The use of wood for construction and energy in the natural city: The case of Canada

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The author received a Ph.D in physical chemistry from the University of Washington, Seattle, USA in 1962. At present he is Professor for Physical and Theoretical Chemistry at the Division Geo Sciences and Geography, Institute for the Atmosphere and the Environment, Goethe University of Frankfurt, Germany. His work ranges from the quantum mechanical description of molecules to the dynamics of global systems. In 1973 he introduced the first interdisciplinary course on "chemistry and environment; an ecological approach to chemical processes in nature and technology" at the University of Frankfurt. Later his emphasis focused on biogeochemical cycles, in particular, the "global carbon cycle, biosphere and climate." In cooperation with his co-workers he developed a world model for the CO_2 exchange between the biosphere and the atmosphere, the "Frankfurt Biosphere Model, FBM." He was visiting professor at the University of California, Berkeley, as well as Los Angeles and San Diego (Scripps Institution of Oceanography), University of Louvain-la-Neuve, Belgium, Tropical Science Center of Costa Rica, University of Paris, Orsay, the National Australian University, Canberra, and most recently Stanford University, USA. He was director of the Institute for Physical and Theoretical Chemistry and of the former Center for Environmental Studies (Zentrum für Umweltforschung ZUF) of the University of Frankfurt. In 1991 he was awarded the Philip Morris Research Prize "Challenge Future" for his work on the carbon cycle connected with the development of the Frankfurt Biosphere Model. In 1998, following a workshop in Freising, Germany, he, together with his colleagues M. Weber and R.A. Houghton, published the Springer Book: Carbon Dioxide Mitigation in Forestry and Wood Industry. *Professor Kohlmaier became a member of the World Society of Ekistics in 2001, returning to his roots as his father* was an architect. *The text that follows is an edited and revised version of a paper presented at the international symposion on "The Natural City," Toronto, 23-25 June, 2004, sponsored by the University of Toronto's Division of the Environment, Institute for Environmental Studies, and the World Society for Ekistics.*

Introduction

Within the discussion of "global climate change and cities," the issue of cause and of effect of climate change needs to be distinguished:

- Cause of climate change: the deforestation and in particular the burning of fossil fuels with a relatively large contribution of cities to greenhouse gas emissions and change in climate;
- Effect of climate change: the expected negative impact of climate change, climate variability and possibly increasing frequency of extreme events menacing life in the cities in many aspects.

This contribution focuses on the first factor and can be viewed as one aspect of the worldwide movement: Cities for Climate Protection with 662 cities participating worldwide including Toronto, Ontario, Canada (2004). At the world congress in Athens of the International Council for Local Environmental Initiatives (ICLEI) in November 2003, the eco-efficient large-scale application of renewable energies and of developing sustainable mobility was emphasized.

Sustainable forestry has the ability to assimilate CO_2 from the atmosphere and to transform it into the valuable and sustainable resource, wood. The use of wood for construction material of houses and other long-lived goods provides an intermediate carbon sink, while the burning of wood provides an energy source which is practically climate neutral (KOHLMAIER, WEBER and HOUGHTON, 1999).

Canada has a large potential to reduce its greenhouse gas emissions both by using wood in construction of private and public housing, and at the same time by replacing part of its fossil fuel use by fuelwood, often connected with residues of the forest industry. Canada ratified the Kyoto Protocol in December 2003 and promised to reduce its greenhouse gas emissions by 2010 by 6 percent relative to the base 1990. However up to now, secondary energy consumption and greenhouse gas emissions have risen by 18 percent relative to 1990 (NATURAL RESOURCES CANADA, 2004). Canada needs to focus all efforts to reach its goal by the commitment period from 2008 to 2012.

This paper is proposed by a physical chemist, whose interest has been focused on the global carbon cycle, energy consumption, CO_2 emissions, and stabilization of the carbon cycle and climate change. But I think that there are many useful interactions between chemistry and human settlements. As one example I should like to mention Buckminster Fuller whose dome-like structures with interesting networks have inspired chemists to name a whole class of molecules after him, the fullerenes.

Energy consumption and the greenhouse gases

At first the aggregated data are presented with respect to energy use and CO_2 emissions in both Europe (table 1) and the overseas OECD countries (table 2) with emphasis on the North American continent. Table 1 shows the mean primary energy use and mean CO_2 emission per capita. All CO_2 data are given in tons of carbon; the corresponding number in t CO_2 can be obtained by multiplication with the factor 44/12 = 3.667. There is no unique conversion between energy and CO_2 emission because different proportions of fossil energy and non-fossil energy are valid for different countries. Despite some efforts it is seen that the primary energy consumption has increased from 1990 to 1997. The base year for the Kyoto Proto-

Table 1
A reference view of the European Union with respect to energy consumption and CO_2 emission

Countries	Primary Energy Consumption (1990) [Quads BTU] 1 Quad = 1.0548 EJ	Primary Energy Consumption (1997) [Quads BTU]	CO2 emission 1990 [million tons carbon]	CO2 emission 1997 [million tons carbon]	Population 1996 [million]	1997 energy per capita [GJ/cap.]	1997 CO2 emission per capita [t C per capita]	Reduction or allowance goal [%]	emission reduction(-) or allowanc(+) [Mt C]
AU	1.16	1.29	17.2	16.7	8.1	168.0	2.1	-13	-2.2
B-L	2.16	2.58	35.91	38.64	10.6	256.7	3.6	-7.5	-2.7
DK	0.81	0.97	15.3	19.4	5.3	193.0	3.7	-21	-3.2
FI	1.14	1.19	14.7	15.3	5.1	246.1	3.0	0	0.0
FR	8.84	9.73	103.1	101.7	58.4	175.7	1.7	0	0.0
GE	14.76	14.18	267.2	234.4	81.9	182.6	2.9	-21	-56.1
GR	1.05	1.18	22.3	23.8	10.5	118.5	2.3	25	5.6
IR	0.37	0.48	7.1	9	3.6	140.6	2.5	13	0.9
IT	7.02	7.65	113.3	115.7	57.4	140.6	2.0	-6.5	-7.4
NL	3.26	3.88	59.9	64.3	15.5	264.0	4.1	-6	-3.6
PO	0.74	0.91	12.1	13.4	9.9	97.0	1.4	27	3.3
SP	3.93	4.48	62	67.8	39.3	120.2	1.7	15	9.3
SW	2.15	2.16	14.8	15	8.8	258.9	1.7	4	0.6
UK	9.44	10.08	167.4	156.9	58.8	180.8	2.7	-12.5	-20.9
EU-15	56.83	60.76	912.31	892.04	373.2	171.7	2.4	-8	-73.0

Table 2
A comparison view of five selected OECD countries: Australia, Canada, Japan, New Zealand and USA, with respect to energy consumption and CO_2 emission

Country	Primary Energy consumption (1990) [quadrillion Btu] 1.0 Quad =1.0548 EJ	Primary Energy consumption (1997) [quadrillion Btu]	CO2 emission 1990 [million tons of carbon]	CO2 emission 1997 [million tons of carbon]	Population 1996 [million]	1997 energy per capita [GJ/cap.]	1997 CO2 emission per capita [t C per capita]	reduction or allowance goal [%]	emission reductions(-) or allowances(+) [million t C]
AUS	3,7	4,5	74,4	88,8	18,3	259,4	4,9	8	6,0
CAN	10,9	12,2	127,8	143,4	30,0	429,0	4,8	-6	-7,7
JAP	18,1	21,3	273,6	296,7	125,8	178,6	2,4	-6	-16,4
N-Z	0,7	0,79	7,9	8,9	3,6	231,5	2,5	0	0,0
USA	84,1	94,2	1352,1	1488,4	265,3	374,5	5,6	-7	-94,6
Total	117,5	133,0	1835,8	2026,2	443,0	316,7	4,6	-6,1	-112,8

col is 1990, in which Canada pledged to decrease its greenhouse gases by 6 percent until the first commitment period between 2008 and 2012, corresponding to 7.7 million tons of carbon or 28.2 million tons of CO_2 equivalents. Only CO_2 out of the 6 Kyoto greenhouse gases (CO_2, methane, N_2O, HFCs, PFCs and SF_6) is considered here in detail as its share corresponds approximately to 70 percent of all greenhouse gases and also is, in most cases, the greenhouse gas which is most easily reduced.

