom, such agreements can represent strong motivators, with rigorously analysed, negotiated and monitored targets, and significant penalties for non-attainment such as loss of large tax benefits.

- **Environmentally-motivated taxes:** these are less widespread than voluntary approaches. Their impacts are usually muted through explicit exemptions for steel and other energy-intensive industries and through differentiated rates on fuels and consumption levels that favour heavy industry.

- **Emissions allowance regulations and trading:** this is the newest instrument and will probably be the strongest policy motivation behind future energy efficiency improvements and CO_2 emissions reductions in the steel industry. In most OECD countries, regulations will require industrial firms to redeem an allowance or permit for each tonne of CO_2 they emit. This instrument enables industry to cut emissions in the least expensive way possible – companies can either cut their own emissions, or if it is less expensive, purchase allowances from companies that have cut their own emissions by more than the required amount.

EU Emissions trading scheme (EU ETS)

Under the EU ETS all installations covered by the scheme (which includes iron and steel mills) will be required to surrender an allowance for each tonne of CO_2 emitted during each year.[35] Each individual installation's best strategy will depend on the price of allowances on the market and the technical options

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[34] Energetics Inc. (2003).

[35] The EU scheme covers energy combustion installations greater than 20MW, as well as oil refineries, coke ovens, metal production and processing, as well as producers of cement, glass, ceramics, pulp from timber and paper products, and include 4000 to 5000 installations (European Commission 2001).

for emissions abatement at the facility. The Directive stipulates that the majority of allowances will be allocated freely and a portion will be auctioned (i.e. up to 5% auctioned during 2005–2007 and up to 10% during 2008–2012).

As a first order impact, the EU ETS directly increases the production costs for any output that leads to emissions that are not covered by the initial allocation. The IEA has estimated the extent of the cost increases to the steel industry of the emissions constraints under the EU ETS. The analysis assumes an average allowance price of €10 per tonne of CO_2, and that electricity pricing would lead to a full pass-through of the carbon opportunity cost in power prices, leading to an 11% price increase in electricity prices in Continental Europe. On top of this indirect cost, the steel industry would face the cost of complying with its own emission objective. It is assumed the industry purchases allowances to cover its shortfall.[36] Table C5 indicates the impact of both direct and indirect carbon cost under two scenarios -- the 2% scenario, in which industry is allocated allowances to cover 98% of its emissions; the 10% scenario, in which industry is allocated allowances to cover 90% of its emissions.[37]

Table C5 Simulated effects of the EU Emissions Trading Scheme on steelmaking costs

	Unit cost increases ($/tonne of finished product)			
	2% scenario		10% scenario	
	Integrated steelmaking	Electric furnace steelmaking	Integrated steelmaking	Electric furnace steelmaking
Average costs				
Indirect costs from electricity price increases	1.34	1.80	1.34	1.80
Costs of compliance (abatement + allowances) on direct emissions	0.41	0.07	2.06	0.34
Total average costs	1.75	1.87	3.40	2.14
Marginal costs				
Indirect costs from electricity price increases	1.34	1.80	1.34	1.80
Costs of compliance (abatement + allowances) on direct emissions	19.26	1.60	19.26	1.60
Total marginal costs	20.60	3.40	20.60	3.40

Source: Reinaud (2004).

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[36] The possibility that installations would take abatement measures was not treated explicitly in the study, for lack of certain information on allocation levels, the price of CO_2 and the abatement potential for covered industries, with the corresponding cost per avoided tonne of CO_2.

[37] Reinaud (2004).

REFERENCES

Arcelor (2005), Presentation.

Baumert, K., T. Herzog, and J. Pershing (2005), *Climate Data: A sectoral perspective*, World Resources Institute, Washington, http://www.pewclimate.org/docUploads/Sectoral Data.pdf, draft.

Daniels, B. (2002), *Transition Paths towards CO_2 Emission Reduction in the Steel Industry*, Universal Press, Veenendaal.

Energetics Inc. (2003), *Outcomes of the CO_2 Breakthrough Program Concept Discovery Workshop*, September 8–9, 2003.

EU ATLAS (1997), *The EU Atlas project, an information base to support energy Research and Technological Development (RTD) strategies*, funded under 4th Framework Programme for Research and Technological Development, http://europa.eu.int/comm/energy_transport/atlas/homeu.html.

Heaney, A., *et al.* (2005), *New Emerging Technologies: Measuring potential impacts in APEC*, APEC Energy Working Group, Report no. APEC #205-RE-01.1, Australian Bureau of Agriculture and Resource Economics, Canberra, http://www.apec.org/apec/publications/all_publications/energy_working_group.html.

IISI (2005), *World Steel in Figures 2005 edition*, International Iron and Steel Institute, Brussels.

IISI (2004a), *Steel Statistical Yearbook 2004*, International Iron and Steel Institute, Brussels.

IISI (2004b), *World Steel in Figures 2004 edition*, International Iron and Steel Institute, Brussels.

Mæstad, O. (2003), *Environmental Policy in the Steel Industry: Using economic instruments*, OECD, Paris.

Mæstad, O. (2000), *Data For a Steel Industry Model*, Foundation for Research in Economics and Business Administration (SNF) working paper no. 86/00, Bergen, Norway.

Newman, J. (2005), *Policies to Reduce Greenhouse Gas Emissions in Industry: Implications for steel*, presented at the OECD/IISI Outlook for Steel Conference, Paris, 12–13 January 2005.

OECD (2004), *Background and Issues Paper for the OECD/IISI Outlook for Steel Conference 12–13 January 2005*, (SG/STEEL (2004/7)), OECD, Paris.

OECD/IEA (2000), *Emission baselines: Estimating the unkown*, OECD/IEA, Paris.

OECD/IEA (2001), *An Initial View on Methodologies for Emission Baselines: Iron and steel case*, OECD/IEA, Paris.

Reinaud, J. (2004), *Industrial Competitiveness Under Emissions Trading*, IEA Information Paper, IEA/OECD, Paris, http://www.iea.org/Textbase/Papers/2004/Industrial_Competitiveness.pdf.

Tanaka, K. and H. Kudo (2005), *Sectoral Evaluation of the Utilization Potential of Energy Efficient Technology*, The Institute of Energy Economics, Japan.

UN Comtrade: *United Nations Commodity Trade Statistics Database*, UN Statistics Division, http://unstats.un.org/unsd/comtrade, accessed March 2005.

Worrell, E., N. Martin and L. Price (1999), *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector*, Lawrence Berkeley National Laboratory, LBNL-41724.

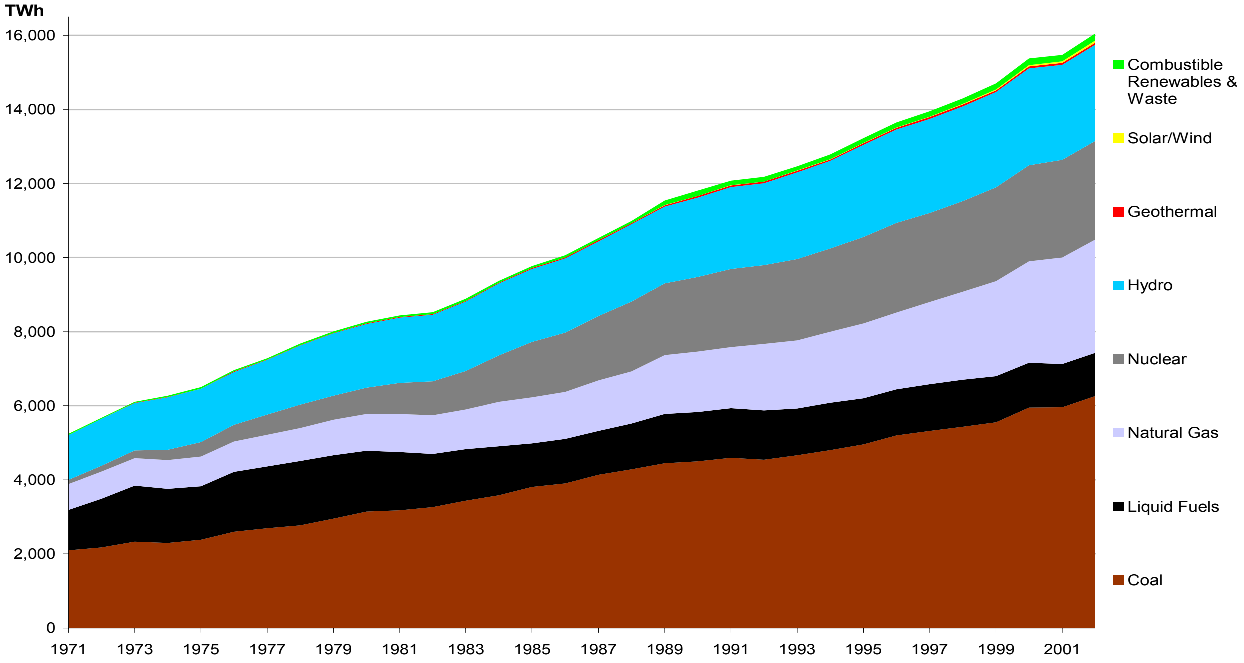
ANNEX D – COAL-FIRED ELECTRICITY GENERATION

PRODUCTION

Between 1973 and 2002, world electricity production[1] increased from 6 124 Terawatt hours (TWh)[2] to 16 129 TWh. The average annual growth rate during that time span was 3.4%. In 1973, 72.9% of electricity production was in countries that are currently members of the OECD. In 2002, 60.9% of electricity production was in OECD countries. The increase in the electricity production share of non-OECD countries reflects their higher average growth rate. In the last 30 years, electricity production has increased at an annual rate of 4.7% in non-OECD countries while in OECD countries the annual growth rate was 2.8%.

Coal remains the most important fuel source, accounting for 39.0% of electricity production. The share of liquid fuels has dropped significantly, while natural gas has increased significantly, with most of the growth being in the last 10 to 15 years. In 2002, fossil fuels combined (coal, liquid fuels and natural gas) accounted for 65.3% of world electricity production, down from 74.2% in 1971. The largest percentage increase for 1971–2002 was in nuclear, which increased its share nearly eight-fold from 2.1% to 16.5%. Note that most of this growth was prior to 1990. Hydro has fallen from 23.0% to 16.6%, but in absolute terms has still increased. In 2002, renewable energies, excluding hydro, accounted for less than 2% of total production.

Figure D1 World electricity production by fuel source, 1971–2002



Sources: Data derived from IEA Statistics (2004d) and IEA Statistics (2004e).

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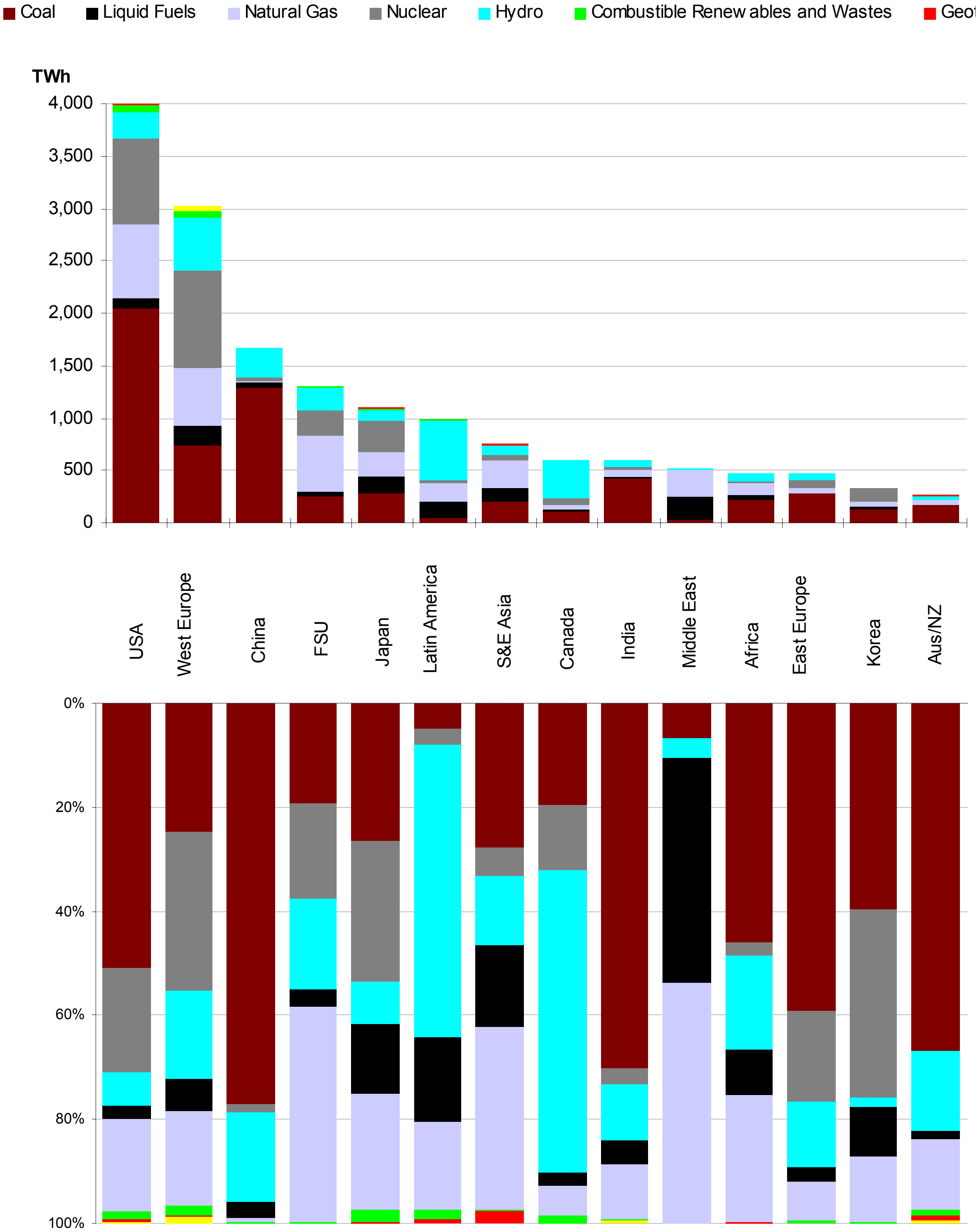
[1] All statistics in this profile include electricity (and heat) from public producers and autoproducers. Public producers generate electricity and/or heat for sale to third parties, *as their primary activity*. Autoproducers generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity. See IEA (2004a) Part II.7. Unless stated otherwise electricity statistics do not include heat.

[2] One Terawatt hour (TWh) = 1 000 Gigawatt hours (GWh) = 1 000 000 Megawatt hours (MWh).

Figure D2 Electricity production by region and fuel source, absolute and relative shares, 2002



Sources: Data derived from IEA Statistics (2004c) and IEA Statistics (2004d).

Coal-fired generation in OECD countries reached 3 733 TWh in 2002. The USA produced 2 047 TWh of coal-fired electricity in 2002, accounting for 32.7% of the world's coal-fired electricity generation. China was the next largest coal-fired producer at 20.5%, followed by Western Europe at 11.9% and India at 6.7%.

There is a wide variation in the extent to which countries and regions are dependent on coal for their electricity. In Latin America coal provides only 4.9% of total electricity and 6.8% in the Middle East. On the other hand, coal accounts for 75.5% of all electricity in China; in Australia/New Zealand and India coal fuels 70% of total electricity production.

Electricity and heat[3] account for 69% of global coal consumption. China is the world's largest coal producer and consumer, overtaking the USA in the late 1980s. This is despite a decline in production from a peak of 1 402 Mt in 1996 to 1 231 Mt in 2000. China has also become the second-largest exporter of coal after Australia.[4] Japan continues to be the world's leading coal importer, importing nearly all of its coal.[5]

The electricity market is organized around power companies whose size varies substantially. The ten largest power companies in the world account for one-fifth of the world's installed capacity.[6] In the past decade, many companies chose to invest in other countries in their region or overseas.[7]

COAL TYPE

Coals with a higher carbon content have a higher quality and rank, i.e. they contain more energy. There are many different ways to categorise coal. We adopt the categorization used by the IEA[8], which splits coal into two groups. The first is hard coal which contains energy greater than 23.9 GJ/t (5 700 kcal/kg). Hard coal includes coking coal (used in blast furnaces) and steam coal. The second is brown coal which contains energy less than 23.9 GJ/t. Brown coal includes sub-bituminous coal[9] and lignite.[10] In addition to hard and brown coal, energy statistics for coal include peat (the lowest in carbon content) and coal gases.

In 2002, hard coal accounted for 86% of coal production, with brown coal accounting for 12%, and peat and coal gases the remaining 2%. Figure D3 shows that brown coal is important in Eastern Europe, Canada and Latin America, accounting for 63%, 57% and 54% of total coal production.[11] It accounts for around 25–30% of coal in Western Europe, Australia and New Zealand, and the Former Soviet Union. China, Japan, Africa, Korea and the Middle East use no brown coal.

