The Use of Biomass for Energy in Sweden

- Critical Factors and Lessons Learned

Bengt Johansson, Pål Börjesson, Karin Ericsson, Lars J Nilsson and Per Svenningsson

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The Use of Biomass for Energy in Sweden – Critical Factors and Lessons Learned

**Abstract**

In this report the development of Swedish biomass use during recent decades is discussed. The relations between biomass supply, biomass demand and various policy initiatives are explored. The objectives are to discuss the most important factors affecting the biomass development and to establish which factors are specific for Swedish conditions and also to identify general factors that are relevant in assessing the possibility of expanding biomass use in different contexts. The focus is on the use of biomass for heat and electricity production.

Biomass contributed 14% to the Swedish energy supply in 1999. The major fraction of Swedish biomass is used within the forest industry (63%) and in district heating systems (23%). The remaining fraction is used in small-scale boilers in one- and two family dwellings. Between 1990 and 1999 Swedish bioenergy use (including waste and peat) increased by 44%. During the same period there has been a fourfold increase in the district heating systems. By-products from forestry and the Swedish forest industry dominate the supply of biomass in Sweden, but the importation of biomass increased significantly during the 1990s.

A number of factors of various kinds have interacted to bring about the increased use of biomass in Sweden during the past twenty years. These factors can be divided into three categories: structure, policies and actors. The existence of a major forest industry and well-developed district heating systems has enabled a rapid response to strong and standing policy commitments to biomass. The reformation of the taxation system, with the introduction of a high carbon tax on fossil fuels, has led to significantly improved competitiveness for biomass when used for heating purposes.

**Keywords**

Biomass, biofuels, wood fuels, Swedish energy policy, market, forest industry, energy tax, district heating, energy crop

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Foreword

This report was prepared within the project "Sustainable Energy in Poland: The Role of Bioenergy". It was written with the intention of analysing the biomass use in Sweden, one of the few industrial countries where biomass plays a significant role in the energy system. We believe that the experience and lessons learned from Sweden presented here can be useful for energy policy and decision making in other countries, such as Poland, after some further evaluation, and adjustment to national conditions and objectives.

We gratefully acknowledge the financial support of the Swedish National Energy Administration and Vattenfall AB.
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1. Introduction

During the past twenty years Swedish energy policy has been characterised by conflict between reducing oil dependence, phasing out nuclear power and the aim to reducing emissions of greenhouse gases and other pollutants. Another important objective of the Swedish energy policy is to provide industry with low-cost electricity.

Biomass can play an important role in solving the conflict between the different goals of Swedish energy and environmental policies. Accordingly, biomass has attracted significant attention in Swedish energy policy during recent decades. During this period the use of biomass has also increased significantly and currently provides 14% of the Swedish energy supply (Swedish National Energy Administration, 2000a).

In this report the development of Swedish biomass use during the past decades is discussed. The interactions between biomass supply, biomass demand and various policy initiatives are explored. The objectives are to discuss the most important factors affecting the biomass development and to establish which factors are specific for Swedish conditions and also to identify general factors that are relevant in assessing the possibility of expanding biomass use in different contexts. The focus is on the use of biomass for heat and electricity production.
2. Biomass in the Swedish Energy system – a Brief Overview

The dominating form of fuel in Sweden is oil, about 50% of which is used in the transportation sector (Figure 2.1). Electricity is supplied in two approximately equal parts by nuclear and hydro power while other thermal production contributes relatively little to the Swedish electricity supply. Biomass currently contributes 15% to the Swedish energy supply (Figure 2.1). Waste and peat also play a role in the Swedish energy system, especially in district heating systems. District heating provides approximately 45% of the heat used for building heating (industry excluded). Compared with other OECD countries, Sweden has a rather high electricity intensity (17 MWh/capita), while the net carbon emission intensity is relatively low (approximately 6 tonne CO$_2$/capita.y). The reason for the high electric intensity is the existence of energy-intensive industries and the widespread use of electric heating in a relatively cold climate. The almost total absence of fossil fuels in electricity production partly explains the low carbon intensity of the Swedish energy system.

Figure 2.1. Total Swedish primary energy supply in 2000 (Swedish National Energy Administration, 2001a). On the left nuclear power is expressed as the electricity produced and on the right in accordance with the international standard procedure in which the energy conversion losses in the nuclear power plant are also included.