It is seen from table 1 that the European Union of 15 member states pledges to reduce its greenhouse gases by 8 percent, with different shares for the individual countries, as for example Germany hoping to reduce by 21 percent or 56.1 Mt carbon corresponding to 205.7 Mt CO_2 equivalents.

The Kyoto Protocol has been signed by the European as well as by the Canadian Parliament. However, it is still waiting for ratification by the Russian and the United States Parliament in order to go into force (the Russian ratification would suffice for the Kyoto Protocol to become valid).

Secondary energy (end use energy) and primary energy are related approximately by the factor of 2/3, as is shown below.

The global carbon cycle: Circulation Models for climate change

Within the expected additional, manmade greenhouse effect, three different focus points should be distinguished:

- scenarios for future greenhouse gas emissions in relation to population and economic growth;
- CO_2 emissions from fossil energy use and land use changes and increase of atmospheric CO_2;
- the relation between atmospheric greenhouse gases and climate change according to three-dimensional coupled atmospheric and ocean circulation models.

Scenarios for future development

There are four Intergovernmental Panels on Climate Change (IPCC) scenario groups (IPCC, 2000a) that should be considered equally sound that span a wide range of uncertainty, as required by the Terms of Reference. These encompass four combinations of demographic change, social and economic development, and broad technological developments, corresponding to the following four scenarios: A1, A2, B1, B2.

● **The A1 storyline and scenario family** describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis:

- fossil intensive (A1FI),
- non-fossil energy sources (A1T), or
- a balance across all sources (A1B).

● **The A2 storyline and scenario family** describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

● **The B1 storyline and scenario family** describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

● **The B2 storyline and scenario family** describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than in A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Fossil fuel emissions and the global carbon cycle

The impact of fossil fuel CO_2 emissions in the past has been measured directly by C.D. Keeling et al. at the Mauna Loa Observatory, Hawaii since 1957. They show a clear correlation between consumption of fossil fuels and atmospheric CO_2 increase. To understand the CO_2 increase, knowledge of the global Carbon Cycle is required. For the time range of the order of 1 to 100 years, the carbon reservoirs' atmosphere, ocean and ocean biota and land biosphere with both living biota and soils need to be considered. Water vapor, CO_2 and methane are the most important components of the natural, unperturbed greenhouse effect of the earth, which increased the mean surface temperature from a shivery -18°C to an agreeable +15°C.

Perturbations of the carbon cycle by man are given in figure 1 for the last decade of the 20th century. The mean fossil fuel emission was 6.3 billion tons (Gt) of carbon, with a mean of approximately 1 t of carbon per capita. The industrial countries, as shown in tables 1 and 2, have a much higher contribution than the developing countries. Atmospheric measurements show that only 3.3 Gt C remain in the atmosphere, while the greater other part is absorbed by the oceans. There is still uncertainty about the ocean uptake indicated in figure 1 by the horizontal set of three numbers, a lower, an intermediate and an upper value. The total balance of input and output is usually achieved by the reservoir of the remaining land biosphere, which is a CO_2 source and sink at the same time in different regions and by differing mechanisms. Tropical deforestation still is a large source of CO_2, ranging between 0.6 and 2.0 Gt C/yr (with a mean of 1.6 Gt C/yr), indicated by the vertical arrangement of the two numbers. Carbon Balance is then only achieved if the land biosphere other than tropical deforestation is a large sink of between 1.3 and 2.7 Gt C/yr.

These sinks are due to different processes: regrowth of forest on lands which were formerly agriculture, regrowth of forest following perturbations during the first half of the 20th century including wars, CO_2 and nitrogen fertilization due to higher atmospheric CO_2 concentrations as well as nitrogen deposition. For many commercial forests, including most of the European forests and those of the United States, the growth increment has been larger than the annual cut in the past 30 years, which implies a building up of carbon.

With the fossil fuel emissions taken from the development scenarios A1, A2, B1 or B2 and the knowledge from the carbon cycle on the response to CO_2 emissions, the atmospheric CO_2 concentration can be extrapolated until the end of the 21st century, making intelligent guesses about the long-term ocean uptake and the behavior of the land biosphere.