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[3] See page 103 for information on combined electricity and heat plants.

[4] IEA (2003b).

[5] Energy Information Agency (2004).

[6] The world's ten largest electricity companies, ranked by installed capacity, are: RAO-UES (Russia) at 156 GW, EDF (France) at 121 GW, Tepco (Japan) at 59 GW, E.ON (Germany) at 54 GW, SUEZ (France) at 49 GW, ENEL (Italy) at 45 GW, RWE (Germany) at 43 GW, AEP (USA) at 42 GW, ESKOM (South Africa) at 42 GW and ENDESA (Spain) at 40 GW. The country in brackets represents the company's home base. Data was taken from company websites. See IEA (2003b).

[7] IEA (2003b).

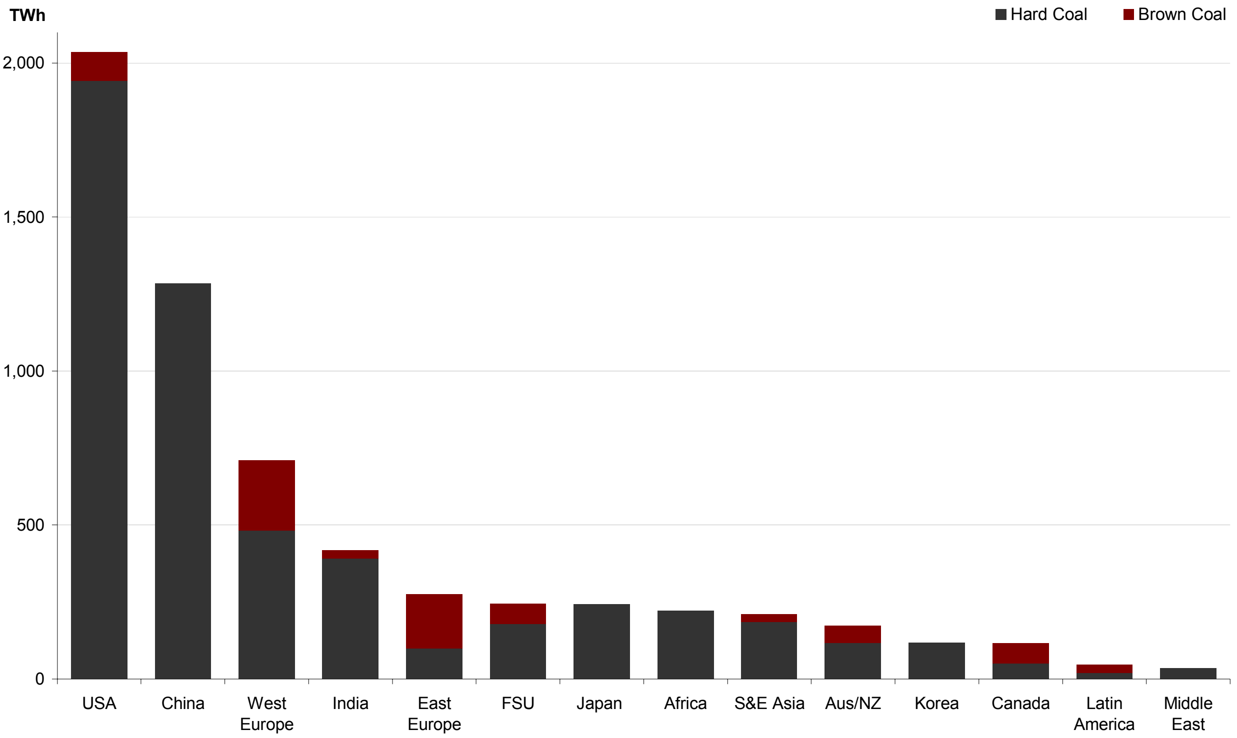
[8] Classification of different types of coal into practical categories for use at an international level is difficult because classification systems vary between countries. IEA (2004a) adopts the International Coal Classification of the Economic Commission for Europe (UN/ECE) which recognises two broad categories of coal: hard and brown.

[9] There are exceptions to this: sub-bituminous coal is included with hard coal in Australia, Belgium, Finland, France, Iceland, Japan, Korea, New Zealand, Portugal and the USA (IEA (2004b)).

[10] Sub-bituminous coal as non-agglomerating coal with a gross calorific value between 4 165 and 5 700 kcal/kg. It defines lignite as non-agglomerating coal with a gross calorific value less than 4 165 kcal/kg. See IEA (2004a).

[11] The graph excludes the two coal categories – coal gases and peat – because they are typically a very small source of electricity. Coal gases account for a small share of electricity in Japan (4.5%), Korea (3.8%), Belgium (3.2%) and the Netherlands (3.0%). Finland and Ireland generate 8.6% and 8.3% respectively of their electricity from peat. Aside from these countries the contribution coal gases and peat make to electricity is negligible.

Figure D3 Coal type used for electricity generation by region, 2002



Sources: Data derived from IEA Statistics (2004d) and IEA Statistics (2004e).

TRADE

In 2002, 509 TWh of electricity, or 3% of production was exported. OECD countries imported nearly 360 TWh of electricity in 2002 (including from other OECD countries) and exported over 341 TWh (including to other OECD countries). Accordingly, net imports of electricity in 2002 amounted to 18.7 TWh. In 2002, non-OECD countries imported nearly 163 TWh and exported 168 TWh.[12]

Table D1 Top ten electricity exporting countries

In absolute terms			Relative to domestic production	
Country	Exports (TWh)	% of domestic output	Country	Exports as % of domestic production
France	80	14	Paraguay	87
Paraguay	42	87	Mozambique	84
Germany	38	7	Luxembourg	78
Canada	36	6	Lithuania	62
Switzerland	32	48	Switzerland	49
Czech Republic	21	27	Slovak Republic	34
Russia	18	2	Slovenia	33
Norway	15	11	Ivory Coast	30
Sweden	15	10	Zambia	30
Austria	15	24	Denmark	28

Source: IEA Statistics (2004b).

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[12] IEA (2004a).

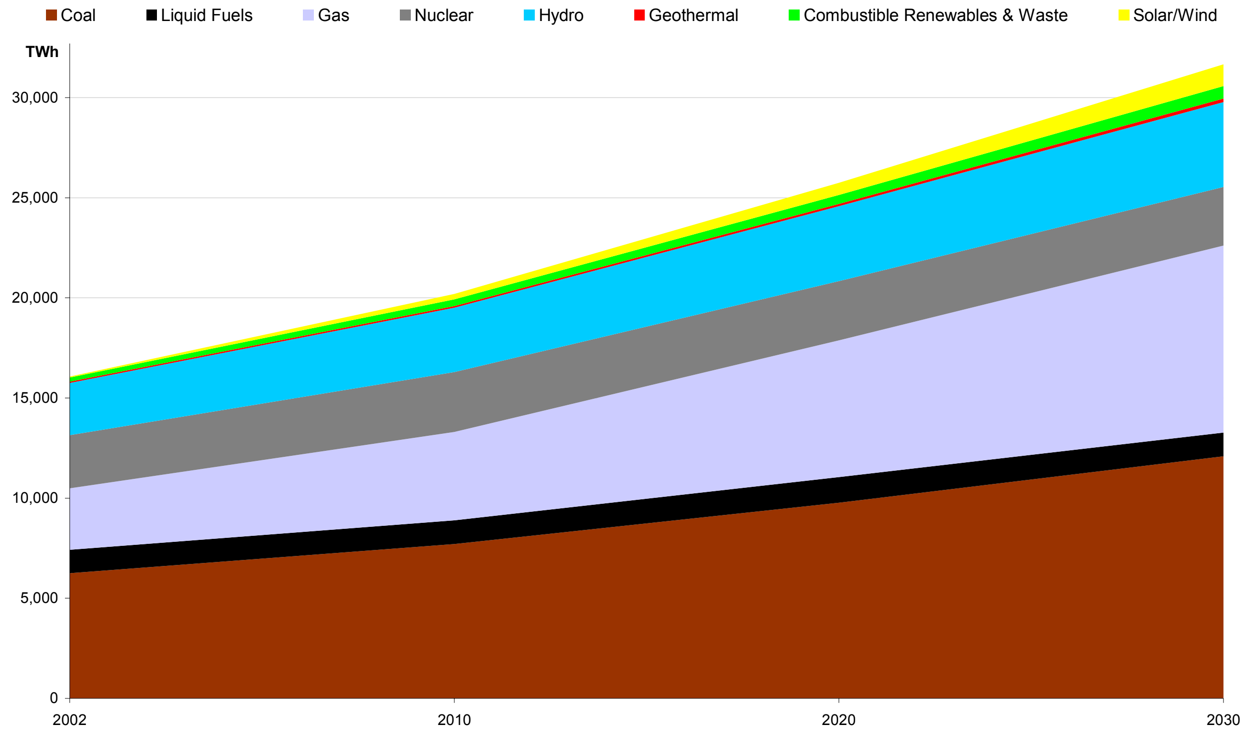
The top ten importing nations as a percentage of total energy supplied in 2002 were Luxembourg, Benin, Togo, Mozambique, Congo, Lithuania, Switzerland, Namibia, Moldova and Latvia.[13]

DEMAND AND INVESTMENT PROJECTIONS[14]

Demand for electricity is closely linked to economic growth. World electricity demand is expected to double between now and 2030, with most of the growth occurring in developing countries where economic growth will be higher.

The global power sector will need about 4 800 GW of new capacity to meet the projected increase in electricity demand and to replace ageing infrastructure. In total, electricity investment will amount to about $10 trillion, more than $5 trillion of that amount for developing countries alone. For many, investment will need to increase substantially.

Figure D4 Projected world electricity production to 2030, by fuel source



Source: IEA (2004d).

Natural gas-based electricity production is expected to triple between now and 2030, increasing its share in OECD countries to 29% and to 26% in developing countries. This reflects the competitive generating costs of gas (see Figure D5). Coal, the most abundant fossil fuel,[15] will remain the electricity sector's main fuel, with its share of electricity falling only slightly to 38% in 2030.

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[13] IEA Statistics (2004a).

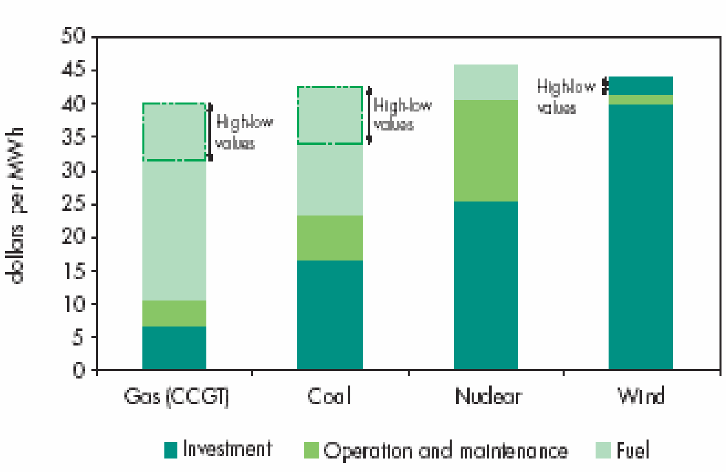
[14] Unless stated otherwise material from this section is sourced from IEA (2003b) and IEA (2004d).

[15] At current production levels, proven coal reserves are estimated to last nearly 185 years (IEA Statistics (2004a)). In contrast, proven oil and gas reserves are equivalent to around 40 and 60 years at current production levels respectively (World Coal Institute (2002)). In 2003, the USA

Coal's market share in the OECD is expected to decline substantially over the projection period, falling from 38% in 2002 to 33% in 2030. Nearly 60% of the world's current coal-based electricity production is in OECD countries. However, by 2030 developing countries are projected to account for almost 60% of world coal-based electricity in 2030. Coal will remain the dominant fuel in power generation in developing countries because of their large coal reserves and coal's low production costs. China and India together will account for 44% of worldwide coal-based electricity generation, up from 28% in 2002.

Electricity generation will account for 90% of global coal demand growth over 2002–2030. Coal demand will increase most in developing Asian countries. China and India alone will be responsible for 68% of the increase in demand.

Figure D5 Indicative mid-term generating costs – gas, coal, nuclear and wind



Source: IEA (2004d).

Coal-fired power plants are among the oldest power plants in operation in the world on average. A large number of plants will reach their economic lifetime within a decade[16] although there are significant regional variations. For example, most standing capacity in Europe and North America is over 25 years old while most standing capacity in Japan and China is less than 20 years old. Coal-fired plants are typically assumed to have a lifetime of 40 to 50 years.[17]

Investment in coal-fired electricity generation plants is expected to be around $1.3 trillion over 2003–2030. Nearly 1 400 GW of new coal-fired power capacity will be built worldwide during that time. About two-thirds of these plants will be built in developing countries, especially in developing Asia. These plants will be, in general, less efficient than coal plants in OECD countries, because of the technology used, the type of coal burnt, and the maintenance of the plants and their size.

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contained 24.0% of global coal reserves, Russia 13.7%, China 11.8%, India 11.1%, Australia 8.3% and South Africa 6.6%. Together these countries account for 76% of global coal reserves. See Baumert *et al.* (2005). The type of coal reserves differ considerably. Indian coal is generally of low quality with high ash content and low calorific value. On the other hand, 84% of China's coal is estimated to be bituminous or sub-bituminous coal, with the balance being brown coal. Fifty-four per cent of Australia's reserves are hard coal; it also has abundant reserves of high-quality metallurgical and steam coal. Around half of OECD Europe's reserves (11% of world total) are brown coal and the hard coal reserves are relatively expensive to mine. Much of the brown coal production is commercially competitive, while much of the hard coal production remains uneconomic at current world market prices and is dependent on subsidies and/or policies that protect its domestic market. The USA has reserves of hard coal and lignite.

[16] See Otter, H. (2002), *Clean power generation technology for 21st century – a perspective from the power plant supply industry* cited in Lako (2004).

[17] See IEA (2003c) which assumes a lifespan of 40–50 years for coal-fired electricity plants.

In many developing countries the efficiency of coal use is still at the level reached by OECD countries over 50 years ago. The average efficiency of coal-fired generation in the OECD was 36% in 2002, compared with just 30% in developing countries. This means that one unit of electricity produced in developing countries emits almost 20% more CO_2 than does a unit of electricity produced in an OECD coal plant. The efficiency gap between developed and developing countries will narrow, but not close. In 2030, the average conversion efficiency of coal plants in developing countries will reach 36%, while the OECD will have attained 40%.[18]

Very few coal plants are now under construction in OECD countries, where the cost of gas-fired generation has been lower than coal. This has particularly been the case in Europe, and to a lesser extent in North America where gas prices have risen significantly over the last few years. Significant new coal-fired capacity is expected to be built in these regions after 2010 as tighter gas markets push up gas prices to a point which makes coal-fired plants competitive.

TECHNOLOGY

There are three main types of coal-fired plants operating today: pulverized fuel combustion, fluidized bed combustion and gasification. Each technology is discussed below.

Pulverised fuel combustion

In pulverized fuel combustion (PFC) plants, coal is milled to a powder and blown into a boiler with air. As a powder, the coal has large surface area and is easily combusted in burners. This provides the heat which is used to produce superheated steam to drive turbines and hence generate electricity.[19]

In terms of both number of plants and installed capacity, PFC combustion plants dominate the world electricity generating market.[20] Around 1 000 GW of capacity is installed in PFC technology, accounting for virtually all coal-fired electricity capacity.[21]

PFC power plants can be categorized into subcritical (also called conventional), supercritical, advanced supercritical, and ultra supercritical. Table D2 provides an indication of each type (there is no one categorisation). Note that supercritical, advanced supercritical and ultra supercritical plants are often referred to singly as supercritical plants. These plants require specially developed high strength alloy steels because of their higher steam pressures and temperatures.

Table D2 Classification of pulverised fuel combustion plants

	Subcritical/ conventional	Supercritical	Advanced supercritical	Ultra supercritical
Live steam pressure (MPa)	16.5	≥22.1	27.5–30	≥30
Live steam temperature (°C)	540	540–560	560–600	≥600
Generating efficiency (%)	~38[22]	~41	~44	~46+

Source: International Union of Producers and Distributors of Electrical Energy (UNIPEDE) cited in Lako (2004).

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[18] The efficiencies in this paragraph are from IEA (2004d). The IEA reports efficiencies in Low Heating Value. See footnote 49.

[19] World Coal Institute (n.d.).

[20] See IEA (2003a).

[21] Lako (2004).

[22] Modern subcritical cycles can attain efficiencies close to 40%. See Paul (1999).