The major fraction of Swedish biomass is used within the forest industry (67%) and district heating systems (21%), Figure 2.2. The remaining fraction is used in small-scale boilers in one- and two family dwellings. Between 1990 and 1999 Swedish use of bioenergy (including municipal waste and peat) increased by 44%, see Figure 2.3. In district heating systems there has been a fourfold increase during the same period (Swedish National Energy Administration, 2000a). In industry the increase in biomass use has been less manifest, with an increase by 20% between 1990 and 1999. Today, biomass constitutes 35% of the total energy use in industry and approximately 55% of the total fuel use.

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1 We find it useful to express the energy content of fuels, electricity and heat in a common unit. In this report we use TWh, commonly used in Swedish statistics, as our basic energy unit.

2 We use the term biomass in a broad sense including wood fuels, industrial by-products, wood waste and agricultural products. We do not, however, include municipal refuse or peat.
Industrial residues dominate the biomass supply but logging residues, imported biomass and domestic fuel wood also contribute significantly to the biomass supply (Table 2.1).

Figure 2.2. Total Swedish biomass use in 2000 (Swedish National Energy Administration, 2001).

Figure 2.3. Development of Swedish bioenergy use (including waste and peat) between 1980 and 2000 (Swedish National Energy Administration, 2001).
Table 2.1. Swedish biomass supply in 2000. Our own estimate based largely on Swedish National Energy Administration (2001).

<table>
<thead>
<tr>
<th>Source</th>
<th>Biomass supply TWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logging residues</td>
<td>7</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>10.5</td>
</tr>
<tr>
<td>Industrial residues</td>
<td>65</td>
</tr>
<tr>
<td>Imported biomass</td>
<td>6</td>
</tr>
<tr>
<td>Agriculture</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>89</strong></td>
</tr>
</tbody>
</table>

There is a correlation between the availability of industrial and logging residues, and the production of sawmill products and paper and pulp. An increase in the demand for forest products may increase the amount of residue suitable for energy utilisation. On the other hand, only a fraction of the potentially available logging residues is currently used for energy purposes (approximately 7 TWh/y or 10-20% of the future potential, see Gustavsson et al. (1995)). Although a fraction of the residues should be left in the forests for environmental reasons, increased utilisation appears to be feasible.

Most biomass has hitherto been used for heating purposes, due to reasons of technology, taxation and the structure of the Swedish energy system. Biomass-based boilers constitute a well-developed technology, whereas technologies for utilising wood fuels to produce transportation fuels are not yet available on a commercial scale. The taxation system has, furthermore, encouraged the substitution of fossil fuels for heating purposes, while the lack of energy and carbon taxes on fossil fuels used for electricity production has discouraged biomass-based electricity production. A more important obstacle to the use of biomass for electricity production is, however, the availability of low-cost fossil-free hydro and nuclear power which together produce most of the electricity required in Sweden. Although the electricity demand at the end of the 1990s exceeded the domestic supply, the production capacity in the integrated grid in the Nordic countries was able to provide the extra electricity required.

Regardless of the historical reasons for using biomass for heating, studies (e.g. Gustavsson et al., 1995 and Ekström et al., 2001) have shown that replacing fossil fuels with biomass in the heating sector is more resource- and cost-efficient than replacing fossil fuels in electricity production. The use of biomass-based fuels for transportation fuel production is even less efficient.
3. Biomass and Swedish Energy Policy

3.1 General Swedish energy policy and its consequences for biomass
At the beginning of the 1970s the Swedish energy supply was totally dominated by oil, accounting for 80% of the total supply, being used widely also for domestic heating purposes. As a result of the oil crises during the 1970s, a reduction in oil became an important aim in line with the on-going development of nuclear power. This resulted, amongst other things in efforts to increase energy efficiency in buildings and, in an international perspective, a considerable expansion of electric heating.

From the middle of the 1970s the political resistance to nuclear power increased and the Three Mile Island accident triggered a Swedish referendum on nuclear power. The Swedish Parliament subsequently decided that nuclear power should be phased out by 2010. Nuclear power production has, however, increased, even after the referendum, and reached its highest level, 73.5 TWh/y, in 1991. Although no final date for the phase-out is now set, the closure of nuclear power plants commenced in 1999 when the first of Sweden’s twelve reactors was closed. During the 1990s the greenhouse effect became a major issue in Swedish energy policy and the intrinsic conflict between nuclear shut-down and CO$_2$ reduction formed the agenda of Swedish energy policy.

A factor that complicates Swedish energy policy is the country’s large energy-intensive industries, which are responsible for a major fraction of the value added in Swedish industry. These industries also have strong lobby groups. The availability of low-cost energy for these industries has played an important role in Swedish policy making through both its impact on the pace of the nuclear shut-down and the design of the energy taxation system. Another factor which, especially during the 1970s and 1980s, played an important role in energy policy, was the desire to expand domestically available energy sources.