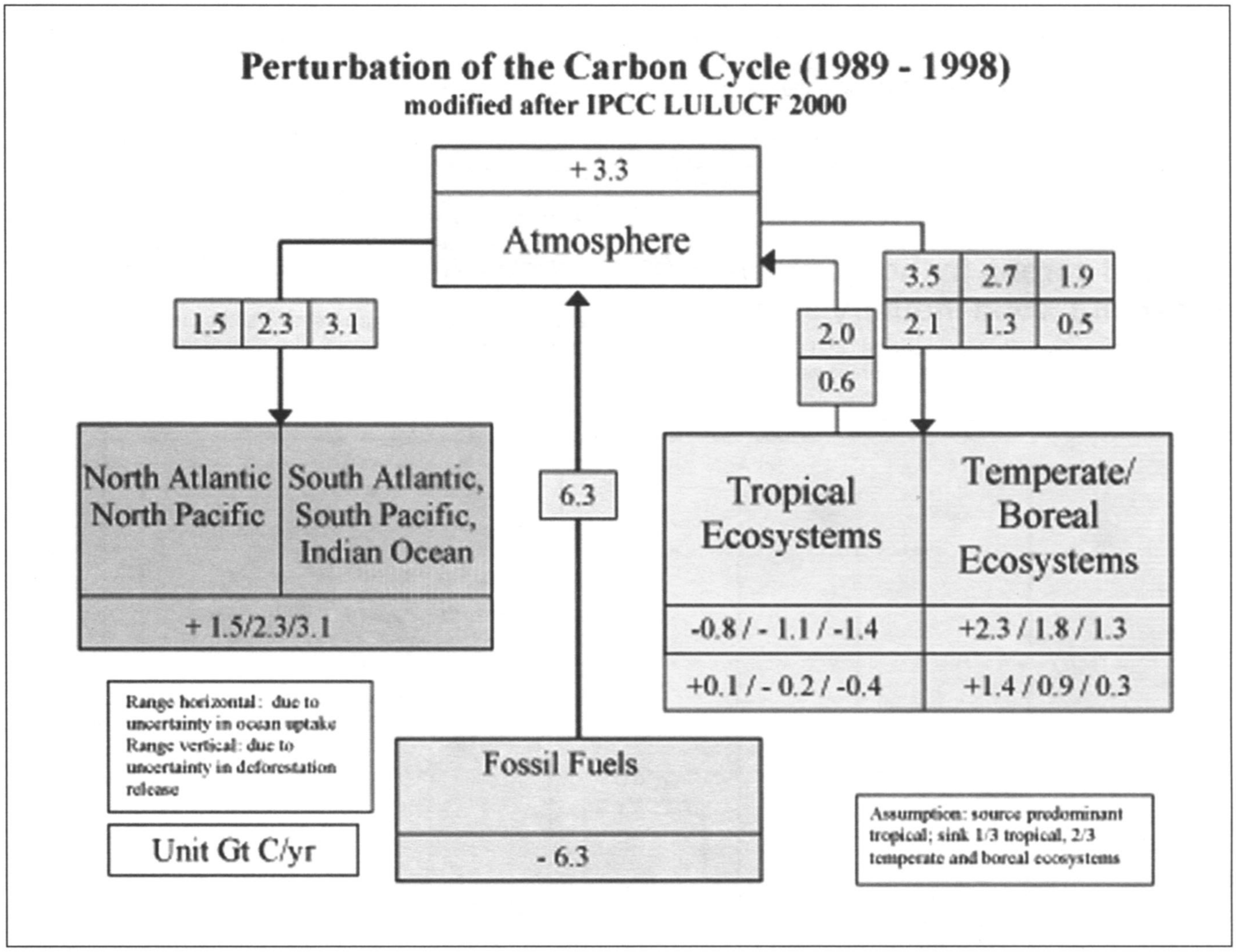

Fig 1: The Global Carbon Cycle (modified after IPCC 2000b).

General Circulation Models and their prediction of a future climate change

There are several well known General Circulation Models (GCMs) which translate CO_2 and the other greenhouse gas concentrations in combination with the change of the reflective properties of the earth surface and the atmosphere, the albedo, into the future temperature and precipitation changes in different parts of the world. The Dutch Institute RIVM (2001) has made a comparison of the following GCMs:

- HADCM2, model of the Hadley Centre for Climate Prediction, as part of the British MET Office, Great Britain;
- ECHAM4, model of the Climate Calculation Center in Hamburg, Max Planck Institute for Meteorology, Germany;
- CGCM1, model of the Canadian Center for Climate Modeling and Analysis, Canada;
- GFDL-LR15a, model of the Geophysical Fluid Dynamics Laboratory Princeton in cooperation with the National Oceanic and Atmospheric Administration (NOAA, USA);
- CSIRO-MK-2, model of the Commonwealth Scientific and Industrial Research Organization, Australia.

It is interesting to compare the predicted results for global warming for Canada. For instance, in 2080, the following warming is predicted for the business-as-usual A1F scenario and the ecologically oriented scenario B1 by the different models.

From tables 3a and 3b, it is clear that the choice of the B1

Table 3
Global Warming in °C for Canada, predicted by different GCMs in 2080 relative to 1990, Scenario A1F and Scenario B1

a. Scenario A1

City	HADCM2	ECHAM4	CGCM1	GFDL-LR15	CSIROMK-2
Toronto	2.5*	5.5	2.5	4.5	3.5
Churchill	4.5	5.5	4.5	6.5	6.0
Vancouver	2.5	2.5	2.5	2.5	2.5

*All numbers are read off a color map, and are therefore approximate.

b. Scenario B1

City	HADCM2	ECHAM4	CGCM1	GFDL-LR15	CSIROMK-2
Toronto	2.0*	2.5	2.0	2.5	2.5
Churchill	2.5	2.5	2.5	2.5	2.5
Vancouver	2.0	2.0	1.5	2.5	2.5

*All numbers are read off a color map, and are therefore approximate.

path is much sounder and connected with fewer risks than the choice of A1F, the business-as-usual path. Warming alone is insufficient to describe the expected man-made greenhouse effect. It is absolutely necessary to look at the precipitation changes as well, including extreme events like long hot-spells, cold-spells, storms, etc. Warming and precipitation changes determine soil moisture, which is most important for plant growth. Detailed analyses are needed here and will not be presented in this short summary.

CO_2 and carbon in the Northern forest and wood industry sector

Article 3.3 of the Kyoto Protocol specifies that the net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, shall be included in the national greenhouse budget. The Kyoto Protocol further states in article 3.4 that additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I of the UN Framework Convention on Climate Change UNFCCC (Annex I of the UNFCCC or equivalently Annex B of the Kyoto Protocol is an appendix in which the industrial countries are summarized). Figure 2 shows some first estimates of the sources and sinks of the activities related to forestry and wood industry. The study focused on the temperate and boreal