Worldwide there are more than 400 supercritical plants in operation, chiefly in Japan, Korea, the USA, Russia and Europe.[23] Only when coal is expensive will competitive pressures by themselves lead to efficiency improvements. While most of the new pulverized coal combustion installed commissioned during the 1990s in OECD countries is supercritical, this has been predominantly in those countries where the cost of the coal is higher, such as Western Europe, Japan and Korea.[24] Subcritical plants were still built in Australia, Canada and the USA, where coal is relatively cheap, and where the availability and reliability of well proven technologies is valued highly as a design criterion.

State-of-the-art pulverized plants have a generating efficiency of 46% for hard coal and 45% for lignite.[25] Application of new advanced materials (such as nickel-based alloys) to PFC plants should enable efficiencies of 55% to be achieved in the future.[26] The Japanese Electric Power Development company already operates a 1 000 MW plant with a generating efficiency of 49%.[27]

Fluidised bed combustion

Fluidised bed combustion is a method of burning coal in a bed of heated particles suspended in a gas flow. At sufficient flow rates, the bed acts as a fluid resulting in rapid mixing of the particles. Coal is added to the bed and continuous mixing encourages complete combustion and a lower temperature than that of pulverized fuel combustion.

Fluidized bed plants are commercially available now as two types: (1) circulating fluidized bed combustion (CFBC); and (2) pressurized fluidized bed combustion (PFBC). CFBC plants are the most commonly encountered for power generation purposes and are mainly used for Combined Heat and Power plants.[28] They are well suited to co-combustion of coal with biomass.[29]

There are a handful of fluidized bed combustion plants now in commercial operation in Europe, the USA and Japan[30] with efficiencies up to 45%.[31] Their capacity stands at around 3 GW for CFBC plants and around 1 GW for PFBC plants.[32]

The efficiency of most fluidized beds used for power generation is similar to that of PFC plants. As with PFC plants, employing higher steam conditions would further boost efficiency. However, use of this technology, in particular circulating fluidized combustion power plants,[33] has been stimulated by its better environmental performance when using low grade, high ash coals that are difficult to pulverize[34] and its low specific investment cost.[35] PFBC plants are only competitive because of their fuel flexibility.[36] It is not expected that there will be significant investment of fluidized bed combustion plants in the next few decades.

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[23] Paul (1999). In 2001, 62.9% of coal-fired capacity in Japan was supercritical; in Korea 58.5%; in the US 24.4%; and the Russian Federation 15.5%. China also has a small number of supercritical plants, accounting for 3.3% of China's coal-fired electricity capacity. Figures from Heaney *et al.* (2005). Figures were not published for Europe as the study focused solely on the APEC region.

[24] IEA (1998).

[25] Even higher values of up to 47% and 48% have been reported, but these can be attributed to exceptional conditions with low temperature seawater cooling. See IEA (2004c).

[26] World Coal Institute (n.d.).

[27] Lako (2004).

[28] IEA (2003a) and Lako (2004). See page 103 for information on combined heat and power plants.

[29] World Coal Institute (2004).

[30] *Ibid.*

[31] IEA (2003a).

[32] Lako (2004).

[33] IEA (2003a).

[34] World Coal Institute (2004).

[35] Lako (2004).

[36] *Ibid.*

Gasification

An alternative to coal combustion is coal gasification. These systems give increased efficiencies by using waste heat from the product gas to produce steam to drive a steam turbine, in addition to a gas turbine. In integrated gasification combined cycle (IGCC) plants, coal is reacted with steam and oxygen in a gasifier, generating a fuel gas that consists predominantly of carbon monoxide and hydrogen. This gas is cleaned using a number of available techniques and burned in a gas turbine to generate electricity. The exhaust heat is used to drive a steam cycle, producing additional electricity. IGCC plants allow high efficiencies to be attained even when using low grade coals. Plant designs close to 50% efficiencies are available.[37]

There is a number of major demonstration and pre-commercial IGCC plants now operational in Europe, the USA and Japan, and several other projects are at the preparation stage. Around 1 GW of coal-fired IGCC plants is operating today.[38] Significant increases are expected in the future. For example, around 16 GW of IGCC is expected to be operating in the USA by 2020.[39]

The goal gasification technology used in IGCC plants has been operating on a small scale for more than 100 years.[40] The challenge, however, is to successfully apply the technology to the very large scale required for electricity generation. IGCC needs some further research and development to reach its full technical and economic potential and to improve reliability. Some of the first generation plants have been over-complex and expensive. Efforts are being made by technology developers to increase plant reliability and reduce capital and operating costs. Future improvements with advanced designs of both steam and gas turbines[41] may increase efficiencies up to 56%[42].

Future Technologies

The existing technologies, in particular pulverized fuel combustion and gasification, have significant scope for reducing emissions through improving thermal efficiencies up to 56%. This is mainly dependent on the development of new advanced materials to allow for higher steam pressures and higher temperatures.

Hybrid combined cycles are also under development. These combine the best features of both gasification and combustion technologies, using coal in a two-stage process. The first stage gasifies the majority of the coal and runs a gas turbine, the second stage combusts the residual “char” to produce steam. Efficiencies greater than 50% are possible.

The use of fuel cells has been demonstrated at the 2 MWe size and plans are underway to use hydrogen from coal gasification in this and other technologies. However, lower cost equipment and more particularly markets for hydrogen need to be developed, although hydrogen can be consumed internally and it is also possible to run on syngas mixtures[43].

R&D initiatives are in place in Europe, the USA, Canada, Australia and Japan in addition to the Carbon Sequestration Leadership Forum. Together they cover R&D related to supercritical steam conditions, coal gasification for use in fuel cells, coal-fuelled IGCC plus hydrogen production plants, and CO_2 capture and storage.[44]

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[37] World Coal Institute (2004).
[38] Lako (2004).
[39] World Coal Institute (2004).
[40] Correspondence with Cinergy 02.05.2005.
[41] IEA (2003a).
[42] World Coal Institute (2004).
[43] Correspondence with Klaus Lackner 18 May 2005.
[44] *Ibid.*

EMISSIONS

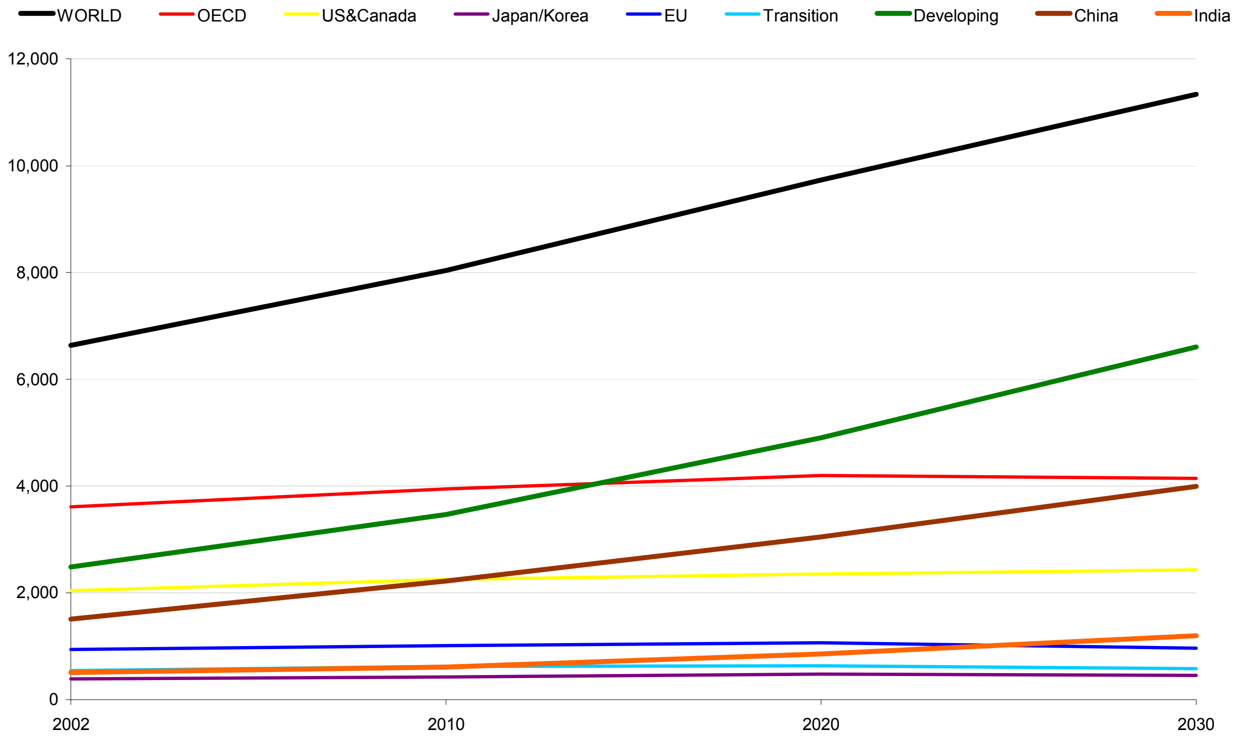
Electricity and heat combined account for 22% of global anthropogenic emissions. Of this electricity accounts for 71%, combined heat and power and heat 15%, and other energy industries 14%.[45] At 9 417 Mt the sector accounted for 40% of all CO_2 energy-related emissions in 2002.[46]

In 2002, emissions from coal-fired plants accounted for 70% of emissions from electricity and heat generation. Emissions from coal-fired electricity and heat plants have risen from 2 385 Mt in 1971 to 6 636 Mt in 2002. Emissions will grow at a lower rate than production because of improved generating efficiency. By 2030, emissions are projected to rise to 11 334 Mt (see Figure D6).[47]

The percentage of coal-fired electricity and heat emissions emitted in OECD countries will fall from 54% in 2002 to 37% in 2030. Emissions in the EU are forecast to remain around current levels, but emissions in the USA and Canada are forecast to moderately rise from 2 044 Mt in 2002 to 2 429 Mt in 2030.

Emissions from China will increase from 1 507 Mt in 2002 to 3 990 Mt in 2030, increasing its share of coal-fired electricity and heat generation emissions from 23% to 35%. Coal will continue to account for around 95% of Chinese electricity and heat emissions. India's emissions will more than double from 505 Mt to 1 198 Mt in 2030, increasing its share to 11%.

Figure D6 CO_2 emissions from coal-fired electricity and heat generation



Source: IEA (2004d).

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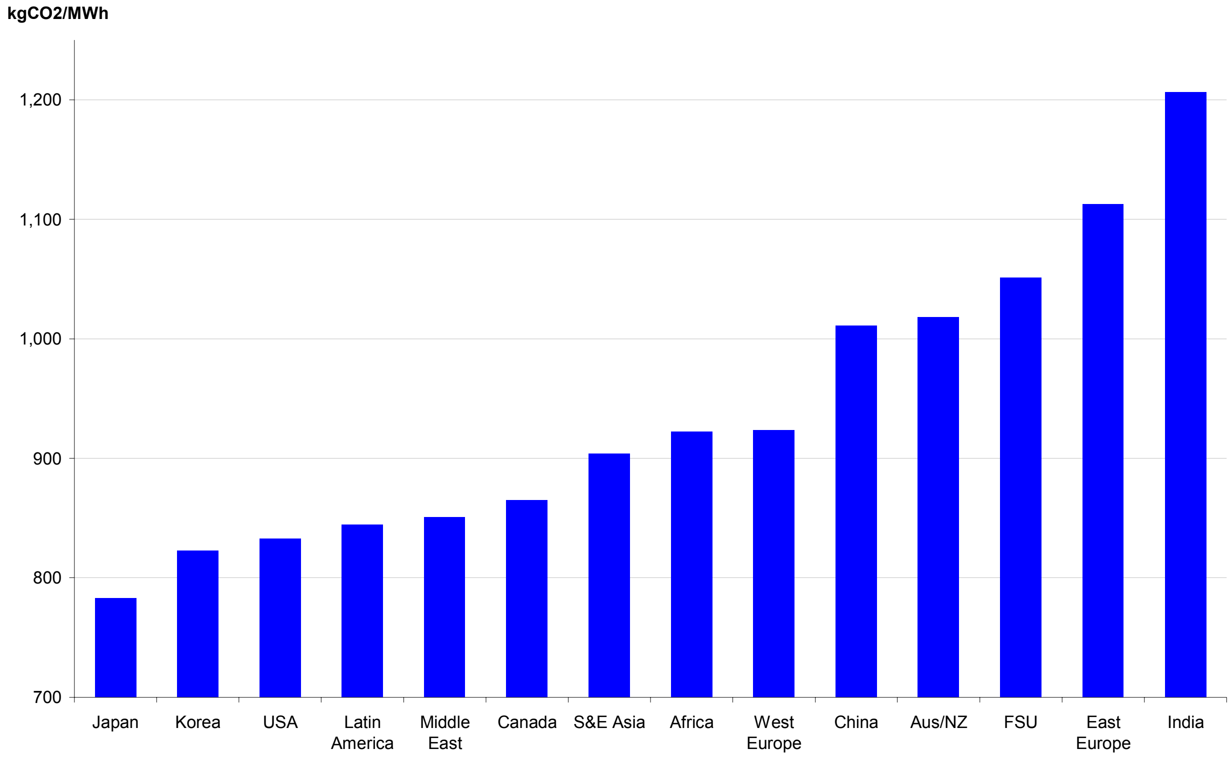
[45] Baumert *et al*. (2005).
[46] IEA (2004d).
[47] 1971 and 2002 emissions data and emissions projections are drawn from IEA (2004d).

CO_2 emissions from coal-fired plants are primarily determined by plant efficiency levels where the efficiency describes how much of the energy that is fed into the cycle is converted into electrical energy. A one percentage point increase in efficiency reduces average emissions by around 2%.[48] Figure D7 shows CO_2 intensities by region. Figures range from a low of 783 kgCO_2/MWh to 1 113 for Eastern Europe and 1 207 for India.

A number of reports provide data on generation efficiencies illustrating the inverse relationship between efficiency and CO_2 intensities. For example, according to Tanaka and Kudo (2005) Japanese coal plants have the highest generation efficiency at 40%.[49] Regions with higher emissions intensities have lower efficiencies, e.g. Australia/New Zealand's efficiency is 31%. Hard coal plants in Eastern Europe have efficiencies of 27% and Indian plants average 28%.[50] The average efficiency of coal-fired generation in the OECD was 36% in 2002, compared with just 30% in developing countries.[51]

Figure D7 Coal-fired electricity generation CO_2 intensities by region, 2002



Sources: Calculated from IEA Statistics (2004c), IEA Statistics (2004d) and IEA Statistics (2004e). Intensities based on production from all coal types.

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[48] World Coal Institute (2004).

[49] Efficiencies in this study are based on High Heating Value. Thermal efficiencies of coal fired power plant based on High Heating Value are typically 2–3 percentage points lower than thermal efficiencies based on Low Heating Value (Heaney *et al.* (2005)).

[50] IEA (2004c). Gross efficiency, excluding own electricity consumption. Based on Low Heating Value.

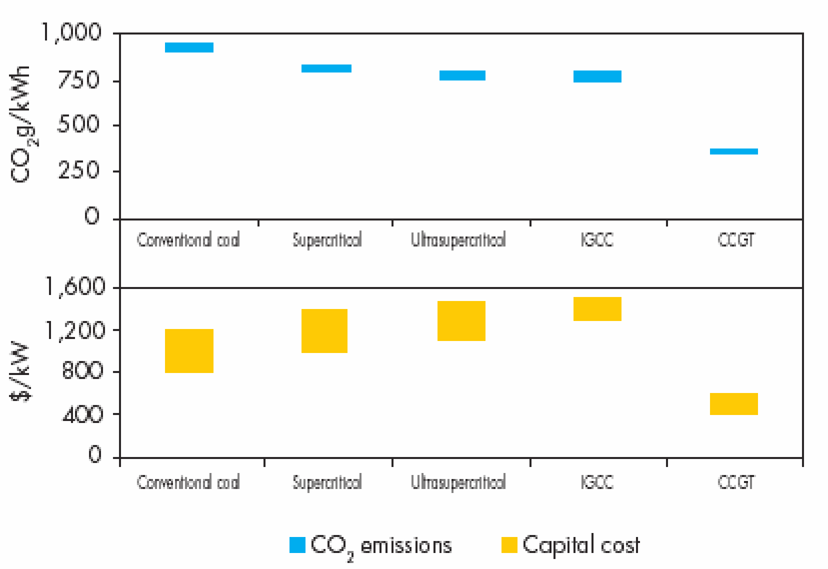
[51] IEA (2004d).

Emissions reduction potential

The key to reducing CO_2 lies in increasing efficiencies so that less coal is burned for the same power output. The most important driver behind higher efficiencies is better technology. While there remain a number of barriers to the adoption of more efficient technologies[52], the most important is their high cost.[53]

Figure D8 demonstrates that the technologies with lower emissions have higher capital costs, with the exception of natural gas power generation (combined-cycle gas turbine (CCGT)) which is included as a point of comparison.[54] Conventional pulverized plants have the highest CO_2 intensities, but the lowest capital costs. Supercritical plants require special materials and manufacturing capabilities because of their higher temperature and pressure operating conditions. Their capital costs are therefore higher.[55] IGCC plants have the lowest CO_2 intensities and the highest capital costs. The variability in costs is accounted for by the availability of materials and skills, coal type[56] and plant size (installation costs generally decrease with plant size[57]).