A result of the expansion of nuclear power at the end of the 1970s and the beginning of the 1980s was a rapid increase in domestic electric heating. Electric heating has the advantage of low investments in the heating system in the building and high local energy efficiency. In the future development of the energy supply system, with the phasing out of nuclear power and reduction in greenhouse gases, this method of heating may prove to be a problem as the replacement of nuclear power with conventional thermal power plants would either result in high emissions of greenhouse gases or significant demand for renewable energy sources.

3.2 Energy and environmental taxation – a central policy instrument

Energy taxes have a long history in Sweden. High taxes on oil products were introduced already in the 1970s as one means of achieving the main objective of the energy policy at that time, namely oil substitution. During the 1980s this led to significant reductions in oil consumption while the use of biomass, coal and electricity was increased (Swedish National Energy Administration, 2000a). As part of a major tax reform at the beginning of the 1990s significant changes were introduced in the taxation of energy. A carbon tax (0.25 SEK/kg CO$_2$) was introduced while the energy tax was simultaneously reduced by 50%.

The energy tax reform was part of a wider tax reform intended to make taxation on different areas such as income, capital and energy more congruent. As a consequence of this value added tax was levied on energy. The competitiveness of biomass in relation to especially coal was significantly improved as a result of these changes in energy taxation. The competitiveness of fossil fuels with low carbon content was also improved.

To maintain the competitiveness of Swedish industry the energy tax was lifted for this sector on January 1", 1993, while the carbon tax on fuels used in industry was simultaneously reduced to 25% of

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1 10 SEK ≈ 1 USD.
the general level. At the same time, the general carbon tax was increased to 0.32 SEK/kg CO₂. For energy-intensive industries special rules apply that allow further reductions in the carbon tax. The 1991 and 1993 tax reforms together led to reduced tax levels for industry, amounting to reductions of over 50% for some fuels (Energidata et al., 1995).

The tax on CO₂ subsequently increased following several decisions until it reached a level of 0.36-0.37 SEK/kg CO₂ where it remained constant between 1996 and 2001. The CO₂ tax on industry was increased to 50% of the general level on July 1st, 1997. The increases in 1996 and 1997 were partly motivated by a need to cover the cost of membership in the European Union (Government Bill 1994:95/203). In 2001 the general CO₂ tax was increased from 0.37 to 0.53 SEK/kg CO₂, while energy taxes were reduced. No increase in the CO₂ tax in industry was proposed. The government stated that this was the beginning of a green tax reform in which taxes on energy would be increased while other taxes were reduced. This tax proposal was expected to result in an increase in energy and environmental taxes of approximately SEK 3,000 million. The total energy taxes contribute approximately SEK 50,000 million, equal to 7% of the state tax revenues (Ministry of Finance, 2000). In the autumn of 2002 an increase in the general carbon tax corresponding to inflation was decided.

No energy or carbon taxes are levied on fuels used for electricity production. There are, however, taxes on the heat produced in cogeneration plants but the taxation of this fraction has changed several times during the past decade. At the moment, full carbon tax but only 50% of the energy tax are levied on fossil fuels used for heat production in cogeneration plants in district heating systems. The Swedish government has in 2002 proposed further reductions of the taxes on fossil fuels used in cogeneration plants (Government Bill 2001/2002:143). There is no energy tax on biomass or peat.

Apart from the energy taxes on fuels there are environmental taxes and charges on sulphur and nitrogen oxide emissions as well as taxation on nuclear power capacity. Finally, there is a tax on the consumption of electricity. The taxes applicable in Sweden in 2002 are summarised in Table 3.1.

In Table 3.2 the revenues from energy taxes during the past decade are summarised. The taxes as a fraction of Sweden’s GDP remained quite stable during the 1990s, at around 2.5%, while the fraction of the state revenues has fluctuated more significantly. The fraction of the state revenue was higher during the economic recession when income tax fell drastically, whereas the energy and environmental taxes remained stable.

The taxation system explains much of the increase in biomass use in Sweden during the 1990s. The cost of producing heat using different fuels in the late 1990s is shown in Figure 3.1. In district heating systems biomass-based heat can be produced at a much lower cost than heat produced from fossil fuels. In industry, however, heat produced from oil is less costly than heat produced from biomass.