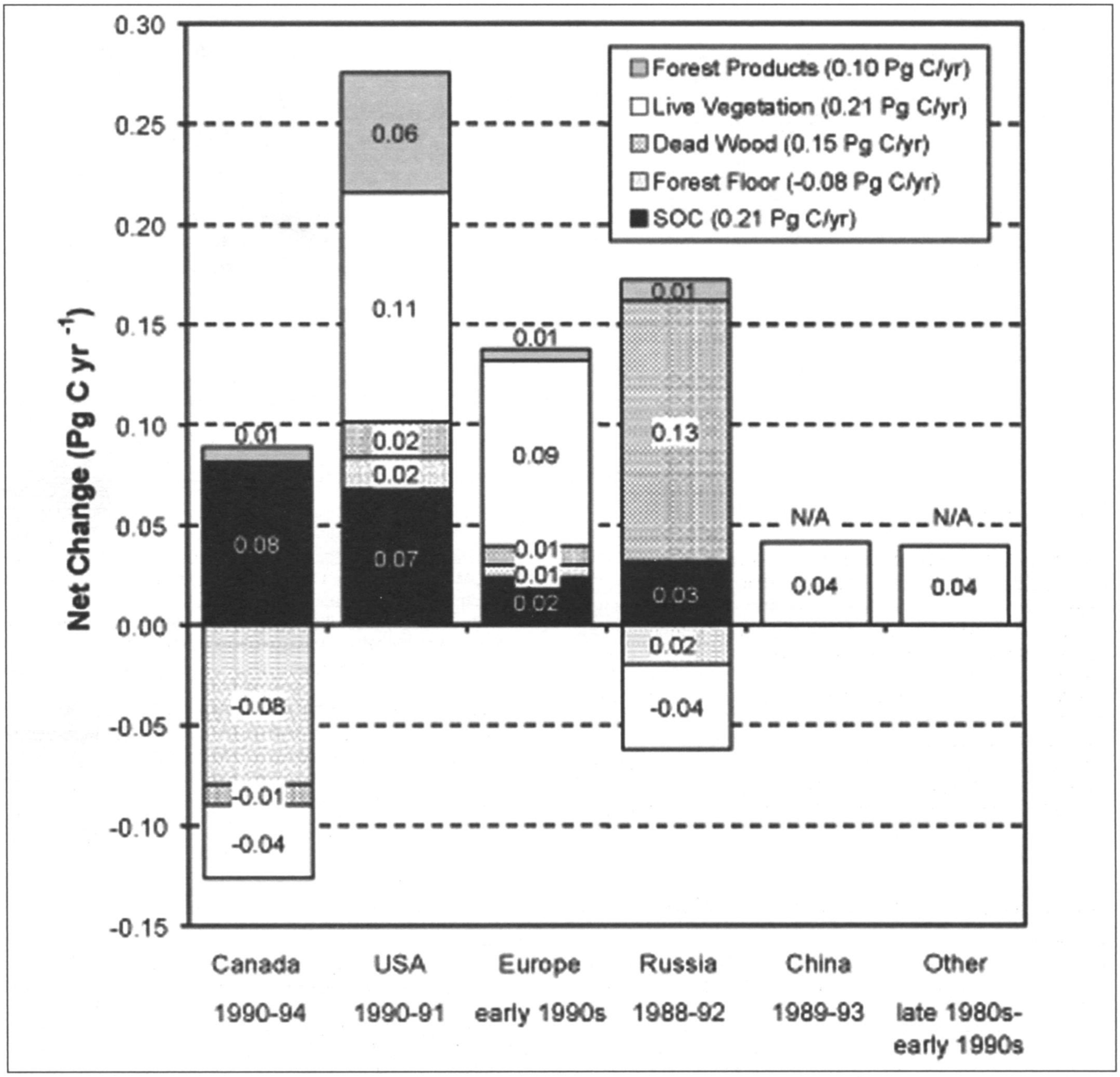

Fig. 2: Sources and sinks of the Northern hemisphere forests and wood industry.

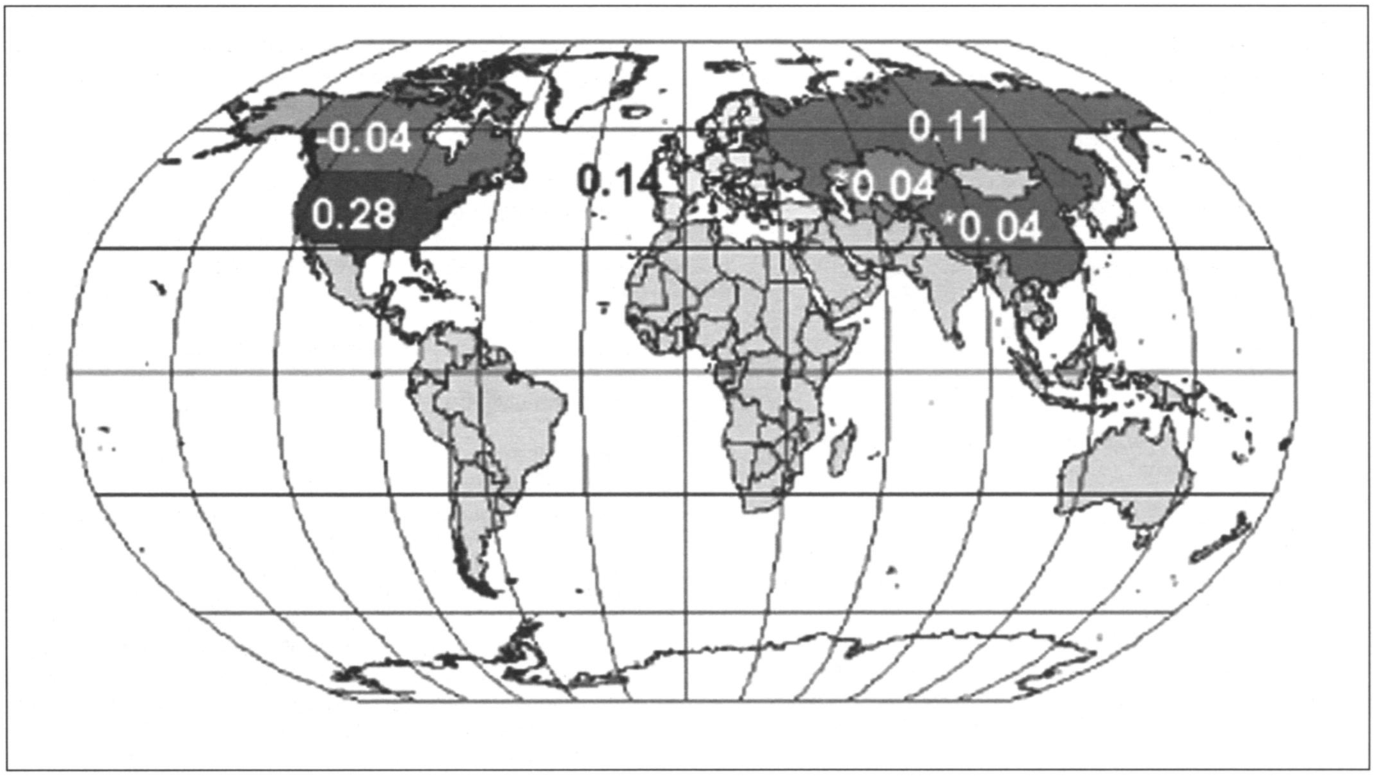

Fig. 3: Carbon balance of Northern forests (Gt C/yr). (*Source*: Christine L. Goodale, et al., "Forest carbon sinks in the Northern hemisphere," *Ecological Applications*, vol. 12, no. 3, pp. 891-899, 2002).

forests of the industrial countries, and distinguished Canada, USA, Europe, Russia, China and other developed northern hemisphere countries. The following categories were distinguished:

- live vegetation,
- forest floor,
- dead wood,
- soil organic matter, and
- forest products.

Within large error bars it showed that soil organic matter increased in all country groups studied, and the same was true for the forest products pool. The forest floor, however, decreased in Canada and Russia, while it increased in the USA and Europe.

There was a considerable increase also in live vegetation for the USA and Europe, while again a decrease was noted for Canada and Russia. Dead wood increase was noted in the USA and Europe and in particular in Russia, while there was a decrease in Canada. Summing up all components for each country group, shown in the bar graph of figure 2, the map of the Carbon Balance of the Northern Forests, shown in figure 3, has been obtained. All together, all categories added up to a carbon sink of 0.59 Pg or Gt of carbon, respectively.

Canada and its energy and CO_2 budget

In table 2 it is shown that 30 million Canadian citizens had an average primary energy consumption of 429 GJ/ (cap.*yr) and an average CO_2 emission of 4.8 t C/ (cap.*yr) equivalent to 17.6 t CO_2/ (cap.*yr) in 1997. The total primary energy consumption was then 12.9 EJ or 12,600 PJ (1 EJ = 1 ExaJoule = 10^{18}J, 1 PJ = 1 PetaJoule =10^{15}J) out of which 600 PJ or 5 percent were supplied by woodfuels. The total CO_2 emissions amounted to 127.8 Mt C (468.6 Mt CO_2) in 1990 which should be reduced according to Canada's Kyoto goal by 6 percent or 7.67 Mt C or 28.1 Mt CO_2 by the commitment period between 2008 and 2012.