Figure D8 CO_2 emissions and capital costs by technology



Source: IEA (2003b).

The graph above excludes operating costs. While capital costs for supercritical plants are higher than conventional plants, life-cycle costs of supercritical plants are lower than subcritical.[58] This is because fuel costs are considerably lower due to increased efficiency.

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[52] IEA (1998) provides an account of potential barriers to investment of clean coal technologies in a number of countries. Potential barriers identified were concerns about reliability of new technologies, limited local skills and infrastructure, and increased competition arising from deregulation which is making companies less able to accept the long-term returns associated with new technologies (decisions are being driven by short-term considerations related to financial risk).

[53] IEA (2004d).

[54] Note, however, that natural gas (CCGT) plants have higher variable costs (operating, maintenance and fuel costs) than coal, nuclear and wind plants. See Figure D5.

[55] IEA (1998).

[56] For example, the specific investment cost of an IGCC plant based on a mixture of lignite and petroleum cokes may be up to 15% higher than for hard coal as the main fuel. See Lako (2004).

[57] Paul (1999).

[58] *Ibid.*

The structure of a country's industry affects emissions. China, for example, has around 2 800 coal-fired plants that produce less than 100 MW each. These smaller plants, while decreasing in number, account for around 31% of capacity and are less efficient than larger plants. Efficiencies are as low as 20%.[59] The degree of private and public ownership also affects plant efficiencies. It has been noted that in China, for example, independent power producers achieve greater levels of efficiencies than those run by the State Power Corporation.[60]

Plant maintenance and general operating efficiency also affect emissions. Computer-based controls, for example, are becoming an essential component in the increasingly sophisticated environmental control systems now coming into use. Such systems can allow for the optimisation and integration of boiler operating conditions and emissions performance.[61]

The type of coal burnt also affects plant efficiencies and operating cost. Indian coal, for example, is generally of low quality with high ash content and low calorific value. This raises costs to power generators as it lowers boiler efficiency and increases ash disposal costs.[62] The lower plant efficiencies raise CO_2 emissions.

Coal preparation (also called coal washing and coal cleaning) reduces ash content and cleans coal of impurities such as dirt and sulphur. Coal preparation increases the heating value and the quality of the coal. It can reduce the ash content of coal by over 50% improving thermal efficiencies. While coal preparation is standard in many countries, it could be extended in developing countries as a low-cost way to reduce emissions. Only around 11% of thermal coal in China, for example, is currently washed. If a greater proportion of this coal were cleaned, there is the potential for thermal efficiency improvements of at least 2–3% and possibly up to 4–5%.[63] This could reduce emissions by 4–10%.

Japanese coal-fired plants have the highest average efficiency levels in the world at around 40%. One study sheds light on what would happen to emissions if each region improved its technology adoption. The study compared the scenario where each region achieved the efficiency level of Japan in 2020[64], against a business-as-usual (BAU) case[65]. It concluded that this would result in emissions falling by **1 419 Mt**, a reduction of 17.2%, relative to BAU. Under an alternative scenario of all existing power plants improving their efficiency by 1% *and* all plants built prior to 1980 being replaced by current best available technology, the emission reduction is **1 010 Mt**, a reduction of 12.2%, relative to BAU.[66]

Carbon capture and storage[67]

The most promising technologies for *significantly* decreasing emissions from large scale stationary sources such as coal-fired electricity plants involves separating and capturing the CO_2, compressing it, and then storing it in geological or other locations where it will not leak back into the atmosphere. The main challenge of CO_2 capture and storage is the high cost of the technology. Separation and compression of CO_2 are the most important cost factors. The IEA estimate that, compared to plants without CO_2 capture, investment costs would increase by 28% to 78%. In addition, efficiency losses would be 6–12 percentage

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[59] Chronowski (2005).

[60] Lam and Shiu (2004) *Efficiency and productivity of China's thermal power generation* cited in Heaney *et al*. (2005).

[61] IEA (2003a).

[62] IEA (2003b).

[63] IEA Clean Coal Centre (2003) *Improving Efficiencies of Coal-Fired Power Plants in Developing Countries,* cited in World Coal Institute (2004).

[64] That is an efficiency of 40.8% (high heat value). See Tanaka and Kudo (2005).

[65] The business-as-usual case was based on IEA (2004d) projections. Efficiencies for the business-as-usual case in 2020 were based on projections for the quantity of electricity generated and the fuel input. See Tanaka and Kudo (2005).

[66] For further information see Tanaka and Kudo (2005).

[67] Material sourced from Cook (2002) and IEA (2004c) unless stated otherwise.

points due to additional fuel requirements.[68] Of the different types of coal-fired plants, IGCC plants lend themselves best to CO_2 capture because of their higher pressure and higher CO_2 concentration.[69]

CO_2 capture

Technologies for capturing CO_2 from emission streams have been used for many years to produce a pure stream of CO_2 from natural or industrial CO_2 emissions for use in the food processing and chemical industries. The gas industry routinely separates CO_2 from natural gas before it is transported to market by pipeline. These methods can be applied to a range of industrial processes. However, their use for separating out CO_2 from high volume-low CO_2 concentration flue gases, such as those generated by conventional pulverized plants, is much more problematic. The very high capital costs of installing the huge post-combustion separation systems needed to process massive volumes of flue gases is a major impediment to post-combustion capture of CO_2. The second problem is the large amount of additional energy (25–35%) used to release the CO_2 from solvents or from solid adsorbents after separation.

Some major technical and cost challenges therefore need to be addressed before retrofit (or new build) of post-combustion capture systems becomes an effective mitigation option. A key to achieving lower capture costs lies in the production of a more concentrated, pressurized stream of CO_2 (the average pulverized fuel combustion generator has only 10–14% CO_2 in the flue gas stream). This can be achieved through the pre-combustion capture of CO_2[70] or oxyfuel combustion[71].

CO_2 capture needs to be combined with high efficiency plants. New types of power plants such as IGCC plants allow the use of much more efficient low-cost capture and storage technology. A second reason is that capture equipment costs are subject to economies of scale. Power plants in developed countries (with higher efficiencies) are often a factor of two to five times larger than in developing countries.

CO_2 storage

The technology to store CO_2 underground should be considered proven technology. The problem is whether CO_2 will leak from underground storage sites back into the atmosphere. In most world regions storage capacities will not pose a constraint to carbon storage for decades.

Geological storage is the most comprehensively studied type of CO_2 storage. Injecting CO_2 into the subsurface, down to a depth of 600–800 metres, offers by far the greatest potential for geological storage of CO_2. The CO_2 is compressed to a dense near critical state allowing for large amounts of CO_2 to be stored. An obvious site for geological storage is depleted oil and particularly gas reservoirs. In the USA it is estimated that the storage capacity of depleted gas reservoirs is about 80–100 Gigatonnes of CO_2 or enough to store US emissions of CO_2 from major stationary sources for 50 years or more.

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[68] In 2010, pulverised fuel combustion plants with CO_2 capture are estimated to cost 70–77% more than plants without CO_2 capture. Their efficiency loss with capture is estimated to be 12 percentage points with 39% more fuel required. In 2010, IGCC plants with CO_2 capture are estimated to cost 45–52% more than IGCC plants without CO_2 capture. Their efficiency loss with capture is estimated to be 8 percentage points with 21% more fuel required. In 2020, costs are expected to fall a little for pulverised fuel combustion, but almost halve for IGCC plants. Efficiency losses are expected to be cut by up to 40% with the additional fuel requirements considerably reduced to between 15% and 22%. See IEA (2003b) p.420.

[69] Paul (1999).

[70] Pre-combustion capture is only possible together with IGCC plants. Few IGCC plants are used for base loadpower or incorporate CO_2 capture. Figures currently available indicate that – even allowing for the initial capital costs – “new build” IGCC producing a pure stream of CO_2 is a cheaper option than the retrofit of a power station coupled with post-combustion capture.

[71] An alternative approach is oxyfuel combustion, which relies on burning coal in an oxygen-rich atmosphere to produce a pure stream of CO_2. While the principle is simple, there are major issues to overcome, including the very high combustion temperatures and the cost of producing the oxygen. Oxyfuel combustion for power generation may be a future option, though it has yet to confirm its operational and commercial viability. Much the same oxycombustion technique is used in steel making and consequently there may be no insurmountable technical barriers to CO_2 storage linked to oxyfuel power generation in the future.

Saline aquifers offer great potential to store large amounts of CO_2 in deep saline water-saturated reservoir rocks, particularly sandstones, with the CO_2 stored as a result of hydrodynamic trapping. One major project is already being conducted by the Norwegian company Statoil in the sediments of the North Sea Basin. A comprehensive regional analysis of the storage potential of saline reservoirs has been undertaken in Australia. This study has indicated a CO_2 storage potential for Australia, adequate to store CO_2 emissions for many hundreds of years at the current rate of emissions. Worldwide between 1 000 and 10 000 Gigatonnes of capacity is estimated to be available, possibly even more.

Ocean storage involves two main options. The first is dispersal of CO_2 as droplets at intermediate water depths of around 500 to 1 000 metres. The second is disposal at depths of 5 000 metres or more as liquid CO_2. Ocean storage is, however, most unlikely because the impact of elevated levels of CO_2 on marine ecosystems is poorly known and difficult to monitor. There are also legal uncertainties with the potential application of the London Dumping Convention.

Capture and storage R&D

Large-scale uptake of capture and storage technologies is probably ten years off. Only one power plant demonstration project on a Mt-scale has so far been announced: the FutureGen project in the USA.[72] Without a major increase in R&D investment, carbon capture and storage technology will not be in place to realize its full potential as a post-2030 emissions mitigation mechanism. A five-fold increase in funding for R&D on capture and storage (currently at over USD 100 million per year) will be needed to prepare technologies for full-scale commercial introduction within 10–15 years.

R&D should continue to focus on storage projects which enhance fossil-fuel production and those which advance knowledge on sub-sea underground storage, and aquifer storage in locations with low population density, in order to minimize planning hurdles. Procedures for independently verifying and monitoring storage and related activities should also be established. Finally, a regulatory and legal framework for CO_2 storage projects must be developed to address issues around liability, licensing, leakage, landowner, royalty and citizens rights.

REFERENCES

Baumert, K., T. Herzog, and J. Pershing (2005), *Climate Data: A sectoral perspective*, World Resources Institute, Washington, http://www.pewclimate.org/docUploads/Sectoral%20Data%2Epdf, draft.

Chronowski, R. (2005), *Coal Fired Power Plants: Emission reduction potential related to efficiency increase*, informal Carbon Finance Business note, World Bank. Quoted with permission from Carbon Finance Business.

Cook, P. (2002), “A Pathway to Decreasing Carbon Intensity”, *Ecoal* (44), World Coal Institute, pp. 1–5.

Energy Information Agency (2004), *International Energy Outlook 2004*, EIA/DOE-0484(2004), Washington, http://www.eia.doe.gov/oiaf/ieo/index.html.

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[72] This is a coal-fired advanced power plant for cogeneration of electricity and hydrogen. Its construction is planned to start in 2007.

Heaney, A., *et al.* (2005), *New Emerging Technologies: Measuring potential impacts in APEC*, APEC Energy Working Group, Report no. APEC #205-RE-01.1, Australian Bureau of Agriculture and Resource Economics, Canberra, http://www.apec.org/apec/publications/all_publications/energy_working_group.html.

IEA (1998), *Regional Trends in Energy-Efficient Coal-Fired, Power Generation Technologies*, Coal Industry Advisory Board, OECD/IEA, Paris.

IEA (2003a), *Control and Minimisation of Coal-fired Power Plant Emissions: Zero emissions technologies for fossil fuels*, OECD/IEA, Paris, http://www.iea.org/textbase/papers/2003/Coal_Fired_Fossil_Fuels.pdf.

IEA (2003b), *World Energy Investment Outlook*, OECD/IEA, Paris.

IEA (2004a), *Electricity Information 2004*, OECD/IEA, Paris.

IEA (2004b), *Energy Statistics Manual*, OECD/IEA, Paris.

IEA (2004c), *Prospects for CO_2 Capture and Storage*, OECD/IEA, Paris.

IEA (2004d), *World Energy Outlook 2004*, OECD/IEA, Paris.

IEA Statistics (2004a), *Coal Information 2004*, OECD/IEA, Paris.

IEA Statistics (2004b), *Electricity Information 2004*, OECD/IEA, Paris.

IEA Statistics (2004c), *CO_2 Emissions from Fuel Combustion*, OECD/IEA, Paris.

IEA Statistics (2004d), *Energy Balances of Non-OECD Countries*, OECD/IEA, Paris.

IEA Statistics (2004e), *Energy Balances of OECD Countries*, OECD/IEA, Paris.

Lako, P. (2004), *Coal-fired power technologies: Coal-fired power options on the brink of climate policies*, Energy Research Centre of the Netherlands, Petten.

Newman, J. (1995), *Combined Heat and Power in IEA Member Countries*, presented at the APEC Waste Heat Recovery and Cogeneration Workshop in Singapore, 11–13 November 1995.

Paul, I. (1999), *Supercritical Coal Fired Power Plants: A technology successfully deployed in developing countries*, Energy Issues #19, Siemens/World Bank Partnership Program, http://www.worldbank.org/html/fpd/em/supercritical/supercritical.htm.

Tanaka, K. and H. Kudo (2005), *Sectoral Evaluation of the Utilization Potential of Energy Efficient Technology*, The Institute of Energy Economics, Japan.

World Coal Institute (n.d.): *Coal: Power for progress – Clean coal technologies*, http://www.wci-coal.com/uploads/ccts.pdf, accessed February 2005.

World Coal Institute (2002), *Ecoal* (44), World Coal Institute, London.

World Coal Institute (2004), *Clean Coal: Building a future through technology*, World Coal Institute, London.

COMBINED HEAT AND POWER PLANTS

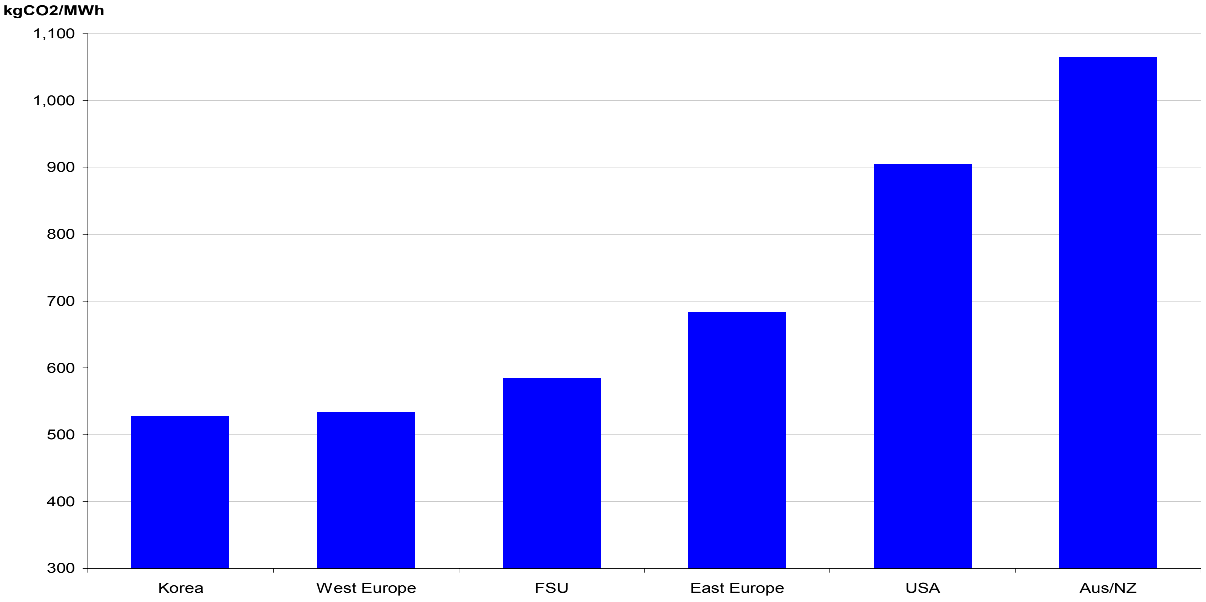
Combined heat and power (CHP) or cogeneration is the simultaneous production of electricity and heat using a single fuel such as natural gas (the most common fuel source) or coal. The heat produced from the electricity generating process – for example from the exhaust systems of a gas turbine – is captured and utilised to produce high and low level steam. The steam can be used as a heat source for both industrial and domestic purposes and can be used in steam turbines to generate additional electricity. The following factors affect the attractiveness of a CHP operation:

- Relatively constant and well-balanced requirements for heat and electricity.
- Favourable physical site conditions, e.g. short distances for heat transport.
- Low-cost supply of fuel, e.g. wood waste at a paper-processing plant.
- Energy costs that represent a significant share of total operating costs.[73]

CHP plants operate in a number of regions accounting for 92.2% of electricity production in the Former Soviet Union and 61.4% in Eastern Europe. They account for small shares in Western Europe (7.5%), Korea (2.8%), Australia and New Zealand (2.6%) and the USA (2.5%).

