changes so drastically? Laboratory and field studies reveal that mercury, hydrogen peroxide, hydrochloric acid and nitric acid are taken up more readily by growing than by stable ice. Experiments are needed to measure this uptake accurately and over a range of growth rates. Tracking uptake in individual growing ice crystals would be a good start.

How long will ice last? Satellite data indicate that the Arctic perennial sea-ice cover is declining by around 10% per decade. Glacier shrinkage at the Greenland and Antarctic ice sheets is accelerating. Our understanding of the observations is insufficient for us to predict the rate at which snow and ice could disappear from our planet in this century. Studying the impact of ice chemistry on molecular-scale melting processes will help us to predict the fate of Earth's snow and ice.

BACK TO THE LAB

How shall we answer these questions? Good starting points are existing research networks, such as the Air–Ice Chemical Interactions programme of the International Global Atmospheric Chemistry project, with which I am involved, the European Science Foundation's network on the microdynamics of ice, Micro-DICE, and the Arctic health-risks project ArcRisk, which is supported by the European Community.

These collaborations of scientists from different disciplines and countries should be broadened. We need to bring in materials scientists working on crystal and surface structures in metals, cell biologists who study the biota of frozen environments and food scientists who study how compounds change during freezing.

More funds for fundamental, laboratory-based experiments must be raised. I believe that all ten questions could be answered with an investment of €5 million (US$7 million). Sadly, this will be difficult to find, but now that we have identified basic key questions, the time has come for complex, well-defined experiments in laboratories using sophisticated analytical techniques, including synchrotron facilities. Lack of recognition of the importance of ice chemistry may be one reason why many ice and snow research groups have moved into field studies. We need to reverse this flight and use the expertise gained over the past decades to understand the role of ice in the global Earth system — before it vanishes. ■

Thorsten Bartels-Rausch *studies the surface chemistry of ice and snow at the Paul Scherrer Institute, Villigen, Switzerland.*
e-mail: thorsten.bartels-rausch@psi.ch

1. Bartels-Rausch, T. *et al. Rev. Mod. Phys.* **84,** 885–944 (2012).
2. Bartels-Rausch, T. *et al. Atmos. Chem. Phys. Discuss.* **12**, 30409–30541 (2012).

STEPHANIE MAZE/NATL GEOGRAPHIC/GETTY

Brazil distils vast quantities of fermenting sugarcane into alcohol for fuel.

Build a biomass energy market

Governments must offer incentives to drive a switch to biofuels and other renewables, argues **Heinz Kopetz**.

Biofuels — which include wood, straw, charcoal, ethanol derived from corn (maize) and methane-rich biogas — currently generate about 10% of the world's energy, or 53 exajoules[1]. The majority goes towards heat, with the rest used for electricity and transportation (see 'Biomass boost'). But biofuels hold the potential to deliver at least one-quarter of the world's projected energy needs of 623 exajoules by 2035 (ref. 2). This would help to limit global warming, create jobs in rural areas and improve energy security. To achieve it, countries will need to dramatically accelerate their development of biofuel technologies.

Some countries have made huge strides in this respect, notably Sweden, Austria, Brazil and China. Many others are not making the most of their resources: in Australia, for example, millions of tonnes of straw are still burned in fields after ▶

the harvest each year; this 'waste' could be used to generate energy.

Critics often argue that the development of biofuels for transportation has caused more hunger in the world by eating up land that could be used to produce food, but there is little scientific evidence of that. In fact, the development of bioenergy goes hand in hand with increased investment and higher productivity in agriculture and forestry. And because many of the by-products are protein-rich, it could actually improve the food supply.

I believe that by making agriculture and forestry more efficient, we could boost the production of biofuels worldwide without displacing food production. Policy-makers need to be made more familiar with the options available and introduce incentives, taxes and subsidies that encourage households and industries to switch to bioenergy and provide investment for the long-term development of advanced fuels.

PLANT POWER

Biomass comprises 76% of all renewable sources of energy[1]. The carbon it contains is captured by plants from the atmosphere through photosynthesis and released back into the atmosphere by decay or other processes of use. Biomass is therefore a carbon-neutral source of energy. By contrast, the carbon in fossil fuels stems from Earth's crust, so burning these fuels injects additional carbon into the atmosphere.

Every year, plants convert 4,500 exajoules of solar energy and 125 gigatonnes of carbon from the atmosphere into biomass — an equivalent of almost 300 million tonnes of oil per day. Most plant material is broken down by microorganisms within the natural carbon cycle, but hundreds of exajoules per year remain exploitable[3].