The conversion factor between the burning gas CO_2 and black carbon C is just given by the ratio of the molecular weight of CO_2 to the atomic weight of C (44/12=3.667). The conversion of 1 cu.m of wood into carbon can be broken into two steps:

- The weight of dry wood to the volume of fresh wood is different for different woods grown in different regions of the world. A crude, but not always applicable conversion from volume dry matter (dm) is for softwood (0.4 t dm/cu.m) and for hardwood (0.6 t dm/cu.m);
- The carbon content of wood in the dry matter state is ~0.5. If the average density of wood is taken to be 0.55 t dm/cu.m, then a very simple relation is obtained:

1.0 cu.m of fresh wood = 0.55 t dry matter wood

= 0.275 t carbon = 1.0 t CO_2

Data from the *Energy Use Data Handbook* (NATURAL RESOURCES CANADA, 2004) show the time series of 6,950 EJ (1990), 7,737 EJ (1997) and 8,217 EJ (2002) for secondary energy (final energy) with a clear upwards trend. According to their statistics the greenhouse gas emissions rose by 18 percent from 1990 to 2002, in accordance with an energy increase of 18 percent, still far from the Kyoto goal to reduce its emissions by 6 percent. In 1997 (chosen here as the base year) the secondary energy use was divided up into the following categories (table 4):

The per capita use of secondary energy was in 1997 (7,738 PJ/30 million) 258 GJ or 71.6 MWh, out of which 18.1 percent was used in the residential sector, corresponding to 46.7 GJ or 13 MWh, with a use of over 80 percent for space heating

Table 4
Secondary energy consumption and CO_2 emission equivalents for different sectors of the Canadian economy. Reference year 1997

Category	PJ (1997)	Percentage [%] energy	Mt CO2 equiv. (1997)	Percentage [%] CO2
Residential	1,394	18.1	72.7	16.3
Commercial/Institutional	999	12.9	54.2	12.1
Industrial	2,998	38.7	152.4	34.1
Total transportation	2,117	27.3	152.1	34.0
*Passenger transportation	1,233	15,9	87.9	19.7
*Freight and off-road transportation	884	11.4	64.2	14.4
Agriculture	230	3.0	16.0	3.6
Total	7,738	100.0	447.2	100.0

and cooling, and hot water preparation. The corresponding per capita emission of CO_2 was in 1997 (447.2/30) 14.9 t CO_2 with 2.4 t CO_2 arising from energy use in the residential sector (table 4). Fossil energy use for heating and hot water per house per year: about 6 t CO_2/yr (13.4 percent of all emissions for space heating and cooling including hot water; 3 persons per house/apartment).

The majority of Canadian homes are single detached houses with one owner only, where changes can be done most easily. Table 5 shows the types of residential homes in Canada.

In table 6 details of the energy consumption in the residential sector are outlined.

Table 5
Types of residential houses in Canada in the base year 1997

Type of housing	Number of units (thousands)	Floor space (million sq.m)	Average size housing unit
Single detached	6,743	926	137
Single attached	1,235	141	114
Apartments	3,646	308	85
Mobile homes	245	22	92
Total	11,869	1,401	118

Table 6
Residential sector: Secondary energy in space heating, space cooling and hot water preparation, electric lighting and appliances (year 1997)

Space heating by source	PJ	Other energy uses	PJ	Total households (thousands)
Electricity	142.4	Total lighting	56.3	11,224
Natural gas	471.9	Total space cooling	9.4	Heating degree-days average base<18°C
Heating Oil	132.6	Total appliances	179.6	4,474
Wood	97.9	Total water heating	290.5	Cooling degree-days average base >18°C
Other	13.0	Total other energy uses	525.8	171
Total space heating	857.9	Total space heating + cooling + water heating	1,157.8	
Total residential energy use			1,393.0	

Average energy intensity per floor space 0.61 GJ/ (sq.m*yr) = 170 kWh/ (sq.m*yr)

To save on energy and to reduce the CO_2 emissions in the residential sector, the following could be done:

- Substitution of 15 percent fossil fuels by woodfuels would result in savings of 0.9 t CO_2/ (home*yr), or a total of 9 Mt CO_2 (10 million homes and apartments), out of 28.2 Mt CO_2 or 32 percent of the Kyoto goal.
- Energy savings by installing more efficient thermal insulation in the homes could also improve the situation significantly. The energy consumption per 3 person home or apartment is presently 140 GJ/yr or 39 MWh/yr corresponding to an emission of 9.2 t CO_2. Low energy houses, as described below, consume in the order of 50-100 GJ/yr and emit in the order of 2.5 to 5 t CO_2/yr. If energy savings could be achieved in the order of 15 percent this would result in a savings of 14 Mt CO_2 annually, about 50 percent of the Kyoto goal.

However, there are also opportunities of energy reduction on the part of the Canadian forest companies:

- The Canadian industrial roundwood production is presently 183 Mcu.m (corresponding approximately to 183 Mt CO_2 removed from the atmosphere), as given in the *State of the World's Forests,* 1999. Forest and wood industry operations produce a significant amount of wood residues. Four categories of wood residues are distinguished: forest residues, industrial residues, black liquor (an energy-rich by-product in pulp production) and recovered products (old wood), which have been examined in detail by M. Trossero, FAO. All residues can be used energetically and constitute a significant fraction of the entire category of woodfuels. The total of all fuelwood residues in relation to the annual roundwood production is an interesting indicator of the environmental concern for fossil fuel energy substitution.
- In Austria this ratio is highest with 76 percent, the average of the European Union is 54 percent, the United States of America has a ratio of 48 percent, but Canada has only a ratio of 16 percent. If only 15 percent of additional residues could be used for woodfuels, a savings of 27.5 Mt CO_2 could be achieved, just about the Kyoto goal of 28.2 Mt CO_2.

Mitigation of climate change through reduction of CO_2 emissions

To avoid a serious impact of a future climate change that is unpredictable in detail for the different regions of the world, global greenhouse gas emissions need to be reduced. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) is one international effort to mitigate climate change, by specifying six greenhouse gases:

- carbon dioxide (CO_2),
- methane (CH_4),
- nitrous oxide (N_2O),
- hydrofluorocarbons (HFCs),
- perfluorocarbons (PFCs), and
- sulfur hexafluoride (SF_6).

The most important greenhouse gas in the anthropogenic perturbation of the climate system is carbon dioxide, CO_2, responsible for about 70 percent of the greenhouse effect, which is predominantly due to the burning of fossil fuels.

How can CO_2 be reduced? Perhaps the most important component is the saving of energy through individual changes in lifestyle, which for most cases follow fashions, often supported by the manufacturing industry like, for instance, the use of the highly gas-consuming sports utility vehicles (SUVs). Transport is certainly one sector where savings can be achieved within urban life: public transportation with subways and commuter trains, electric or natural gas buses, and electric vehicles to be rent for short-term distances, let alone bicycles, which can be position-checked electronically and collected to be transferred back to the points of rentals.

Lifestyle also determines the house you build, whether it is a stone or wooden house and the kind of heat insulation you are willing to install and pay for, and the energy you tap from the environment in the form of heat pumps and solar panels. Most older buildings have insufficient thermal insulation and, if energy prices increase continuously, it pays for the home-owner to install it. Energy savings can be influenced by the community or state by higher taxes on fossil fuels or by subsidies on modern energy savings equipment.

Lifestyle includes for instance also holidays in faraway countries, which add to the long distance fuel consumption of overseas air transport.

The energy industry and its task of conversion of primary energy to end energy still allows for substantial improvements in energy efficiency. The same is true for electrical appliances, as, for instance, electric lighting. The steel and aluminum industry consumes a high amount of energy; producing cement, by the same token, releases CO_2. The imbedded energy per unit weight or volume in building materials is often a lot higher than the energy needed to produce the equivalent materials made out of wood.

Carbon storage in forest products with emphasis on housing

The forest products sector is one of the important (yet modest, when compared to the carbon stocks of forests and soils) contributions of carbon storage in human society. The standing stock is determined by its annual input and output. In figure 2, section 4, it was shown that the stock increases in the Northern hemisphere countries by approximately 100 million tons of carbon per year. This estimate includes landfills with wood products in the United States of ~35 Mt C/yr, the product pool without landfills is ~65 Mt C/yr. About half of the annual addition to the product pool can be associated with the balance of wooden materials stored in houses.