CHP technology provides greater conversion efficiencies than traditional generation methods as it harnesses heat that would otherwise be wasted. This can result in up to more than a doubling of thermal efficiency and a significant reduction in CO_2 emissions. Furthermore, the heat by-product is available for use without the need for the further burning of a primary fuel. Figure D9 shows CO_2 intensities for those regions of the world with CHP plants. The CO_2 intensities tend to be much lower than for electricity-only plants (compare with Figure D7 on page 97).

Figure D9 Combined heat and power plants CO_2 intensities, 2002



Sources: Calculated from IEA Statistics (2004c), IEA Statistics (2004d) and IEA Statistics (2004e). Intensities based on production from all coal types.

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[73] See Newman, J. (1995).

ANNEX E – AUTOMOTIVE TRANSPORT – LIGHT DUTY VEHICLES

The automotive transport or road transport sector comprises cars, trucks, buses and motorcycles. This profile focuses on the light-duty vehicles (LDVs) segment of the automotive transport sector, i.e. vehicles used primarily for personal passenger road travel.[1] LDVs account for more than 90% of automotive transport production and 59% of automotive transport GHG emissions. The profile draws heavily on the work of the Sustainable Mobility Project (SMP) of the World Business Council for Sustainable Development.

PRODUCTION AND TRADE

In 2003, 62 million cars, trucks, and buses were produced worldwide (see Table E1). Over 90% of these vehicles were LDVs. Production is heavily concentrated in developed countries, with North America, producing 26% of the vehicles, Western Europe 24% and Japan 16%. The production share of developing countries is expected to increase given their greater demand growth. Both indigenous developing country producers and the large multinational manufacturers are investing heavily in manufacturing facilities in many parts of the developing world, especially China.[2] In 2003, China already accounted for 6% of worldwide production.

Production is concentrated in a dozen or so firms. Most major motor vehicle manufacturers have production facilities on nearly every continent. In 2003, the five largest manufacturers accounted for 50% of the 62 million vehicles produced. The ten largest accounted for 74% and the fifteen largest for 87%.

Trade plays a major role at all stages of the production process from parts and components to finished automobiles. In 2003, $435 billion worth of automobiles was traded. $262 billion was traded across the 14 regions shown in Table E2. Japan ($65 billion), Western Europe ($30 billion), Korea ($18 billion) and Canada ($17 billion) were the largest net exporters. The USA ($100 billion), the Middle East ($13 billion) and Australia/New Zealand ($8 billion) were the largest net importers.

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[1] The exact definition depends on the region and data used, but they are typically cars, sport utility vehicles (SUVs), small passenger vans (up to eight seats) and personal-use pickup trucks. In the USA, LDVs includes all passenger cars, trucks and truck-derived vehicles such as SUVs and vans weighing less than 10 000 pounds (4 500 kg).

[2] Automotive News Europe (2004), *Global Market Data Book* cited in Eads (2005) projects that Chinese production of light-duty vehicles approach 10 million by 2008, compared with 4 million in 2003. If this were to occur, China would rank fourth in production by that year behind North America, Western Europe and just behind Japan.

Table E1 Car, bus and truck production by manufacturer by region (thousand vehicles), 2003

	West Europe	North America	Japan	China	South Korea	India	Australia	Argentina	Brazil	Total of 9	Other	Total
BMW Group	901	166	-	5	-	-	-	-	-	1072	47	1119
Daimler Chrysler AG	1193	2571	-	175	-	11	47	7	27	4031	234	4265
Fiat Group	988	-	-	105	-	13	-	-	361	1467	613	2080
Ford Motor Co.	2006	3724	-	103	-	26	100	40	207	nm	nm	nm
General Motors	1610	5342	-	218	401	12	154	44	372	nm	nm	nm
Honda	185	1259	1171	118	-	16	-	-	34	2782	186	2968
Hyundai Auto. Group	-	-	-	148	2451	154	-	-	-	2752	334	3086
Mazda	41	83	800	notes	-	-	-	-	-	nm	nm	nm
Mitsubishi	86	174	815	notes	-	-	-	-	-	nm	nm	nm
Nissan	391	815	1466	83	118	-	-	16	67	nm	nm	nm
PSA/Peugeot-Citroën SA	2552	-	-	107	-	-	-	23	45	2727	582	3309
Renault	1587	16	-	notes	notes	-	-	notes	notes	nm	nm	nm
Suzuki	22	51	982	68	-	438	-	-	-	nm	nm	nm
Toyota	370	1350	4144	208	-	37	114	16	41	nm	nm	nm
Volkswagen AG	2681	287	-	735	-	2	-	21	441	4168	853	5021
Total top 15 world manufacturers	14613	15838	9378	2072	2969	708	414	167	1594	47753	5754	53507
Other manufacturers	242	434	609	1938	152	309	-	1	0	3685	4806	8491
Total	14855	16272	9986	4009	3121	1017	414	168	1595	51438	10561	61999
Share of top 15 (%)	98.4	97.3	93.9	51.7	95.1	69.6	100	99.4	100	92.8	54.5	86.3

Source: Automotive News Europe (2004) compiled by Eads (2005).

Notes: nm: not meaningful due to joint ventures. Mazda in the USA is Autoalliance, a joint venture between Mazda and Ford. Suzuki in the USA is CAMI, a joint venture between Suzuki and GM. Toyota in the USA includes Toyota plants and NUMMI, a joint venture between Toyota and GM. DaimlerChrysler in China is a joint venture between DaimlerChrysler and Mitsubishi. Mazda in China is a joint venture with Ford. Nissan in China is a joint venture with Renault. Renault in South Korea is a joint venture with Nissan. Renault in Brazil is a joint venture with Nissan. Renault in Argentina is a joint venture with Nissan.

Table E2 Automobile trade by region (USD billion), 2003

Importing: *Exporting:*	Africa	Aus/NZ	Canada	China	East Europe	FSU	India	Japan	Korea	Latin America	Middle East	S&E Asia	USA	West Europe	Total exports	Extra-reg. exports	Net exports
Africa	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.5	0.4	2.3	.1	-4.1
Aus/NZ	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.2	0.0	1.9	1.5	-8.3
Canada	0.0	0.0	-	0.0	0.0	0.0	-	0.1	0.0	0.0	0.0	0.0	38.9	0.3	39.4	39.4	16.9
China	0.1	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.7	0.3	-4.9
East Europe	0.0	0.0	0.1	0.0	1.2	0.3	0.0	0.1	0.0	0.0	0.1	0.0	0.9	9.7	12.5	11.3	1.2
FSU	0.0	0.0	0.0	0.0	0.0	0.8	-	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	0.3	-5.4
India	0.1	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.6	0.6	0.5
Japan	1.3	5.5	2.8	2.0	0.3	0.9	0.0	-	0.1	2.4	5.5	2.8	33.0	14.8	71.8	71.8	65.3
Korea	0.3	0.4	1.1	0.4	0.3	0.3	0.0	0.0	-	0.6	0.8	0.8	8.4	4.7	18.3	18.3	17.6
Latin America	0.1	0.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	16.0	0.8	21.8	18.4	9.5
Middle East	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.7	0.2	-13.1
S&E Asia	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2	0.6	0.0	0.9	2.8	2.2	-2.9
USA	0.3	0.3	15.5	0.1	0.0	0.1	0.0	0.5	0.1	3.7	1.6	0.1	-	5.8	27.9	28.0	-100
West Europe	3.9	2.4	1.7	2.5	9.3	4.0	0.0	5.0	0.5	2.1	3.8	1.2	30.1	163.8	230.3	67.8	29.8
Total imports	6.4	10.1	22.5	6.7	11.3	6.6	0.1	6.5	0.7	12.4	13.8	5.7	128.0	201.9	433†		
Extra-reg. imports	6.1	9.8	22.5	5.2	10.1	5.7	0.1	6.5	0.7	9.0	13.3	5.1	128.0	38.1		262†	

Source: UN Comtrade.[3]

Boxed fields: intra-regional trade. “0.0”: indicates trade of less than $50 million between respective regions. “–”: indicates no trade between respective regions. Extra-regional exports = total exports less intraregional exports. Net exports = trade balance = total exports less total imports (negative values indicate net imports).). †: Exports and extra-regional exports shown in the chart do not necessarily add to the total figure shown because of unspecified items in the raw data.

CONSUMPTION

This profile defines consumption as both the number of LDVs in operation and their use as expressed by a metric such as kilometres driven. We discuss each of these in turn providing a snapshot of the current situation and projections into the future. The following section discusses the factors driving LDV consumption.

Number of LDVs

In 2000, 50 million new LDVs were sold.[4] The SMP estimates that if present trends continue, worldwide sales will rise to 70 million vehicles in 2020 and 140 million in 2050.[5] Taking account of typical retirement rates, the total number of LDVs in use worldwide is expected to grow from 700 million to almost 1 100

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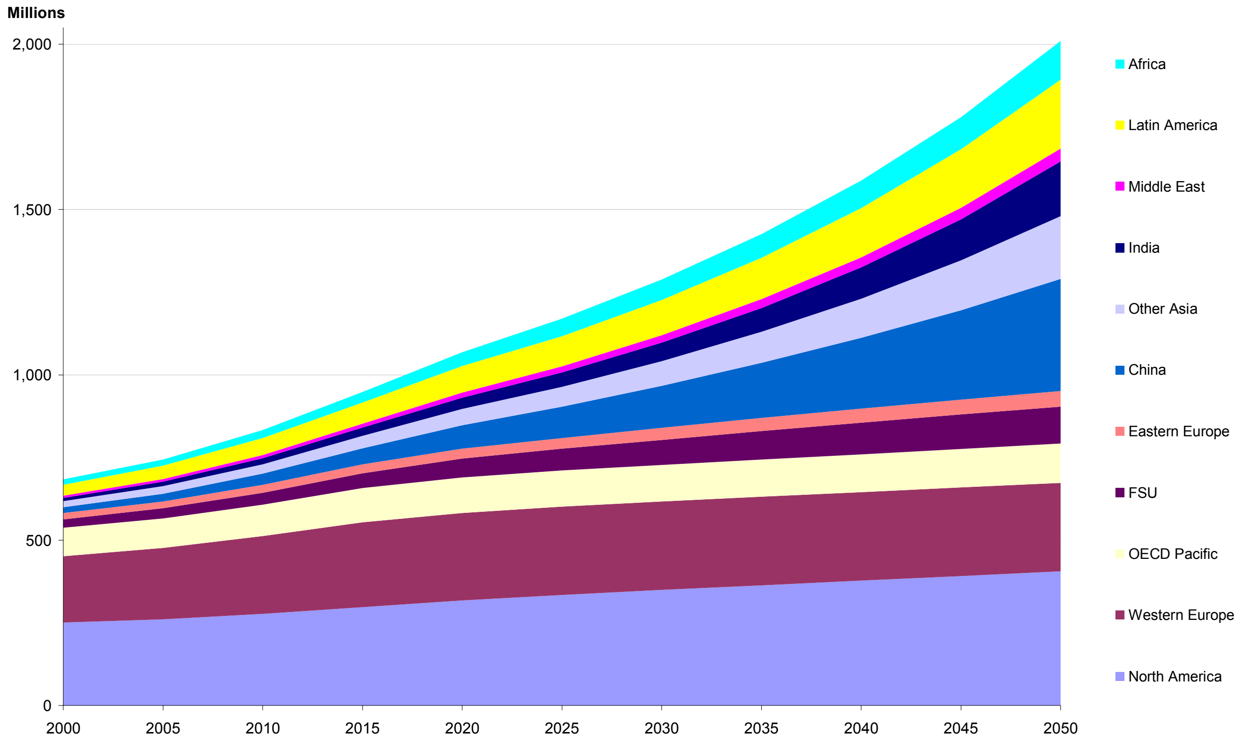
[3] HS-8703, HS-870421 and HS-870431.

[4] SMP Spreadsheet Model.

[5] Mobility and its sustainability is the end result of a complex mix of human behaviour, economic growth and public policy. When the SMP states that its reference case projections assume that “present trends continue”, the underlying assumption is that this behavioural, technical, economic and public policy mix continues essentially unchanged.

million in 2030 and just over 2 000 million in 2050 (see Figure E1). In 2000, North America accounted for 37% of the total fleet, Western Europe 29% and OECD Pacific 13%. North America is expected to have the most vehicles in operation throughout the entire period 2000–2050. Western Europe has the second most at present, but is projected to be overtaken by China in the 2040s. In 2050, it is expected that 20% of all operational vehicles will be in North America, followed by 17% in China, 13% in Western Europe, 10% in Latin America and 8% in India.

Figure E1 LDV fleet by region, 2000–2050



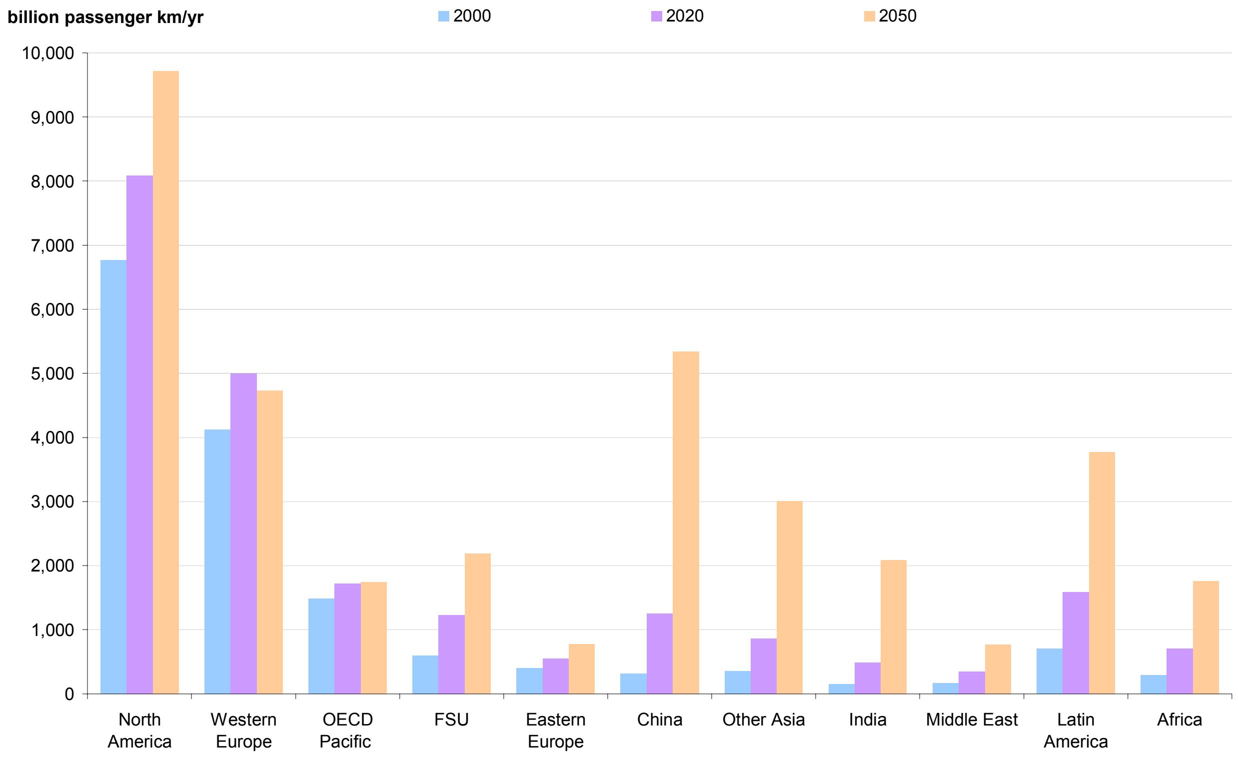
Source: WBCSD (2004b).

LDV use

In 2000, world passenger travel was about 15.4 trillion passenger km/year. If present trends continue, world passenger travel will grow to 21.8 trillion passenger km/year in 2020, a 42% increase from 2000. By 2050, they will grow to 35.9 trillion passenger km/year, a 134% increase from 2000. Developing countries will have higher growth rates.

In 2000, North America accounted for 44% of total travel, Western Europe 27% and OECD Pacific 10% (see Figure E2). The dominance of North America will continue throughout the period, but by 2050 China will have overtaken Western Europe. In 2050, North America will account for 27% of world passenger travel, followed by China at 15% and Western Europe at 13%.