More than 80% of the biomass used for energy comes from forests, in the form of logs, wood chips, wood pellets, sawdust, bark and other by-products. Just one-third of the world's 4 billion hectares of forest is used for wood production or other commercial purposes[4]. And those that are managed have room to grow more feedstock than they currently do. In Sweden and Austria, for example, sustainable forests generate 4–8 cubic metres of wood per hectare per year. Simply improving forestry practices, as has been achieved in parts of Europe, and increasing the forest area by 200 million hectares could deliver an extra 25 exajoules of energy per year.

> *"Biofuels hold the potential to deliver at least one-quarter of the world's energy needs."*

Similarly, better use of low-yielding grasslands, sparse woodlands and degraded land could deliver more biofuels without encroaching on food production. Of the 13 billion hectares of land worldwide, 12% is used for crops and 30% for livestock[5]. But a further 893 million hectares could accommodate rain-fed agriculture and new forests[5]. Planting 170 million hectares of this with energy crops could deliver 15 exajoules, and still leave space for feeding rising populations, urban development and biodiversity protection, and new forests[5].

Admittedly, livestock production on the remaining land would have to be intensified and meat consumption limited.

In regions without bioenergy programmes, waste and most agricultural and forestry residues such as straw and bark are dumped in landfills, burned or left to rot, amounting to a loss of at least 60 exajoules.

THREE SECTORS

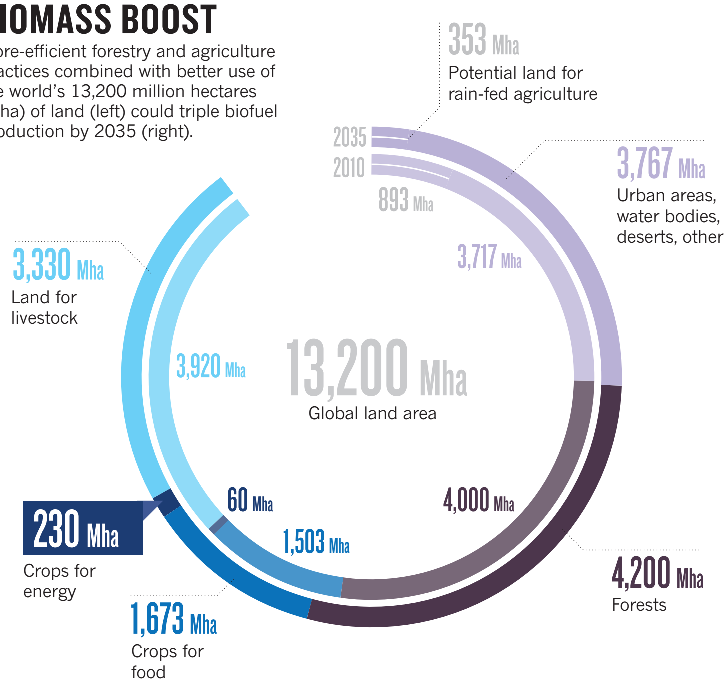
Because fossil fuels are used in the production of biomass — in planting, fertilizing, harvesting, transport and processing, the net emissions savings vary hugely depending on the method of production and on what the fuel is used to produce.

Heat — for cooking, hot water, space heating and industry — is the largest destination for biofuels, and it generates the highest net savings — of more than 95% in many cases, according to several bioenergy associations. Almost half of the world's population is thought to fuel stoves and boilers using firewood or charcoal, often from unsustainable forests[3]. Traditional charcoal production and stoves are inefficient, and their emissions are terrible for air quality and health. I believe that more-efficient stoves, such as those that use ethanol or wood pellets, would save up to 10 exajoules per year.

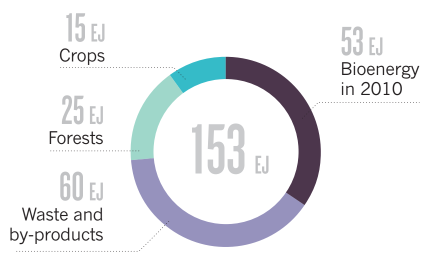
Wood-pellet stoves and boilers are well suited to suburban households because pellets are energy-dense and compact to store. Farms or companies with more storage space prefer wood chips, which are bulkier but cheaper. Wood powder injected into adapted oil burners has helped several Scandinavian companies to escape rising oil prices.

BIOMASS BOOST

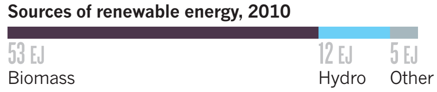
More-efficient forestry and agriculture practices combined with better use of the world's 13,200 million hectares (Mha) of land (left) could triple biofuel production by 2035 (right).