The dependence of energy prices on the choice of fuel in district heating systems can be seen in Figures 3.2 and 3.3. Oil was the dominating fuel until 1980. In 1983 oil prices, in real terms, had increased to a level 3.6 times higher than in 1970 and oil was replaced by coal, electric boilers and heat pumps rather rapidly (electricity prices increased by only 30% during the same period in real terms). In 1991, the tax reform led to coal prices that were more than double the previous level and coal was replaced by biomass, which was both free from taxation and showed price reductions thanks to technology development and market pressure (Figure 3.4). In 1999, biomass, peat and municipal waste contributed more than 50% to the total district heating supply.
Table 3.1. Summary of the energy-related taxes in Sweden in 2002.

<table>
<thead>
<tr>
<th>Type of tax</th>
<th>Tax level</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy tax</td>
<td>Varies for fossil fuels for stationary applications between, 10 and 70 SEK/MWh. The energy tax for petrol and diesel is significantly higher. No tax on fuels used in industry or for power generation.</td>
<td></td>
</tr>
<tr>
<td>Carbon tax</td>
<td>General level: 0.63 SEK/kg CO\textsubscript{2} (USD 230/tonne C). Equals to 140-210 SEK/MWh. No tax is applied for power generation and the level for industry corresponds to 0.18 SEK/kg CO\textsubscript{2}. For energy intensive industries there are special tax reductions rules.</td>
<td></td>
</tr>
<tr>
<td>Sulphur tax</td>
<td>30 SEK/kg (USD 3/kg S) Applied to heavy fuel oils, coal and peat. If sulphur is removed from the exhaust gases tax may be partially refunded.</td>
<td></td>
</tr>
<tr>
<td>Nitrogen oxide charge</td>
<td>40 SEK/kg NO\textsubscript{2} (USD 4/kg) Applied to heat and power plants that use more than 25 GWh fuel/year. The charge is refunded to each production unit in proportion to its production of useful energy (heat and electricity).</td>
<td></td>
</tr>
<tr>
<td>Tax on nuclear electricity</td>
<td>Equivalent to 0.027 SEK/kWh (USD 0.003/ kWh) No tax on electricity used in the industrial sector</td>
<td></td>
</tr>
<tr>
<td>Electricity consumption tax</td>
<td>0.12-0.18 SEK/kWh (USD 0.011-0.016/ kWh) No tax on electricity used in the industrial sector</td>
<td></td>
</tr>
<tr>
<td>Value added tax</td>
<td>25% Applied to all energy consumed</td>
<td></td>
</tr>
</tbody>
</table>

9 The lower level is applicable in northern Sweden and the higher in the rest of the country.

Table 3.2. Revenues from energy and environmental taxes during the 1990s (million SEK). VAT is not included in the table but is levied on the total energy costs including taxes for private consumers (Ministry of Finance, 2000; Statistics Sweden, 2000a).

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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol tax</td>
<td>17169</td>
<td>14538</td>
<td>14344</td>
<td>17544</td>
<td>22030</td>
<td>-52</td>
<td>-52</td>
<td>-52</td>
<td>-52</td>
<td>-52</td>
</tr>
<tr>
<td>Total tax on energy products</td>
<td>15165</td>
<td>18945</td>
<td>18930</td>
<td>18706</td>
<td>17399</td>
<td>38680</td>
<td>45636</td>
<td>46945</td>
<td>49811</td>
<td>50488</td>
</tr>
<tr>
<td>Energy tax</td>
<td>15165</td>
<td>10489</td>
<td>9546</td>
<td>7875</td>
<td>10239</td>
<td>27546</td>
<td>30371</td>
<td>34212</td>
<td>36900</td>
<td>37573</td>
</tr>
<tr>
<td>Carbon tax</td>
<td></td>
<td>8157</td>
<td>9194</td>
<td>10641</td>
<td>6943</td>
<td>11078</td>
<td>15053</td>
<td>12599</td>
<td>12796</td>
<td>12811</td>
</tr>
<tr>
<td>Sulphur tax</td>
<td></td>
<td>299</td>
<td>190</td>
<td>190</td>
<td>217</td>
<td>146</td>
<td>212</td>
<td>134</td>
<td>115</td>
<td>104</td>
</tr>
<tr>
<td>Tax on nuclear power</td>
<td>130</td>
<td>139</td>
<td>117</td>
<td>116</td>
<td>137</td>
<td>133</td>
<td>974</td>
<td>1478</td>
<td>1537</td>
<td>1553</td>
</tr>
<tr>
<td>Tax on hydro power</td>
<td>1018</td>
<td>896</td>
<td>1030</td>
<td>1026</td>
<td>817</td>
<td>908</td>
<td>1423</td>
<td>194</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Special tax to combat acidification</td>
<td>57</td>
<td>73</td>
<td>63</td>
<td>58</td>
<td>63</td>
<td>69</td>
<td>64</td>
<td>58</td>
<td>58</td>
<td>65</td>
</tr>
<tr>
<td>Environmental tax on domestic air transport</td>
<td>27</td>
<td>156</td>
<td>168</td>
<td>190</td>
<td>271</td>
<td>177</td>
<td>128</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sum of energy and environmental taxes 33566 34747 34652 37650 40717 41678 48223 48675 51406 52106