Figure E2 LDV passenger travel by region, 2000, 2020, 2050



Source: WBCSD (2004b).

CONSUMPTION DRIVERS

Many factors shape consumption patterns. This section looks briefly at five key factors.

(1) Average household income levels

Household income is the most important driver of personal vehicle ownership. In addition to ownership it leads to longer and more trips being made over longer distances, particularly for leisure and tourism.[6] Figure E1 shows that the OECD accounts for 79% of the world's LDV fleet even though their share of world population is only 18%. The OECD also accounts for the bulk of LDV passenger travel at 81%.

(2) Acquisition and ownership costs

Acquisition and ownership taxes, provided they are large enough, can significantly lower LDV consumption. These costs are primarily affected by taxes and other charges levied by governments on LDV purchase and use. Data from a 2003 publication by the Japanese Automobile Manufacturers Association comparing acquisition and ownership taxation for a 1.8 litre passenger car in Japan, Germany, the UK, France, and the USA indicates that these taxes differ by a factor of four.[7] Acquisition and ownership costs range from 10% of total purchase costs in the USA to 39% in Japan.

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[6] WBCSD (2004a).

[7] The figures were USD 5 750 for Japan, USD 4 725 for the UK, USD 3 770 for France, USD 3 365 for Germany and USD 1 420 for the USA.

Both Denmark and Singapore have car ownership rates considerably below the level that their real GDP per capita would suggest. While not the only factor explaining their position, both countries have high ownership and acquisition taxes. Denmark has by far the largest car taxes in the EU, which effectively triple the purchase prices of automobiles in the EU.[8] Singapore has a policy of discouraging private vehicle ownership and has adopted probably the highest taxes in the world on LDV acquisition and ownership.[9] According to one estimate, an Audi A4 1.8 litre car costing USD 25 000 in the USA would cost USD 182 000 in Singapore.[10]

(3) Fuel costs

Fuel costs are the largest variable cost of driving, affecting chiefly the number of kilometres driven. Government policies play a dominant role in determining motor fuel prices. Due to government subsidies and taxes, prices range from well below market levels in some countries such as Indonesia, Thailand, Malaysia and India[11] to substantially above market levels in others. Among IEA members, gasoline prices at the end of 2004 ranged from USD 0.50/litre in the USA to USD 1.55/litre in the Netherlands. Prices for automotive diesel ranged from USD 0.45/litre in Mexico to USD 1.50/litre in the UK. Nearly all of this difference is attributable to differences in fuel taxes.[12]

(4)Availability, quality and cost of alternatives to LDVs

The impact of the availability, price and quality of substitutes such as public transport on car ownership and use is significant, although the relationship is complex. Where public transport is of high quality and is relatively inexpensive, it is used much more than when conditions are the reverse. Car ownership rates in central areas of large cities such as London, Paris and New York City are much lower than in the suburban parts of these cities and in other smaller cities in the same countries. Parking availability and cost also affect the relationship as does the geographic distribution of economic activity.

(5) Spatial organisation

Spatial organisation refers to the geographic organisation and distribution of cities and towns. Factors influencing a household's vehicle use include distance to relevant employment, education, retail and social locations. City design aspects which influence vehicle use include size of the central business district compared to the size of the entire metropolitan area, employment density, and employment composition.[13]

ENERGY USE

Energy use is determined by energy intensity (fuel economy) and by the type of energy consumed (fuel mix). The most important factors bearing on fuel economy is a vehicle's size, weight and performance. The materials used, aerodynamic drag, rolling resistance and temperature control are important factors. Energy intensity is also affected by driver behaviour and traffic congestion: the more time a vehicle spends in congestion the higher its energy used per km. Fuel mix is currently limited to fossil fuel based fuels, predominantly gasoline and diesel.

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[8] Based on a car with a 0.2 litre engine. ACEA data in TiS (2002).

[9] World Bank (2001), *World Development Indicators* cited in Eads (2005). Singapore's position cannot be explained entirely by its high taxes on vehicle ownership and use. Its taxes are only one of several policy measures that, directly or indirectly, discourage private vehicle ownership.

[10] "Once You're Here – Cost of owning a car" http://www.expatsingapore.com/once/cost.htm (accessed March 2005) cited in Eads (2005).

[11] Asian Development Bank (2005).

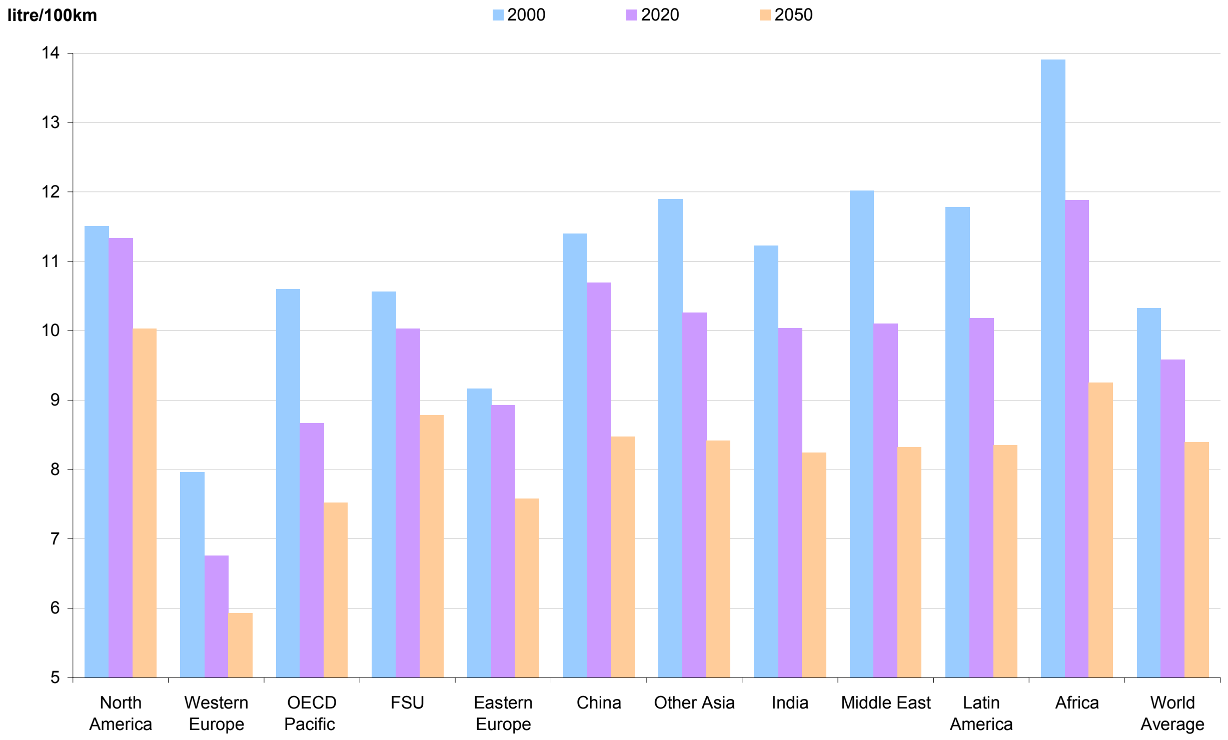
[12] IEA Statistics (2004).

[13] Hunt and Brownlee (2000), *Influences on the Quantity of Auto Use* cited in Eads (2005).

Fuel economy varies considerably across regions. The SMP estimates that in 2000, the fuel consumption of the on-road stock of LDVs averaged 10.3 litre/100km (22.8 mpg; 9.7 km/l) worldwide, ranging from 23% lower in Western Europe to 35% higher in Africa (see Figure E3). The fuel economy of new vehicles sold in 2000 was slightly better, averaging 10.1 litre/100km (23.4 mpg; 9.9 km/l) worldwide. New vehicles were more efficient than the stock in most regions, but were less efficient in North America and China. Given typical new car growth rates and old car retirement rates, the average efficiency of new vehicles leads the stock average by about a decade.

If present trends continue, worldwide fleet LDV fuel consumption will decline to 9.6 litre/100km in 2020 and 8.4 litre/100km in 2050, a 19% decrease from 2000. If present trends continue, the regional differences among developed regions will not only persist, they will grow. Fleet LDV fuel consumption in 2050 is projected to be 5.9 litre/100km for Europe, 7.5 litre/100km for OECD Pacific and 10.0 litre/100km for North America. The ratio of the average fleet LDV fuel consumption per 100 km in Western Europe (the region with the lowest average in all periods) to the similar figure for North America (the region with the highest average in 2050) will decline from its 2000 level of 70% to 60%.

Figure E3 Fuel Economy of Stock Automobiles by Region, 2000, 2020 and 2050



Source: WBCSD (2004b).

In 2000, gasoline was used in 82% of the new LDVs sold worldwide. The principal alternative to gasoline is diesel, which was used in 16% of new LDVs sold in 2000. Diesel engines consume 18% less fuel[14] and emit 12% less CO_2 per km than gasoline internal combustion engines.[15]

The fuel mix varies across regions (see Figure E4). Gasoline accounts for 91% of fuel worldwide, but diesel accounts for a quarter of the fuel used in Western and Eastern Europe and India. New LDVs are over

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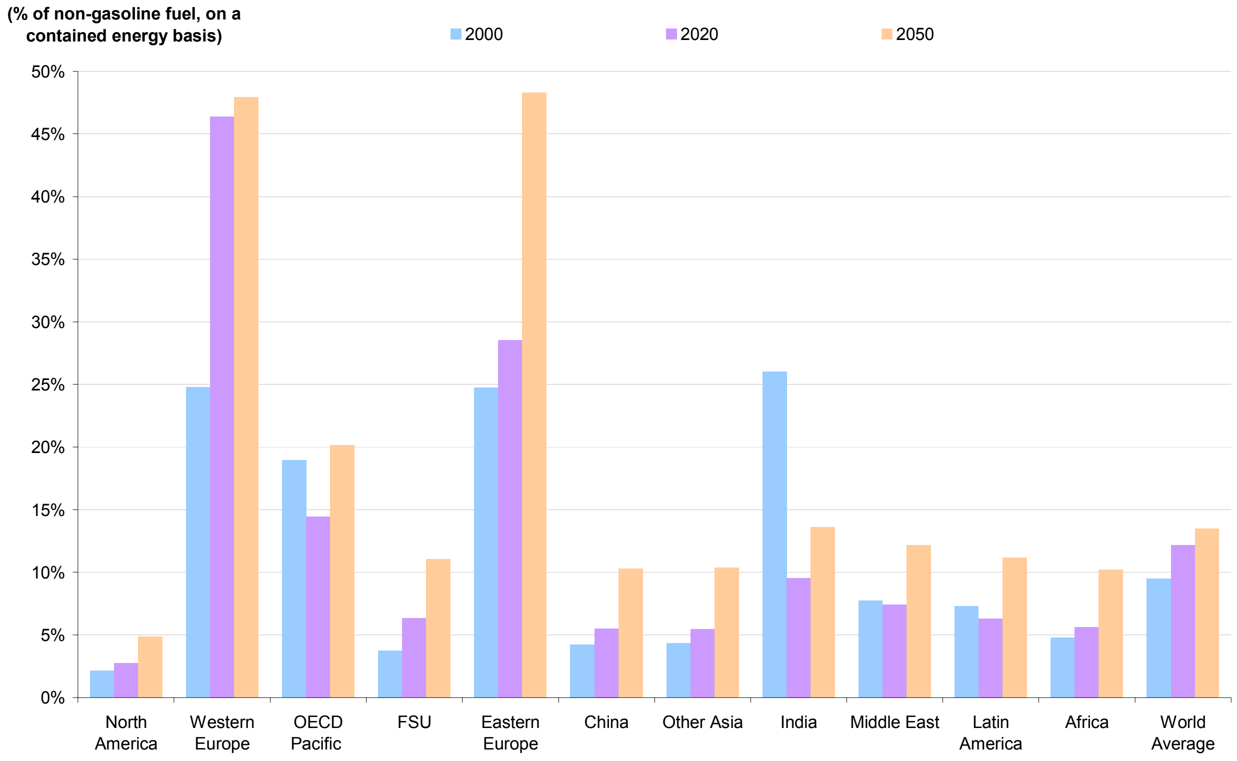
[14] On a contained energy equivalent basis.
[15] WBCSD (2004b).

90% dependent on gasoline in all regions. The exceptions are Western Europe (58% gasoline and 40% diesel), Eastern Europe (78% gasoline and 20% diesel) and OECD Pacific (87% gasoline, 7% compressed natural gas (CNG) and liquefied petroleum gas (LPG), and 6% diesel).

If present trends continue, the proportion of non-gasoline fuels will increase from 9% in 2000 to 12% in 2020 to 13% in 2050. This will occur first in Western Europe and later in other parts of the world. The exception is India, where diesel use is expected to fall to 10% of fuel use by 2020, before rising to 14% by 2050.

Figure E4 LDV diesel and other non-gasoline use by region, 2000, 2020 and 2050



Source: WBCSD (2004b).

EMISSIONS

In 2000, LDVs consumed 980 billion litres of fuel[16] and emitted 2 800 Mt of CO_2 equivalent[17]. This accounted for 6.7% of total anthropogenic GHG emissions. The emissions from LDVs accounted for 59% of total automotive transport emissions and 44% of total transport emissions.[18] Figure E5 shows that 82% of LDV sector emissions in 2000 came from developed regions – 52% in North America, 20% in Western Europe and 9% in OECD Pacific.

If current trends continue annual GHG emissions from LDVs will grow to 3 900 Mt of CO_2 in 2020 and 5 900 Mt of CO_2 in 2050, a 110% increase over 2000. The regions with the largest expected absolute growth

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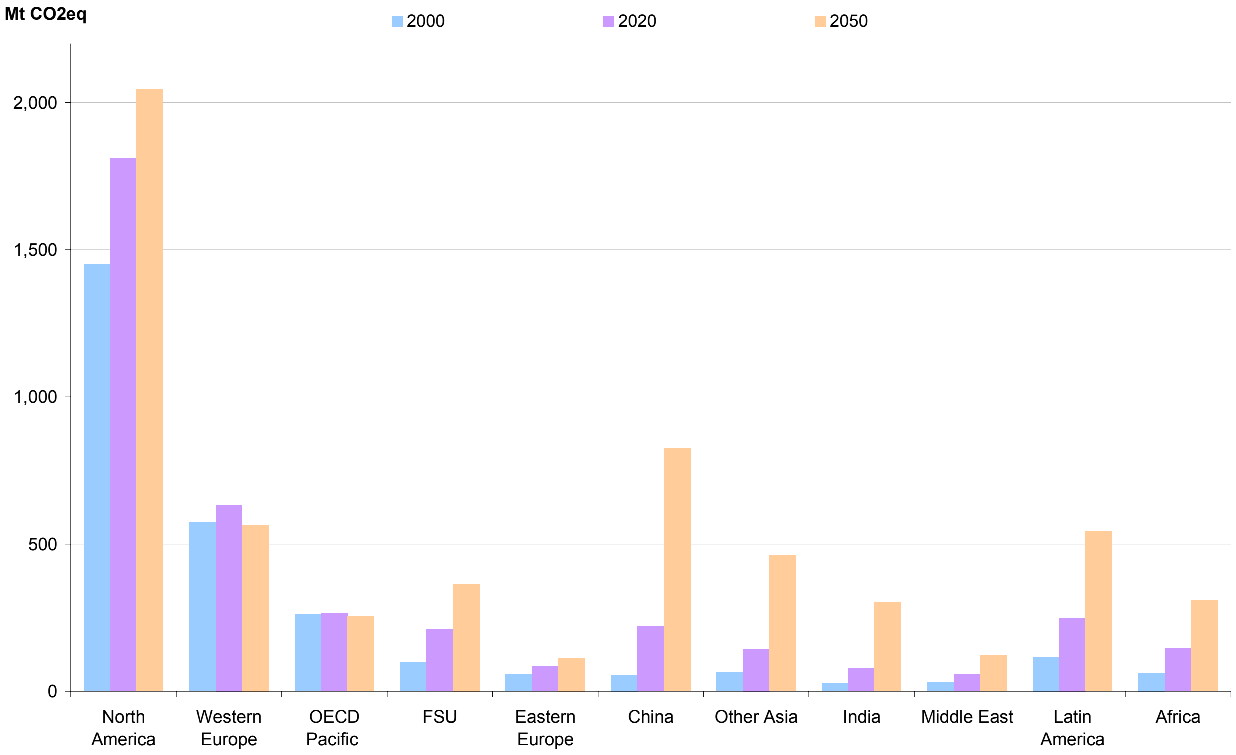
[16] This is a "gasoline equivalent" figure.

[17] This is expressed on a "well-to-wheels" basis. That is, it includes GHG emissions from the production and distribution of transport fuel as well as GHG emissions from the use of that fuel in transport vehicles.