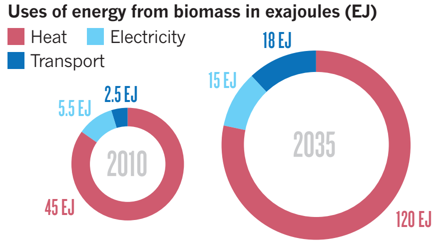
Extra sources of biomass for energy, targets for 2035



Sources of renewable energy, 2010



Uses of energy from biomass in exajoules (EJ)



MONTY RAKUSEN/CULTURA/CORBIS

In the Northern Hemisphere, fossil fuels still dominate the heat market, even though biomass is half the price of oil. But several countries are setting a good example. Thirty years ago, Sweden levied environmental taxes on fossil fuels, which made production of heat from biomass cheaper. Now, less than 5% of the nation's residential heat comes from coal or oil. Furthermore, the nation uses district heating to serve its densely populated downtown areas. In this system, a grid distributes hot water from a central heating source, such as a combined heat and power (CHP) plant, which burns biomass to produce electricity and feeds waste heat into the grid. CHP systems can be twice as efficient as those that produce electricity alone. Denmark and Finland also use district heating.

Italy has a booming wood-pellet market, which serves more than 15% of the nation's apartments. In Austria, government grants that cover 30% of the investment cost have encouraged companies and home owners to install biomass heating systems that burn wood chips or pellets, so that biomass fuels one-third of the heating market.

For electricity production, biofuels supply around 2% of the world's needs[6]. Germany uses biogas from energy crops, manure and waste to deliver about 2% of its electricity. CHP plants are the most efficient option.

Green transport is dominated by first-generation fuels such as ethanol and biodiesel, which are derived from corn, canola, soya beans, oil palm or sugarcane. Production has grown rapidly in the past decade, reaching 86 billion litres of ethanol and 20 billion litres of biodiesel in 2010. The grain and canola planted for biofuels delivered 64 million tonnes of protein feed worldwide — equivalent to 22 million hectares of soya beans. Globally, 1% of the agricultural land was used to produce the feedstock for these fuels and to yield 20% of the world's protein supply. I believe that government support for agriculture and cultivation of these fuels only on disused land could lead to greater yields without harming the food supply.

Another option for the transport sector is advanced biofuels, which are derived from cellulose or hemi-cellulose materials such as straw, wood residues or municipal refuse, or using algae. These are currently expensive, complex to produce and only just entering the commercial phase in small quantities in pilot or demonstration plants. The costs of feedstock and the logistics involved — such as collection, transport and storage — are often underestimated and the production costs are higher than those of fossil fuels. Advanced biofuel production will grow rapidly only with government support.

In sum, by 2035, biomass could deliver 120 exajoules (50% of the world's needs) for heat, 15 exajoules for transport and 18 exajoules (7%) for electricity. Altogether that is one-quarter of the global energy needs — assuming that the growth in energy consumption slows down with the improved efficiency.

Elephant grass and straw can be used to fire power stations.

NEXT STEPS

The top priority should be heating: improving efficiency in developing countries and using biomass and district heating, rather than fossil fuels and electricity, in developed countries. Governments must tax fossil fuels, provide investment grants and support the construction of district heating grids.

Generating electricity from biomass — particularly biogas — would compensate for the intermittence of wind and solar electricity in renewable energy schemes. Because the cost of electricity from biomass is above market price, the best solution is a system of guaranteed sale prices for producers, financed by all consumers, as implemented in Germany more than 15 years ago.

For transportation, we should aim for a modest growth of first-generation biofuels, to 5–7 exajoules by 2035. Successful incentives to promote these fuels include tax exemptions or mandating a minimum share of biofuels, as is done in the European Union. For advanced biofuels, targeted subsidies would compensate for the higher production costs and encourage commercial-scale production.

Fossil fuels receive more than US$500 billion in subsidies worldwide every year and are well established on all markets. Without targeted, long-term government policies, bioenergy will develop too slowly to help in the mitigation of climate change. Rural development based on sustainable agriculture and forestry will have to become an economic policy priority for governments and international organizations.

So that decision-makers can choose the best bioenergy strategies for their countries, I call on international organizations such as the Food and Agriculture Organization of the United Nations and the International Renewable Energy Agency to work with the World Bioenergy Association, of which I am president, to catalogue case studies of successful bioenergy policies. By building on the experience of others, countries can accelerate the transition to more-sustainable systems. ■

Heinz Kopetz *is president of the World Bioenergy Association in Stockholm, Sweden.*
e-mail: hg.kopetz@netway.at

1. International Energy Agency. *Key World Energy Statistics 2012* (2012).
2. International Energy Agency. *World Energy Oulook 2011* (2011).
3. World Bioenergy Association. *WBO Position Paper on Global Potential of Sustainable Biomass for Energy* (WBA, 2009).
4. Food and Agriculture Organization of the United Nations. *Global Forest Resources Assessment 2010* (FAO, 2010).
5. WWF, ECOFYS, Office for Metropolitan Architecture. *The Energy Report: 100% Renewable Energy by 2050* (2011).
6. REN 21. *Renewables 2012: Global Status Report* (2012).