% of GDP 2.5 2.4 2.4 2.6 2.7 2.5 2.7 2.7 2.7 2.6
% of state income 8.3 8.6 8.7 9.9 10.8 9.8 8.0 7.5 7.3 7.2

a. In 1996 the petrol tax was transformed into an energy tax.
b. The tax on hydro power was removed in 1997 and replaced by a real-estate tax which is not included as an energy or environmental tax in this table.
Figure 3.1. Heat production costs for new plants (Swedish National Energy Administration, 2000b). The calculations are based on taxes applicable in 1999, levels which have been decisive in the development of biomass use. Since 1999 the carbon tax on fuels for district heating has increased by 75%, while taxes on fuels used in industry have not changed.

Figure 3.2. Relative prices of oil, coal and biomass from 1983 to 1999. Relative prices are average prices, measured in SEK/MWh, for heat consumers who pay full energy and environmental taxes (Swedish National Energy Administration, 2000a).
The tax advantage for biomass use in small-scale boilers is similar to that in district heating plants but has not been great enough to induce a major conversion to biomass. The need for decentralised distribution and, for practical and environmental reasons, more costly, refined fuels, together with sometimes relatively high cost of conversion from fossil fuel or electric heating, have all acted as obstacles for the increase in biomass use in small-scale heating.
3.3 Investment grants for electricity production

Investment grants for plants producing electricity from biomass were available during the 1990s. The investment grant introduced in 1991 was 4,000 SEK/kW, and resulted in the construction of 16 new biomass-based plants. Twelve of them were cogeneration plants in district heating systems and four cogeneration plants in industry (Ministry of Trade and Industry, 2000). In the 1997 energy programme these investment grants were reduced to 3,000 SEK/kW, or a maximum of 25% of the investment cost. This investment grant corresponded to a subsidy of approximately 0.08-0.10 SEK/kWh (0.008-0.01 USD/kWh) and has been awarded to another nine cogeneration plants (Ministry of Trade and Industry, 2000). The electricity production based on biomass in 2000 was 3.6 TWh (Swedish National Energy Administration, 2001b). The estimated future production in the nine plants awarded grants according to the 1997 programme is approximately 0.8 TWh/y. These levels can be compared with the total Swedish electricity production in 1999, which was 150 TWh.

Even with the investment grants, biomass-based cogeneration has not become economically competitive in a market with low electricity prices (Ministry of Finance, 2000). Nevertheless, several new plants have been built in district heating systems. The reasons for this may include a strong local political commitment to renewable energy, the expectation of increasing electricity prices in the future, and the possibility of transferring the cost to heat consumers through higher district heating prices. Swedish district heating systems still belong to a monopoly and it is difficult for consumers to change to other heating systems in response to higher prices (Swedish National Energy Administration, 1999).

Economic support for biomass-based electricity production is under reform. In the spring of 2002 the Swedish Government proposed a change from investment grants to a system of green certificates, which is to be applied not only to biomass but also to wind, hydro and solar power (Government Bill 2001/2002:143). The system will be based on consumers being obligated to buy certificates to an amount equivalent to a certain fraction of their electricity consumption. The income of the producer of biomass-based electricity will be the sum of the electricity and the certificates sold.

3.4 Local investment programmes

In passing the 1998 Budget Bill (Government Bill 1997/98:1) Parliament approved the allocation of funds to local investment programmes (LIP) for the implementation of ecological sustainability. Altogether, SEK 7.2 billion were set aside for grants for the period 1998-2003 (Swedish Government, 2002). Until December 31, 2001, municipalities, either alone or in cooperation with private companies, were able to apply for these investment grants, which are allocated by the Ministry of Environment. The selected projects received up to 30% of the total investment cost. In June 2001, 165 programmes had been granted SEK 5.6 billion, where conversion to renewable energy sources accounted for SEK 1.2 billion (Hanberger et al., 2002). In this category most of the funds were granted to biofuel-based district heating plants and associated expansion of these systems. According to a study carried out a firm of consultants in 2000, the investments made possible by these grants increased the energy from biomass used in single-family houses and industries by 360 GWh per year, and expanded annual district heating by 2,140 GWh per year (Robertsson and Bejgrowicz, 2000).