Within the project BIOCLIMECO (Biosphere, Climate and Economy), Busch and Alcamo, members of our team, were able to show that the carbon pool in houses will increase over the next hundred years, due to both population growth and economic development of the less developed countries. Two limiting scenarios were studied: the first was a business-as-usual scenario with the present share of wooden homes continued, while the second scenario implied an increased use of wooden homes, wherever the construction statics allowed it. Figure 4 shows that the carbon stock increases from the base line in 1970 to 4,500 Mt C in the year 2100 for scenario 1, whereas a total of 13,500 Mt C is reached in scenario 2. The mean annual increase in carbon stocks for scenario 1 lies between 30 and 50 Mt C/yr, while that for scenario 2 lies between 65 and 150 Mt C/yr. When these figures are compared to the annual CO_2 emissions from fossil fuel energy use, and its possible reduction efforts, they appear relatively small. Present energy consumption already gives rise to 6,500 Mt C/yr and is supposed to increase up to 20,000 Mt C/yr in the global A1 scenario during the 21st century. The carbon storage in houses on a global level is, according to this analysis, only in the percentage range, or even below, in comparison to the CO_2 emissions from energy consumption.

However, the global picture neglects any efforts on the individual, community or country level, where the proportions of the potential savings may be quite different. Avoidance of CO_2 emissions of any individual, community or state is composed of a portfolio of many efforts, in which the contribution of any

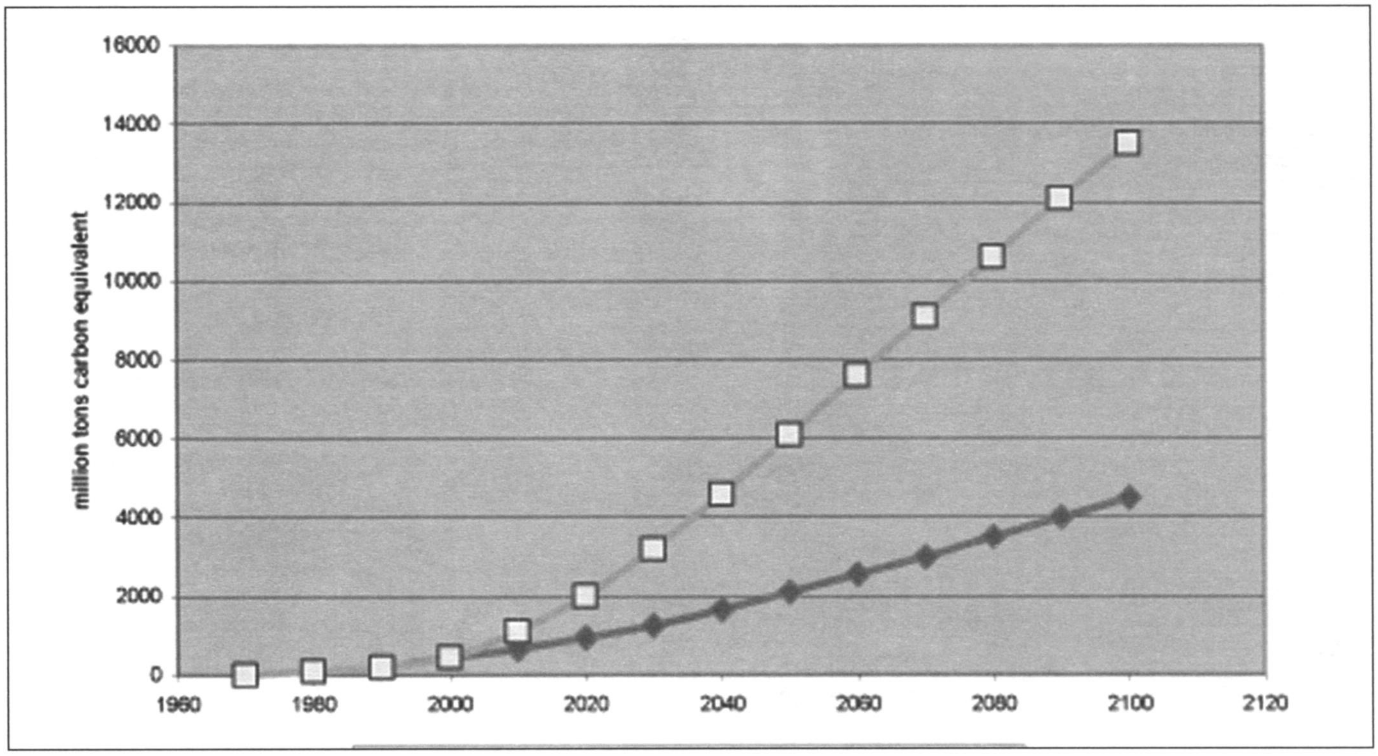

Fig. 4: Carbon accumulated in residential housing in model 1 (continuing trend) and model 2 (preference wooden houses) – A1 scenario for population growth. Base year 1970. (*Source*: G.H. Kohlmaier, et al., *Project BIOCLIMECO: Biosphere, Climate and Economy*, 1998-2001).

specific component may vary substantially. Not unlike investments at the stock markets, the CO_2-savings portfolio must fit the individual or the individual family, community or state. In the next section, a detailed analysis of the "cradle to grave approach" will be given for two different energy-saving prototype homes in Germany.

A life-cycle assessment of two low energy houses in Germany

In his dissertation, Cevin M. Pohlmann examined the life-cycle (fig. 5) assessment of two prototypes of low energy wooden houses in Germany, called House Bremen (to be built in the City of Bremen) and House Würzburg (to be built in the City of Würzburg). Both energy and CO_2 fluxes were studied in detail from the cradle: the crude materials, followed by the building materials, the manufacturing of materials, house construction, house use, to the grave, the deconstruction of the house, the waste disposal including energy use, and finally the material recycling.

With transport of materials being a separate category, the manufacturing of the building materials for the two prototype houses (House Würzburg 250 sq.m living area, House Bremen 210 sq.m living area), was 777 GJ for House Würzburg and 827 GJ for House Bremen.

The bar graph in figure 6 shows the individual components of energy consumption and CO_2 release. The units in figure 6 are 10 GJ, to make the bars comparable in the same graph with the unit of CO_2 emissions, in tons of carbon. These numbers can be viewed with respect to the average per capita secondary energy consumption of 112 PJ in Germany and 258 PJ in Canada, out of which are used in the residential sector about 25 percent (28 GJ) in Germany and about 18 percent (46.4 GJ) in Canada.

The energy needed for the construction of the houses was in both cases rather low, 15 and 13 GJ respectively; the same is true for the transport of materials, being 21 and 19 GJ. The maintenance, extrapolated over a lifespan of 60 years was estimated at 152 GJ for House Würzburg and 156 GJ for House Bremen. Operating expenditures for heating and hot water preparation, again over a lifespan of 60 years, were calculated at 2,500 GJ for House Würzburg and 1,500 GJ for House Bremen. The per annum consumption in this case is 41.7 GJ and 25.0 GJ, or 11.9 MWh and 6.9 MWh, as compared to the average 3-person Canadian family home of approximately 40 MWh. The numbers for the disposal of the two house types are 46 GJ and 49 GJ. Wooden houses are useful carbon stores, which in part can be recycled or used for energy. The total energy embedded in House Würzburg is estimated at 734 GJ, that in House Bremen at 1,200 GJ.