[18] In 2000, automotive or road transport accounted for 11.3% of total anthropogenic GHG emissions. Total transport emissions accounted for 15.1% of total anthropogenic GHG emissions.

in emissions for 2000–2050 will be China, North America, Latin America and Other Asia. The high growth of emissions from developing regions changes the geographical profile dramatically – the share of emissions from developing regions rises from 18% to 52% in 2050. North America, however, remains the top emitter.

Figure E5 Well-to-wheel GHG emissions by region, 2000, 2020 and 2050

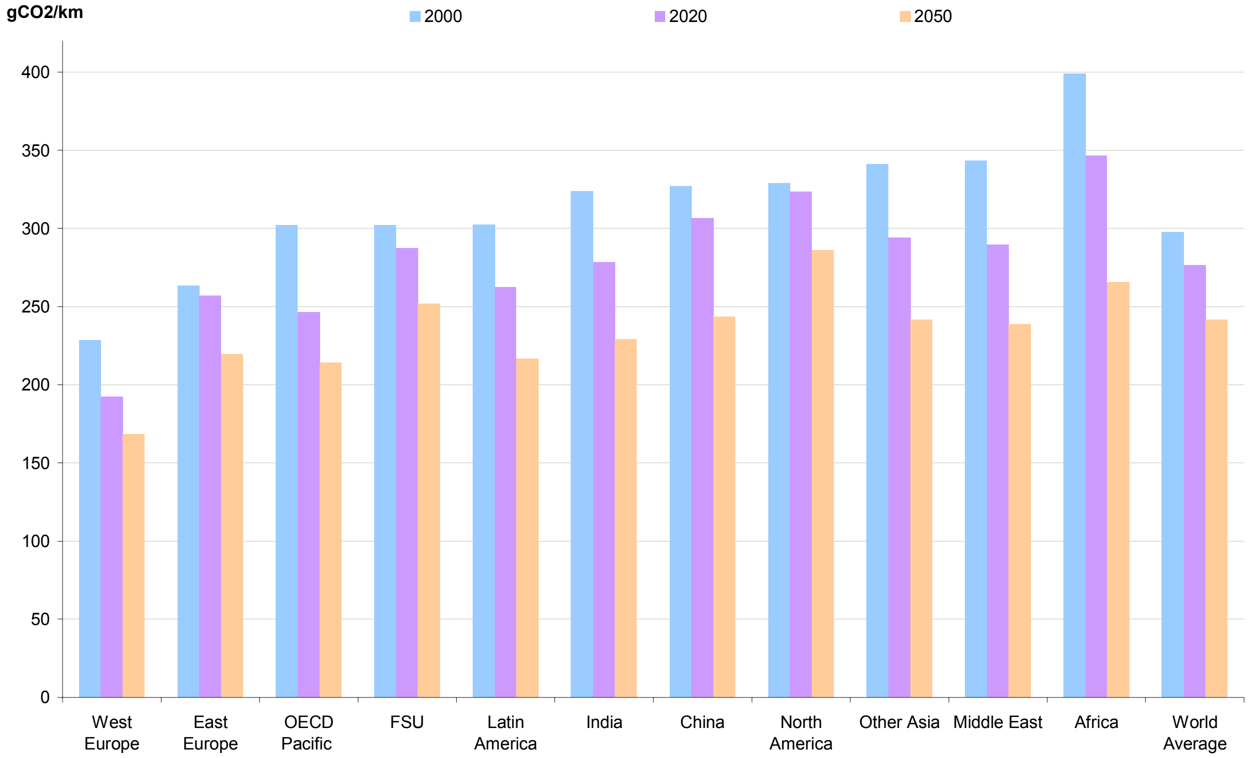


Source: WBCSD (2004b).

Total GHG emissions from the LDV sector are determined by two factors. The first is the emissions intensity of the fleet. The second is the kilometres travelled by the fleet, previously discussed when looking at consumption patterns (number of LDVs and LDV use). Emissions intensity is determined by energy intensity and the carbon intensity (measured as CO_2/litre of CO_2/J) of the fuel mix. Figure E6 shows LDV emissions intensity in terms of CO_2 emissions per km. The average emissions intensity of LDVs worldwide was about 300 CO_2/km in 2000. It is expected to decline 7% by 2020 and 19% by 2050. Western Europe's emissions intensity is 23% lower than the world average. This is due in part to the region's higher than average use of diesel (22% of fuel used compared with 8% worldwide).

Emissions intensities in all regions are expected to decline during 2000–2050. Some convergence is expected: in 2000 the range was 230–400 CO_2/km; in 2050 it is expected to be 170–290 CO_2/km. That said, there is still significant variation suggesting that there is a large opportunity for CO_2 emissions reductions.

Figure E6 Well-to-wheel GHG emissions intensity of automobile stock by region, 2000, 2020 and 2050



Source: WBCSD (2004b).

There are many possible ways to reduce GHG emissions from the automotive transport sector. This profile focuses on those options that reduce the emissions generated by an average vehicle per distance travelled. Reductions of this type are determined by the technical characteristics of the vehicle and fall into two broad categories. The first is incremental changes to energy efficiency by reducing the amount of energy required to perform a unit of transport activity and by changing the fuel mix using known alternatives to gasoline. The second is radical changes to automobile powertrain systems and fuel type. Each is discussed in turn.

INCREMENTAL CHANGES TO ENERGY EFFICIENCY AND FUEL MIX

Reducing size, power and weight and improving technical engine efficiency are key to improving energy efficiency. This can be done by:

- utilising lighter weight alternatives to conventional steel;
- reducing aerodynamic drag and rolling resistance;
- technical innovations in engine design which enable more efficient fuel use;
- improving efficiency of ancillary equipment such as alternators and accessories such as air conditioning;
- more efficient vehicle transmissions; and

- ensuring new drivers learn the driving styles most suited to modern cars (so called "eco-driving").[19]

In addition to these changes, gradually increasing the proportion of the fleet using known alternatives to gasoline such as diesel can improve energy efficiency and lower GHG emissions.

In order to substantially increase the rate at which these changes are developed and incorporated into LDVs, the type of vehicles consumers wants to buy will have to change. If such a major shift is to be achieved, industry and governments have an important role to play. Both "carrots" and "sticks" would be needed to make it profitable for manufacturers to produce more energy efficient cars that consumers will demand. An example of a carrot might be a subsidy for the production or purchase of a fuel-efficient vehicle. A stick might be a fine imposed on a manufacturer for failing to meet certain fuel economy targets. Another regulatory measure might be higher taxes on cars with higher fuel consumption (or lower taxes and registration fees for more fuel-efficient vehicles), or higher fuel taxes on those fuels that emit more emissions such as gasoline.

Government initiatives can significantly influence the energy efficiency and fuel mix of a country's fleet. The three most widely-known initiatives are the European Commission's agreement with vehicle manufacturers, Japan's "Top Runner" Program and the CAFE Program in the USA.

The EC agreement with vehicle manufacturers

During 1999 and 2000 the European Commission reached an Agreement with the European, Japanese and Korean automobile associations[20] in order to reduce substantially CO_2 emissions from new passenger cars.[21] The agreement included the following specific undertakings:

- introduce to the EU market, not later than 2000, some models emitting $120gCO_2/km$ or less (corresponding to an average fuel consumption of 4.9 litre/100km);

- achieve an average CO_2 emission target of 140g/km for their fleet of new cars sold in the EU in 2008 (corresponding to an average fuel consumption of 5.7 litre/100km)[22]; and

- review the situation in 2003 to evaluate the prospects for further reduction [of the average CO_2 emissions level for their fleet of new cars sold in the EU] towards the Community's objective of 120 CO_2/km by 2012.[23]

A significant proportion of the gains to date have been achieved through the large increase in the sale of diesel vehicles. Government policies that have lowered both the cost of more fuel-efficient diesel cars and the price of automotive diesel fuel relative to gasoline have helped facilitate this dieselisation.

The Agreement is voluntary, but in its published endorsements of the commitment[24] the Commission warned of its intention to "present a legislative proposal on CO_2 emissions from passenger cars, should the

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[19] WBCSD (2004a).

[20] European Automobile Manufacturers' Association (ACEA), Japan Automobile Manufacturers' Association (JAMA) and Korean Automobile Manufacturers' Association (KAMA).

[21] The ACEA Commitment applies to the all passenger cars, i.e. category M1 vehicles which have a maximum gross weight not exceeding 2500kg.

[22] This is lower than the fleet fuel consumption level projected for Western Europe for 2050. However, the ACEA Commitment is based on "as tested" fuel consumption, which is considerably lower than "in use" fuel consumption. The SMP estimates the difference at present to be 18%. Also, the ACEA Commitment applies to new vehicles. The average fuel consumption in the on-road fleet generally lags more than a decade behind the average new vehicle fuel consumption. The SMP projects that "as tested" new LDV fuel consumption will be 5.7 litre/100 km in 2010 – i.e. that the ACEA Commitment will be met. By 2050, "as tested" new LDV fuel consumption in Europe is projected to be 4.9 litre/100km (48.0 mpg; 20.4 km/l).

[23] ACEA press release July 1998 http://ww.acea.be/ACEA/290798.html cited in Eads (2005).

[24] EC (2005), *Commission Recommendation of 5 February 1999 on the reduction of CO_2 emissions from passenger cars*, cited in Eads (2005).

Associations fail to achieve the CO_2 emission objective for 2008 in its Commitment or not make sufficient progress towards this objective".

According to official EU data, in 2002, the average specific emissions of ACEA's new car fleet registered in the EU was 165 g/km. For gasoline-fuelled cars, specific emissions were 172 g/km. For diesel-fuelled cars, the corresponding value was 155 g/km and for alternative fuelled passenger cars the value was 177 g/km. ACEA's data, which is not official for monitoring purposes, shows reductions in specific emissions between 1995 and 2002 of 12.1% for all new cars, 9.0% for gasoline-fuelled cars and 13.6% for diesel-fuelled cars.[25]

Japan's "Top Runner" Program

The "Top Runner" Program resulted from a 1998 amendment to Japan's energy conservation law. Under this amendment, all manufacturers and importers of passenger cars and trucks and various other energy using products[26] were obliged to achieve certain targets for improvements in the efficiency of their products. Top Runner requires that the weighted average energy efficiency of each manufacturer's and importer's future shipments in each predefined product category be at least as high as the most energy-efficient model on the current market. It is a modified fleet average standards scheme with two important distinctions. First, the averages apply to predefined categories of products. Second, today's best model sets tomorrow's standards.

The US CAFE Program

The Energy Conservation Act of 1975 established the US CAFE Program. This put in place a fleet fuel economy standard for passenger cars at 27.5 mpg (8.6 litres/100 km) for model year (MY) 1985 and thereafter. This standard was double the fuel economy of the new automobile fleet in MY1974. The National Highway Traffic Safety Administration (NHTSA) was given authority to set higher or lower standards after MY1985.

The legislation did not set specific standards for light trucks.[27] Instead it required that they be set at the "maximum feasible level" which would consider: (1) technological feasibility; (2) economic practicability; (3) the effect of other standards on fuel economy; and (4) the need of the nation to conserve energy.[28] The legislation also required that manufacturers' domestic and import fleets each meet the standard. A fine of \$5 (later raised to \$5.50) was levied on each vehicle sold by a manufacturer for each 0.1 mpg the manufacturer's fleet fell short of meeting the applicable standard. In 2002, CAFE fines collected totalled almost \$20 million, all from European manufacturers.[29]

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[25] See http://europa.eu.int/comm/environment/co2/co2_agreements.htm for the ACEA endorsement, *Commission Recommendation of 5 February 1999 on the reduction of CO_2 emissions from passenger cars*, 1999/125/EC, and the JAMA and KAMA endorsements.

[26] The original products included in the Top Runner Program were passenger cars and trucks, air conditioners, fluorescent lights, refrigerators, TV, VCRs, photocopiers, computers and hard-disk drives. In June 2002, the Japanese Diet approved the expansion of the programme to include additional products and provisions for future energy efficiency target values to be strengthened, i.e. set at a level higher than that of the appliance with the highest energy consumption efficiency of the currently commercialised products (except special items). (IEA Energy Efficiency Policies and Measures database, Top Runner Program, http://www.iea.org/textbase//effi/index.asp)

[27] Light trucks with a gross vehicle weight of 8500 pounds (approximately 3860 kg) or above are exempt from CAFE regulations. http://www.nhtsa.dot.gov/cars/rule/cafe/overview.htm.

[28] The light truck CAFE standard was first established for MY1979 at 17.2 mpg (13.7 litre/100 km) for 2-wheel drive vehicles and 15.8 mpg (14.9 litre/100 km) for 4-wheel drive vehicles. Only vehicles having a gross weight of 6000 pounds or less were subject to the standard. In MY1980 and beyond, vehicles having a gross weight of 8500 pounds or less were made subject to the standards. Standards increased in fits and starts until MY1992, when Congress froze them at 20.7 mpg (11.4 litre/100 km). The freeze was lifted by Congress in December 2001. In March 2003, NHTSA issued new light truck standards that increase to 22.2 mpg (10.6 litre/100 km) for MY 2007.

[29] The In 2000, CAFE fines collected totalled \$51 million. The performance of the European manufacturers reflects the mix of vehicles they choose to sell in the US, not any inability on their part to produce vehicles having fuel consumption characteristics more than adequate to meet the CAFE requirements.

Two other pieces of legislation complement the CAFE Program. The Energy Act of 1978 established a "**gas guzzler tax**" requiring individual passenger car models to achieve a *minimum* fuel economy performance level of 22.5 mpg (10.5 litres/100 km). The tax ranges from $1000 per vehicle for a passenger car averaging between 21.5 mpg and 22.5 mpg to $7 700 per vehicle for a passenger car averaging less than 12.5 mpg (18.8 litres/100 km). Manufacturers are required to disclose the amount of the tax applying to a particular vehicle on the label that must be posted on the window of every vehicle sold in the USA. In 2002, gas-guzzler tax receipts totalled almost $80 million. The Alternative Motor Fuels Act, passed in 1998, permitted manufacturers to obtain CAFE credits (i.e. allowances for surpassing CAFE standards) for producing and selling dedicated alternative fuel vehicles and dual-fuel vehicles.

Under CAFE and the concurrent fuel price regimes, the average fuel efficiency of LDVs sold in the USA increased 37% from 1975 to 1981, increased a more moderate 7% from 1981 to 1987 and declined 6% from 1987 to 2004 (measured in terms of litres/100 km). If the only changes to the automobiles produced and sold in this period had been those related to reducing fuel consumption, the fuel economy improvements would have been much greater. The US EPA has estimated that had the efficiency improvements incorporated into automobiles since 1981 not been offset by the increases in weight and performance, new cars in 2004 would have an average fuel economy of 6.3 litres/100 km rather than the actual 8.2 litres/100 km. Light trucks would have a fuel economy of 8.6 litres/100 km rather than the actual 11.3 litres/100 km.

TRANSFORMATIONAL CHANGES TO POWERTRAIN SYSTEMS AND FUEL TYPE

> *"Today's motorised road transportation system has been built up over the last 100 years following the late 19th century invention of the internal combustion engine and the realisation of the transport fuels potential of light petroleum products (such as gasoline and diesel fuel) produced by the distillation of crude oil. (...) vast multibillion dollar industries have developed worldwide distributing and servicing every transport need. But with a few minor exceptions, these industries are still rooted in the same basic technologies – the internal combustion engine (ICE) and petroleum based fuels." (WBCSD, 2004a)*

Use of the internal combustion engine has endured despite the fact that a current gasoline vehicle with automatic transmission can have a well-to-wheel efficiency of less than 15%.[30] Significantly reducing emissions intensity will rely on developing alternative propulsion systems and/or dramatically increasing the use of lower carbon fuels. The later may require the development of large scale energy conversion such as producing hydrogen using electricity derived from renewable sources and the development of distribution capabilities such as a hydrogen distribution system.

The SMP examined a variety of propulsion-fuel combinations in its examination of pathways to reduced GHG emissions. Figure E7 shows the GHG emissions intensities of these combinations for 10–20 years in the future. There is a large number of options and significant variation in emissions intensities. The highest intensity ranges from around 250 g/km for an internal combustion engine fuelled by liquid hydrogen reformed from natural gas to 0 g/km for a fuel cell using compressed gaseous hydrogen derived from water by electrolysis using electricity which has been produced using renewable energy.

The figure also shows the importance in accounting for the emissions from the production and distribution of fuels (well-to-tank) as well as those from the use of the fuel (tank-to-wheels). In some of the biomass-based systems the production and distribution processes absorb CO_2, wholly or partially offsetting emissions at the vehicle tailpipe. In the hydrogen-based systems, the emissions occur entirely in the production and distribution stages.

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[30] Muta, Yamazaki and Tokieda (2004) cited in WBCSD (2004a).