Table 3.3. The number of renewable energy source (RES) projects and funds received (SEK million) in the period 1998-2000. The total number of projects and allocated funds are also given (Robertsson and Bejgrowicz, 2000).

<table>
<thead>
<tr>
<th></th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>In total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of projects</td>
<td>Million SEK</td>
<td>Million SEK</td>
<td>Million SEK</td>
<td>Million SEK</td>
</tr>
<tr>
<td>Conversion to RES</td>
<td>83</td>
<td>247</td>
<td>89</td>
<td>505</td>
</tr>
<tr>
<td>Total for all categories</td>
<td>2300</td>
<td>1400</td>
<td>1500</td>
<td>5200</td>
</tr>
</tbody>
</table>
During 2002 the local investment programmes are to be replaced by a climate investment programme (KLIMP). SEK 500 million will be transferred from LIP to the new programme, which will have a total budget of SEK 900 million and run from 2002 to 2004. As of 2002 the Swedish Environmental Protection Agency will be in charge of both investment programmes, taking over from the Ministry of the Environment.

Since the local investment programmes are still running although the application period has run out, no final evaluation has been made yet. The results of the funding are therefore somewhat uncertain. The most important question may be whether the grants influenced the decision to make these investments in renewable energy or not. Another issue is that this kind of investment support does not generally benefit new technology. Also, subsidies may bring the unwanted effect of distorted competition.

3.5. Swedish energy and bioenergy RD&D since 1975

Government-funded energy RD&D in Sweden experienced its real start through the first three-year Energy Research Programme, which was launched in 1975. Government-funded energy R&D, was in place long before 1975, but it was after the oil crisis of 1973 that the government decided on an energy research programme, with substantial funding, including bioenergy R&D and other areas relevant to the long-term goal of reducing Sweden’s dependence on oil (Haegermark, 2001). Sweden has since then, through these Energy Research Programmes, consistently supported bioenergy R&D.

3.5.1 The different phases in energy R&D

Driving forces and priorities have changed over time as concerns over oil dependence, nuclear power, acidification and climate change have developed. The character and focus of the Energy Research Programme has also shifted over time (IVA, 1992; Haegermark 2001). The first period was characterised by a broad survey and screening of essentially all energy alternatives (1975-1978). Then followed a period when R&D was focused on commercialisation of technologies and short-term solutions, mainly aimed at reducing oil dependence (1978-1985). After a short transition period (1985-1988), energy research became more long-term and academically based. Various funds for technology demonstrations have also been available throughout the period since 1975, in addition to R&D support through the Energy Research Programmes.

3.5.2 Level of energy and bioenergy RD&D spending

Annual average government spending on energy RD&D since 1975 has been SEK 936 million (2000 prices), of which 11%, on average, has been spent on bioenergy RD&D (see Figure 3.5). Based on earlier assessments (Elforsk, 1995) we estimate that the energy industry has spent roughly two thirds the amount spent by government on energy RD&D since 1975. In the area of bioenergy this includes considerable efforts by the major Swedish utilities Vattenfall and Sydkraft in the late 1980s and 1990s in electricity production technology, not least in the area of biomass gasification. The forestry industry has also contributed substantially to energy and bioenergy RD&D spending in Sweden, but no quantitative estimates are available.

Government bioenergy RD&D spending (Figure 3.5) increased rapidly in the late 1970s, peaked in the early 1980s, after which it decreased and levelled out at its current level in the early 1990s. An international comparison using 1993 data shows that Sweden spent a relatively high amount on biomass energy RD&D per capita compared with other IEA countries; roughly 1 ECU, 1993 per capita

4 Research, Development and Demonstrations. It is often difficult to make a clear distinction between funding for Research & Development and funding for Demonstrations. In this section, R&D is sometimes used to distinguish the government-funded R&D-focused Swedish Energy Research Programme from RD&D in general. It may also be difficult to make a clear distinction between funding for demonstrations, and investment grants or other subsidies which may have technology development or demonstration effects.
in Sweden, Denmark and Finland, whereas the spending of the EU+EU15 member countries was less than 0.2 ECU\textsubscript{1993} per capita (Blok et al., 1996). However, spending in relation to forest and agricultural land area in Sweden was about 0.25 ECU\textsubscript{1993} per hectare, which is about the same as the average of the EU+EU15 member countries.