The CO_2 emission is proportional to the energy use; however there is no unique conversion factor for the different categories. Manufacturing, construction, maintenance, transport, and disposal totaled here 131 t CO_2 for House Würzburg and 107 t CO_2 for House Bremen. Operating expenditures released in House Würzburg totaled 157 t CO_2 and in House Bremen 105 t CO_2 over the time of 60 years. Useful carbon stored in House Würzburg is given at 92 t CO_2 (25 t C), while that for House Bremen is given at 150 t CO_2 (41 t C).

The houses can be optimized with respect to energy consumption and CO_2 emission by installing additional solar thermal and photovoltaic equipment, or alternatively, by using wood furnaces. The savings in energy are then an additional

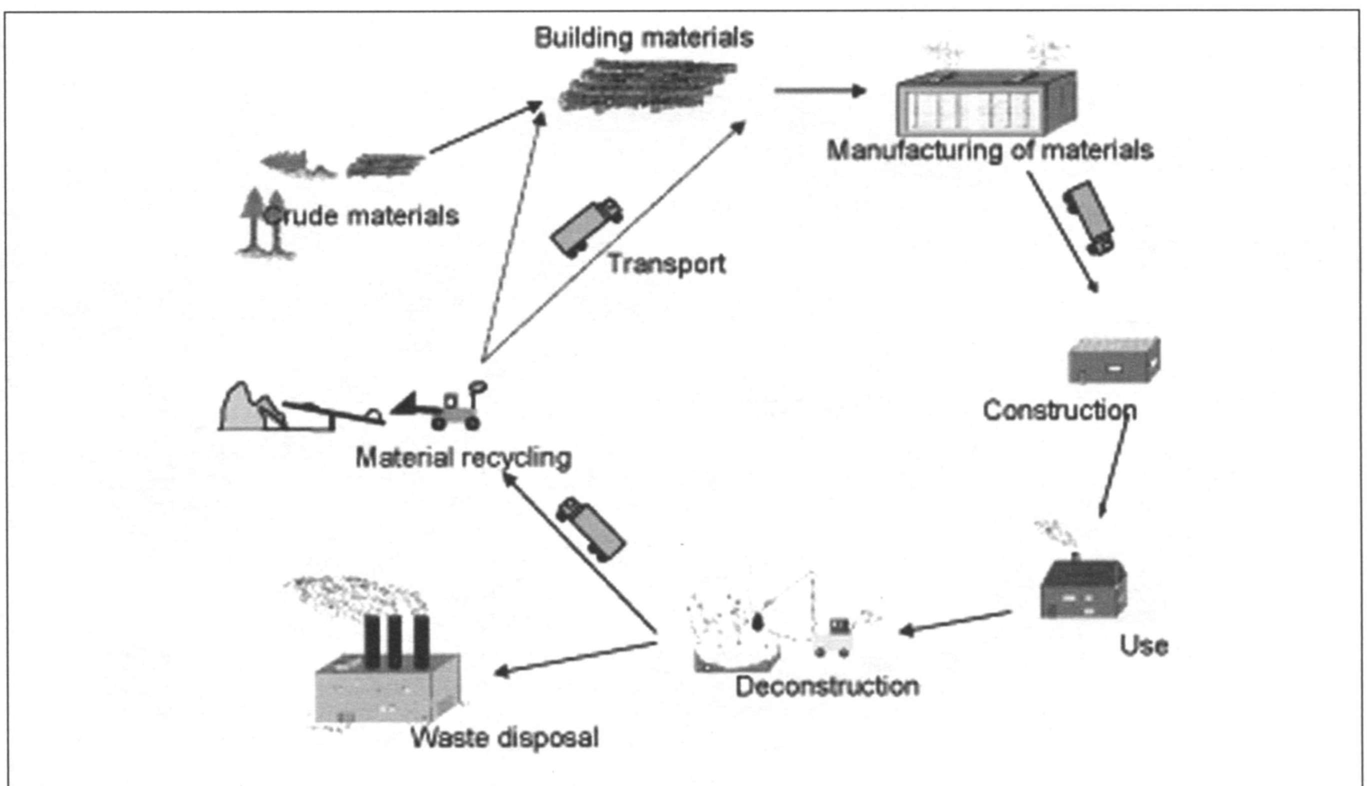

Fig. 5: Life cycle of a wooden house. (After C. Pohlmann, University of Hamburg and Bundesforschungsanstalt BFH).

465 GJ for House Würzburg and 364 GJ for House Bremen. The reductions in CO_2 emissions are 39 t CO_2 for House Würzburg and 29 t CO_2 for House Bremen.

Conclusions

In the review of the data presented above and the data of the *Energy Use Handbook* of June 2004, presented by Natural Resources Canada, it becomes clear that there was a 12.5 percent increase in CO_2 between 1990 and 1997, an 11.9 percent increase in primary energy consumption, and an 11.3 percent increase in secondary energy use until the year 1997, while an even more staggering 18.2 percent increase in secondary energy, and an 18.3 percent increase in CO_2 emissions in the time between 1990 and 2002 has been observed.

If Canada wants to fulfill the ratified Kyoto Protocol, it should reduce its greenhouse gas emissions by 6 percent up to the 5-year commitment period 2008-2012; the same is approximately true for its primary and secondary energy consumption. It is seen that Canada is far behind its plans; instead of decreasing its emission by approximately 4 percent it increased it by 18 percent in 2002. There are many possible sectors to save on energy and greenhouse gas emission: already a 1 percent decrease in a particular sector counts. In this sense the efforts of the forest industry should be viewed.

The commercial forests can be regarded as a big factory for wood, absorbing CO_2 from the atmosphere and transforming it into wood, a carbohydrate carbon compound. Wood is needed for many purposes, and if wood is used in construction for housing, this carbon will stay bound for a lifetime of at least 60 years. Thus carbon is removed from the atmosphere for a long time in which the energy industry can make a transition from a fossil fuel world to a non-fossil fuel world, using then mostly direct and indirect solar energy. Today's world energy budget is about 400 EJ (10^{18}J), the solar energy arriving at the earth's land surface is approximately 1,000,000 EJ, a factor 2,500 larger than the present energy consumption. With new technologies in storing and transporting energy, it should be possible to build a solar internet system, which can serve most countries of the world with enough energy.

Returning to the individual wooden home with good thermal insulation and additional solar panels, and perhaps a wood chip stove, it should be possible to obtain a CO_2 budget over the lifetime of the house, in which the CO_2 emissions from manufacturing of the building materials, the construction and the maintenance of the house, the operating expenditures (heating and hot water preparation, etc.) and the disposal of the house are lower in total than the carbon and its CO_2 equivalent stored in the house in the form of wood. This would indeed be a CO_2 positive house in which more carbon was removed through the forest manufacture than was released into the atmosphere in the lifetime of the house. If, at the end of the lifetime, the greater part of the material is used for energy, this will release CO_2 60 years later than today and at the same time avoids the use of fossil fuels, which are then a precious resource.

Rising energy consumption is the main factor of the expected man-made greenhouse warming. With respect to housing, the improvement of thermal insulation both in new houses and in older houses can help to reduce the greenhouse gas emissions considerably. Cost-benefit analyses show that the additional energy consumption and CO_2 release for better insulated houses are compensated within 10 to 15 years by the reduced energy needs of the house; similarly the additional economic investments do pay back within the same time frame. Additional tax reductions for thermal insulation improvements could help to accelerate this change.