The SMP examined the individual impact of five broad technology options – dieselisation, hybridisation, fuel cells using hydrogen from natural gas, fuel cells using carbon neutral hydrogen, and advanced biofuels – on worldwide road transport CO_2 emissions (see Figure E8). The following was found based on simulations that assumed hypothetical full adoption of each powertrain technology and fuel:

> *"...that even if implemented worldwide, diesels and hybrid ICEs (internal combustion engines) fuelled with conventional gasoline and diesel fuel, or fuel cells fuelled by with natural gas-derived hydrogen,* ***can no more than slow the growth in road transport CO_2 emissions during the period 2000-2050****.* ***Only the use of carbon-neutral hydrogen in fuel cells and advanced biofuels in ICE-powered vehicles can largely or totally offset the growth in CO_2 emissions produced by the growth in road travel during the period 2000-2050 (emphasis added).*** *This does not mean that vehicle energy use characteristics are irrelevant. They may not have a major impact on the trajectory of road vehicle GHG emissions over the very long term, but they will have a major impact on the amount of low-carbon or carbon-neutral fuel that must be produced to power the world's road vehicle fleet. This means that they can have a very important impact on the cost of significantly reducing GHG emissions from road vehicles. Based upon these results, the SMP conclusion is that it will only be through a combination of fuel and powertrain solutions that significant CO_2 reduction will be attained. No single technology pathway stands out enough to compel its selection as the sole long-run solution." (WBCSD, 2004a)*

Over the last ten years Governments have become increasingly active in promoting biofuels. One of the most notable initiatives is the EU Directive (2003/30/EC) on the promotion and use of biofuels and other renewable fuels for transport which establishes targets for a minimum level of biofuels as a proportion of all transport fuels sold from 2005, starting with 2% and reaching just under 6% of fuels sold in 2010. Government activities to achieve this target appear to favour fiscal incentives – in particular reduced or zero excise tax.[31]

The SMP ran an additional simulation that assumed adoption of a combination of the five broad fuel-propulsion options plus additional fleet-level vehicle energy efficiency improvements and better traffic flow and other efficiencies in road vehicle use coming from the materials, ITS, aerodynamics, rolling resistance and temperature control factors mentioned earlier. The simulation used an illustrative target of reducing annual worldwide CO_2 emissions from road transport by half in 2050, a level that would return annual road vehicle CO_2 emissions in 2050 to about their current levels (see Figure E9). The simulation confirmed that meeting such a goal would require the widespread adoption of a combination of fuel and vehicle technologies.

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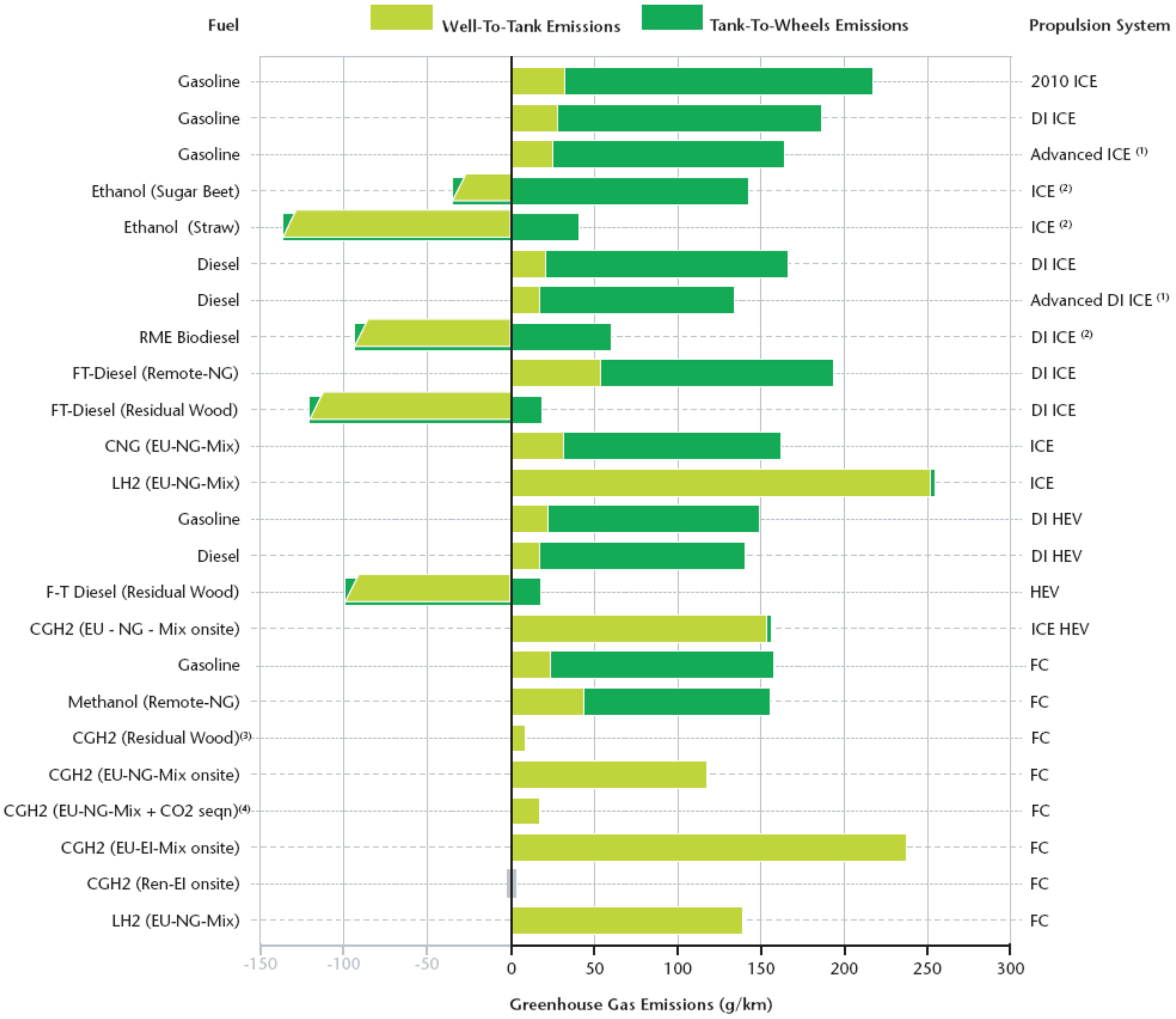
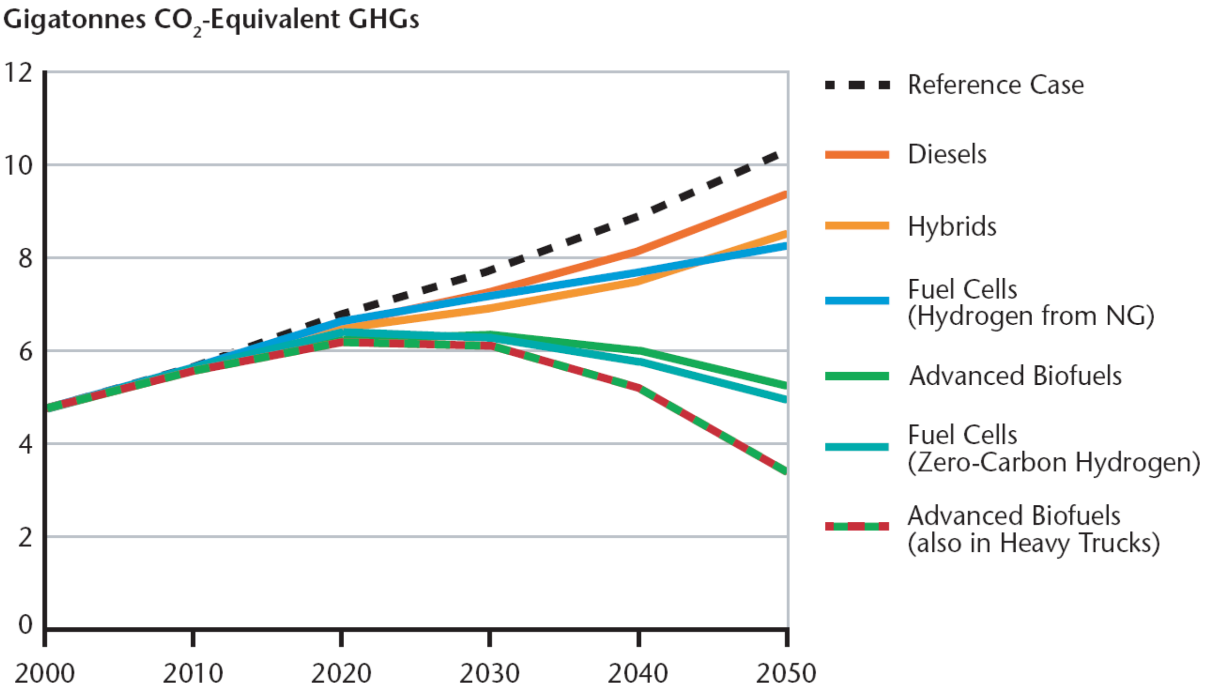
[31] ECMT (2005).

Figure E7 Well-to-wheel GHG emissions for various fuel and propulsion system combinations



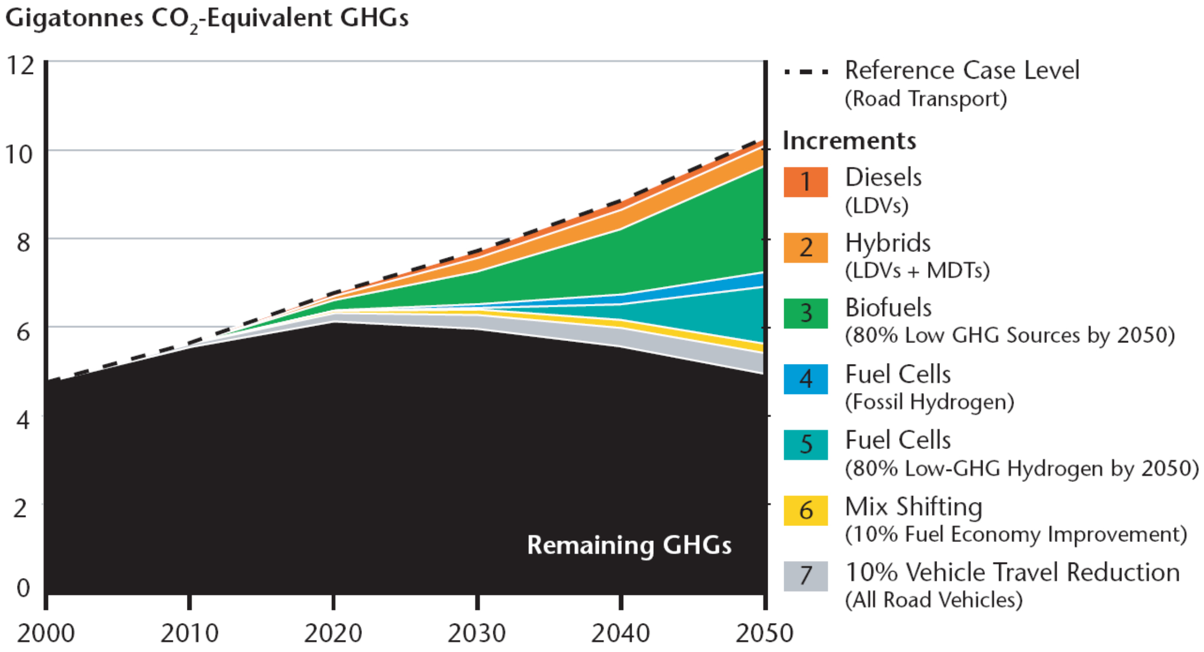
Source: WBCSD (2004a). Keys: *Fuels column:* CGH_2=Compressed Gaseous Hydrogen; CNG=Compressed Natural Gas; CO_2 seqn=Carbon dioxide sequestration; EU-El-Mix=European Union mix of electricity sources; EU-NG-Mix=European Union mix of natural gas sources; FT=Fischer-Tropsch process; LH_2=Liquid Hydrogen; NG=Natural Gas; Ren-El: Electricity from renewable-based power generation; RME=Rapeseed Methyl Ether. *Propulsion Systems column:* DI=Direct Injection; FC=Fuels Cells; HEV=Hybrid Electric Vehicles; ICE = internal combustion engine. Notes: (1) Estimated by VKA; (2) Estimated by BP from GM data; (3) Net output from energy sue in conversion process; (4) Based on Hydro figures.

Figure E8 Hypothetical potential of individual technologies to lower road transport



Source: WBCSD (2004a). Note: Includes all road or automotive transport. Cases represent high hypothetical levels of technology penetrations, thus they cannot be added together.

Figure E9 Hypothetical potential of combined technologies to lower road transport



Source: WBCSD (2004a). Note: Includes all road or automotive transport.

R&D initiatives

Europe and the USA have adopted R&D commitments relating to technologies for next 30 to 50 years. The European Council for Automotive R&D (EUCAR) has been the ACEA's platform for pre-competitive research and development projects for the last decade. Its work is carried out in partnership with public authorities including the EU Commission, associated industries, suppliers and other research institutions. EUCAR facilitates the acquisition of publicly-funded research projects totalling around €100 million annually. EUCAR-facilitated projects are grouped into three major areas: energy and environment; road safety; and materials, processes and manufacturing.[32]

The US Council for Automotive Research (USCAR), formed in 1992, co-ordinates the business and administrative functions for a series of research consortia that had been established by the US "Big 3" manufacturers and, in some cases, their suppliers. It also serves as the organization representing the "Big 3" in government-industry research partnerships. Two such partnerships have gone beyond the "pre-competitive" research phase to which most collaborative research efforts in the motor vehicle industry have restricted themselves.

The Partnership for a New Generation of Vehicles, established in 1993, sought to produce prototypes of vehicles by 2003 with four characteristics. The first was that the vehicle must be capable of up to three times greater fuel efficiency than 1993 vehicles, but at no more cost to own and drive. The second was that performance, size and utility be maintained. The third was that safety and emissions requirements were met or exceeded. The vehicle also had to achieve 80% recyclability. The concept cars that each manufacturer produced appeared capable of achieving the 80 mpg (2.9 litre/100 km) programme goal, but none came anywhere near meeting the cost target.[33] The programme was terminated in January 2002.

In its place the "FreedomCar and Fuel Partnership" was established. According to the Partnership's plan "[a] major thrust of the Partnership is to identify and address the technologies necessary to enable high volume production of affordable hydrogen fuel cell vehicles and fuels, and the national infrastructure necessary to support them. Additionally, the Partnership addresses technology needs to enable mass penetration of hybrid electric and advanced combustion vehicles that also offer the potential to significantly reduce the nation's dependence upon imported oil."[34] Although apparently technology neutral the programme it has become associated with LDV's powered by hydrogen fuel cells within government and amongst the public at large.

REFERENCES

Asian Development Bank (2005), *Asia Development Outlook 2005 – Promoting competition for long-term development*, Asian Development Bank, Hong Kong, China.

Commission of the European Communities (2004), *Monitoring of ACEA's Commitment on CO_2 Emission Reductions from Passenger Cars (2002), Monitoring of JAMA's Commitment on CO_2 Emission Reductions from Passenger Cars*

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[32] ACEA (2004), *European Automobile Industry Report* cited in Eads (2005).

[33] See National Research Council, "Review of the Research Program of the Partnership for a New Generation of Vehicles: Seventh Report," 2001.

[34] Partnership Plan, FreedomCar & Fuel Partnership, November 2004 cited in Eads (2005).

(2002), Monitoring of KAMA's Commitment on CO_2 Emission Reductions from Passenger Cars (2002), Commission Staff Working Paper, 5 September 2003, COM(2004) 78 final.

ECMT (2005), *CO_2 Policies and Measures in Transport Database*, European Conference of Ministers of Transport, draft.

Eads, G. (2005), *Sectoral Strategies and the Automotive Transport Sector*, prepared for the Round Table on Sustainable Development at the OECD by Charles River Associates (CRA), Boston, Massachusetts, USA.

IEA Statistics (2004), *Energy Prices and Taxes, 4th Quarter 2004*, IEA/OECD, Paris.

SMP Spreadsheet Model.

UN Comtrade: *United Nations Commodity Trade Statistics Database*, UN Statistics Division, http://unstats.un.org/unsd/comtrade, accessed May 2005.

WBCSD (2004a), *Mobility 2030: Meeting the challenges to sustainability*, The Sustainable Mobility Project, World Business Council for Sustainable Development, http://www.wbcsd.org/templates/TemplateWBCSD5/layout.asp?type=p&MenuId=ODE&doOpen=1&ClickMenu=LeftMenu.

WBCSD (2004b), *Supporting IEA/SMP Transport Model documentation and reference case projections*, The Sustainable Mobility Project, World Business Council for Sustainable Development, http://www.wbcsd.org/templates/TemplateWBCSD5/layout.asp?type=p&MenuId=ODE&doOpen=1&ClickMen.