![Figure 3.5](image-url)

**Figure 3.5.** Annual spending on biomass RD&D (IEA statistics) and bioenergy R&D (authors’ estimates, data are lacking for the years 1993-1996) in Sweden from 1975 to 2000. The IEA energy RD&D statistics were extracted from IEA (2002) and include some demonstration projects. The authors’ estimates concern the bioenergy R&D component of the Swedish Energy Research Programmes and are based on numerous publications by the Swedish Government and relevant government bodies (e.g., The Energy Research and Development Commission (DFE); The Energy Research Commission (EFN); The National Swedish Board for Energy Source Development (NE); The National Energy Board (STEV); The National Swedish Board for Industrial and Technology Development (NUTEK); and the Swedish National Energy Administration (STEM)).

### 3.5.3 Trends in bioenergy RD&D

Bioenergy RD&D priorities have changed over time partly as a result of changing perceptions and general energy policy priorities, and as RD&D areas mature. For example, bioenergy was generally not viewed as a viable source of energy in the early 1970s, mainly due to resource constraints and competing uses in the forestry industry (Official Report of the Swedish Government, 1992). Consequently, it did not receive much attention in the first Energy Research Programme, 1975-1978. However, interest soon grew and the possibility of using forestry residues and short-rotation forestry was increasingly recognised.

The period following the oil price increases in 1979/80 has the highest level of RD&D support for bioenergy, reflecting the priority given to indigenous resources and reduced import dependence. Key RD&D areas in the 1980s include forest fuels and peat, integrated harvesting of fuels with timber and pulpwood, recirculation of ash, short-rotation forestry or energy crops (Salix and reed canary grass), fuel refinement (chips, pellets, briquettes), and conversion technology (combustion, gasification, ethanol production). These RD&D efforts were largely aimed at accelerating the introduction of
biomass and reducing dependence on oil. In R&D in the area of combustion and gasification of fuels, the biomass share of R&D increased throughout the whole period, reflecting the growing awareness of environmental problems associated with peat and coal. Following the 1988 decision to phase out two nuclear reactors in 1995-1996, new electricity generation technologies became a high priority.

In addition to government-funded R&D, the energy companies Sydkraft and Vattenfall devoted considerable efforts to developing biomass gasification technology capable of high electricity-to-heat ratios. For example, Vattenfall spent approximately SEK 200 million in its bioenergy project in 1990-1993, approximately half of which was used in gasification research, and had advanced plans for a 30-40 MWt demonstration plant for cogeneration in a combined cycle. Sydkraft built their Biomass Integrated Gasification Combined Cycle (BIGCC) demonstration plant (6 MWe and 9 MWth) called Bioflow together with Ahlstrom (now Foster-Wheeler) and started testing in 1993 (Sydkraft, 2001). Vattenfall’s plans for a BIGCC plant were cancelled as electricity market deregulation plans were drawn up and the nuclear phase-out decision was revoked in the first half of the 1990s. The energy companies, together with some forestry companies, now turned their attention towards research into environmental aspects of bioenergy and proprietary R&D into commercial aspects of bioenergy.

The focus of government R&D also changed during the 1990s. Our study of government publications and related material suggests that interest increased in areas of environmental importance (including ash recycling), small-scale combustion, system-oriented studies, energy from waste, and, more recently, forest carbon balances. During the same period there was a decrease in interest in R&D concerning forest fuels and harvesting, short-rotation forestry, fuel refinement and, most recently, also in environmental aspects of logging residue harvesting. This reflects the perception that knowledge in these areas is well developed and that there is not much to gain from additional R&D efforts. Some R&D areas, notably combustion/gasification and ethanol production, have continued to receive steady levels of government funding.

Currently important R&D programmes are presented in Table 3.4. It is worth noting that most of the programmes are very applied in nature. For example, the overall objective of the project "Biofuels from Agricultural Land" is to solve biological and technical problems associated with cultivation, and the dissemination of knowledge has high priority. For "Small-scale Combustion" the target is that products offering the same degree of convenience, reliability and performance as oil-fired boilers should be available on the market by the end of the programme. Thus, what has been conventional R&D in previous programmes, now encompasses product development and demonstrations aimed at influencing the market for furnaces and boilers. In contrast, the programme on ethanol production includes more fundamental research on converting ligno-cellulosic biomass.

Table 3.4. On-going or recent bioenergy R&D programmes funded by the National Energy Agency (Swedish National Energy Administration, 2002).