The use of wood, in particular residual fuelwood from logging and forest industry operations, is a third factor to reduce CO_2 emissions. Here, ..., Canada with 16 percent has the lowest ratio of residual fuel wood to annual roundwood production. An increase in the energetic use of residual fuelwoods

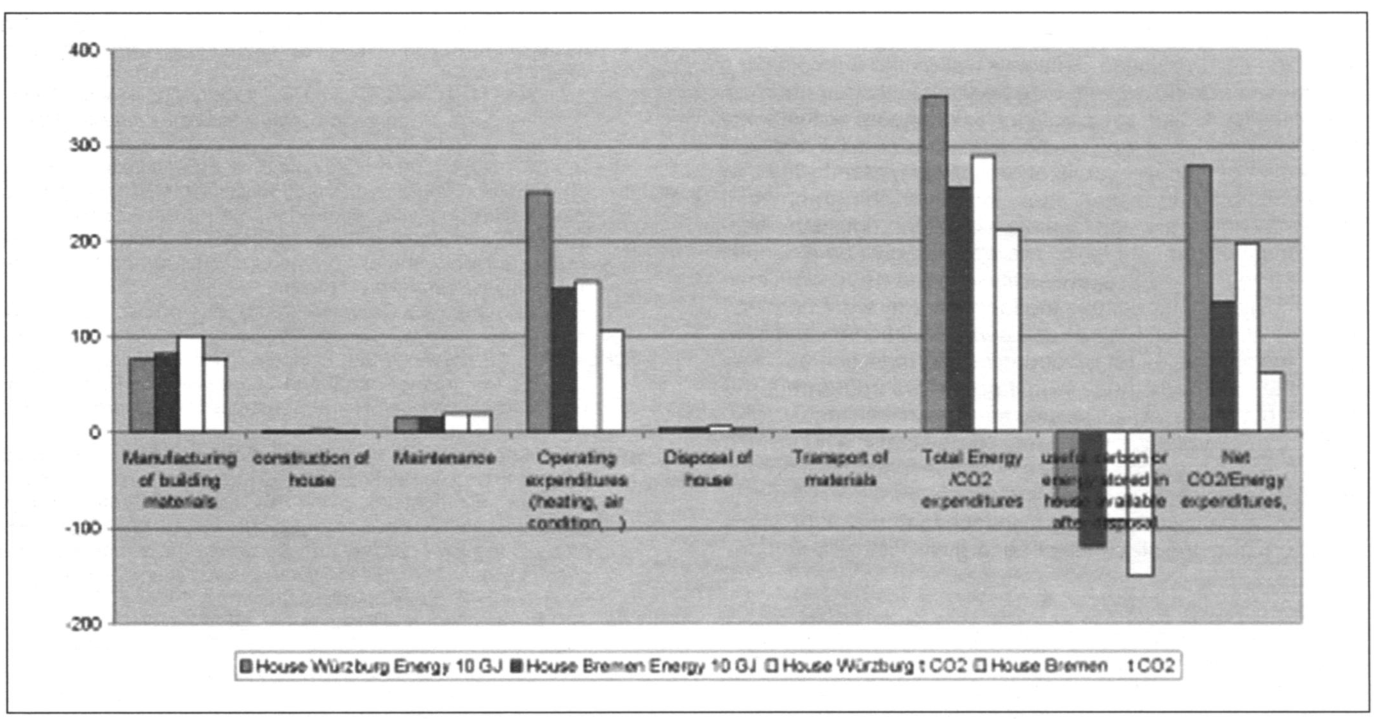

Fig. 6: CO_2 and energy expenditures in Low Energy Houses, Würzburg and Bremen. (After C. Pohlmann, University of Hamburg and Bundesforschungsanstalt BFH).

could improve Canada's CO_2 budget. Centralized heat and power plants, as well as individual stoves with automatic wood chip firing, are convenient means to use this renewable energy source.

The new restrictions with respect to a climate change could present a challenge and an opportunity at the same time to the Canadian forest and wood industry. The development of well insulated wooden houses, both in a standard edition, and in a special edition, which provides an even better insulation combined with heat pumps, solar thermal panels, and perhaps photovoltaic solar cell systems, could help to expand its market shares in its country and its export market. It perhaps would be going a bit too far to ask for commercially available houses with a rotating base, as were presented at a recent Austrian fair, which make use of the best meteorological position of the house during the day or the season of the year.

In summing up, it was shown above that the use of wood in construction and energy in Canada's cities could improve the greenhouse budget, which at present is 22 percent above Canada's Kyoto goal for the end of this decade.

Summary and afterthoughts

- Among the most serious global problems of the 21st century is the expected climate change. Climate change will be affected both by the increasing use of fossil fuels and by land-use transformations, in which forests are converted into grasslands, agricultural land and land needed for the infrastructure of cities and industries. Planning future housing should certainly include the aspects of climate mitigation. Many of the building materials like steel and concrete require in their production a large input of fossil fuels, while wood, a renewable resource, could replace at least part of these materials which have imbedded within them a large energy input. The construction of the future natural city should consider these material aspects as well as the energy needed for heating and cooling of the houses. Again woodfuels, often available as residuals from the wood industry, can replace oil, coal and natural gas as an energy source. Central heating is often more efficient than individual heating in private homes.
- Canada and the United States, as well as the Scandinavian countries in Europe, have a long tradition in wooden homes. Part of the Canadian wood industry is dependent on the home and export market of wooden houses. Knowing the additional benefits of climate stabilization should make them even more valuable and sought after. However, the green spirit alone may not be enough to make a breakthrough in this sector. It must become a fashion, as well. To give an example: about 10 years ago the sports utility vehicles (SUVs) became enormously popular despite the fact that they were consuming large amounts of fuels. For a certain fraction of the population, the opinion leaders, wooden homes must become very desirable. Perhaps these would not be the standard farmhouses, but houses which include many high tech features like solar thermal and photovoltaic energy systems. The spirit: It is great and fashionable to live in a house made from natural materials focusing on valuable and sought-after Canadian timber, and which includes many high tech features at the same time, both from the standpoint of energy as well as communication.
- Wooden homes stabilize the carbon cycle, in as much as the CO_2 absorbed by the photosynthesis of trees stays locked in the buildings during their lifetimes, and can be used for energy purposes when being torn down. Starting with the concept of the tree house, both the concept of house and tree should be followed up in the natural city when thinking about new ideas about living. The tree house obtains natural cooling through the green branches of the tree in the summer time by evapotranspiration of the leaves while in winter the snow-loaded branches of evergreen trees provide additional protection from the winter frost. Tree houses resting on a single stem provide protection from flooding, termites or other unwanted guests. As an extension of the house on one stem, the single stem could be made to turn easily into the direction of the best climate as encountered in the different seasons of the year as well as during the different insolations during the day.
- It makes sense to use woodfuels for heating, supported by solar thermal and solar electric energy. It saves considerable fossil fuels; 20 percent of Canada's primary energy budget is used for heating. Savings of only some additional percentage in this sector could provide the energy reductions needed to satisfy the Kyoto Protocol. In summary, the Canadian forest and wood industry could expand its wooden home exports considerably by designing low energy and high-tech houses, while providing their wastes for heating systems.

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