<table>
<thead>
<tr>
<th>Programme name</th>
<th>Period</th>
<th>Annual budget (million SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels from Agricultural land</td>
<td>2000-2004</td>
<td>12</td>
</tr>
<tr>
<td>Systems Studies, Bioenergy</td>
<td>1998-2000</td>
<td>7</td>
</tr>
<tr>
<td>Biofuels and the Environment</td>
<td>2000-2004</td>
<td>12</td>
</tr>
<tr>
<td>Combustion and Gasification of Solid Fuels for Cogeneration</td>
<td>2000-2004</td>
<td>15</td>
</tr>
<tr>
<td>Carbon Balances (in forests)</td>
<td>2000-2004</td>
<td>5</td>
</tr>
<tr>
<td>Energy from Waste (Biogas, Combustion, Systems Studies)</td>
<td>2000-2003</td>
<td>10</td>
</tr>
<tr>
<td>Small-scale Combustion</td>
<td>2000-2004</td>
<td>22</td>
</tr>
<tr>
<td>Ethanol Production from Forest Resources</td>
<td>1998-2004</td>
<td>30</td>
</tr>
<tr>
<td>Alternative Transport Fuels</td>
<td>2003-2005</td>
<td>16</td>
</tr>
</tbody>
</table>

5 Combustion and gasification has been an item in most of the Energy Research Programme budgets since 1975 but it is difficult to distinguish clearly how much is intended for biomass compared with other fuels, or generic technologies. However, it is clear that the focus on biomass is increasing at the expense of other fuels.
3.5.4 Have R&D efforts produced the desired results?

Have bioenergy R&D efforts in Sweden been successful? The answer is partly yes, if successful means that new technologies and practices have penetrated the market and bioenergy use has increased in accordance with overall energy policy goals. The increased extraction and use of forestry residues in environmentally and economically acceptable ways illustrates this point. In other cases, R&D may have been successful in that the specific objectives of the R&D programme have been met, although the programme may not have resulted in increased use of bioenergy. To determine whether R&D programme objectives have been met would require a systematic evaluation of programme results in relation to the original objectives. This is beyond the scope of this paper but some general observations can be made.

It may be argued that the relatively slow development of short-rotation forestry in Sweden is mainly due to other factors (such as relative fuel prices and disincentives to farmers resulting from agricultural subsidies) than lack of R&D, and that continued high levels of government R&D financing of short-rotation forestry would not yield much new knowledge. There is now a body of basic knowledge facilitating the production of energy crops in an environmentally acceptable manner (Swedish National Energy Administration, 2001c). This is also true for the extraction of forestry residues and recycling of ash.

Another important aspect is that the driving forces that motivated R&D may become weaker over time. R&D efforts into BIGCC are a case in point. Around 1990 it was a widely held belief in government, industry and academia that there was an urgent need for new power generating capacity due to the planned decommissioning of nuclear reactors and increase in electricity demand. However, the postponed closing of reactors and later the electricity market reform resulted in a strong downward trend in electricity prices. Electricity market competition also reduced the willingness of the power producers to subject themselves to technical and commercial risks associated with investing in biomass-gasification-based power generation.

Sweden has sustained bioenergy R&D efforts for about 25 years, covering various aspects of bioenergy from extraction to final energy. Overall, bioenergy R&D has been quite comprehensive with perhaps the notable exception that ethanol has been essentially the only fluid fuel considered.

It is our opinion that, on the whole, the implementation and increased use of biomass in Sweden at present does not appear to be hindered by considerable knowledge gaps or R&D needs (apart from specific technologies, such as those for transportation fuel production from ligno-cellulosic biomass). The main barriers are often found in other areas. In addition to poor economic returns these include barriers resulting from organisational and institutional factors, or from inconsistencies between energy policy and policy in other domains.

4. Key Sectors for the Development of a Swedish Biomass Market

4.1 Forestry and the forest industry

4.1.1 Forest resources

Practically all biomass used in Sweden originates from forests, which makes forestry and the forest industry key sectors of the Swedish biomass market. Forest is one of the most valuable natural resources in Sweden. According to the National Board of Forestry (2001), 22.7 Mha, or 55%, of the Swedish land area is covered by forests (subalpine, coniferous woodland excluded). In 1903 a law – the Forestry Act – was adopted to protect forest resources. Basically, the act made it compulsory to replant trees after felling, thereby introducing the concept of sustainable forestry. The law, however, was not set up out of environmental concern, but due to the economic interests of industries based on the supply of wood products. During the past decade or two, sustainable forestry has also come to incorporate concern for
forest ecosystems. In the 1995 Forestry Act the production and environmental goals have equal importance.

During the past 20 years forest increment has exceeded felling, resulting in an annual growth in standing volume\(^6\) of 20-30 Mm\(^3\) (Figures 4.1 and 4.2). The growth in the increment is mainly due to intensified silviculture, changes in the tree species planted, and fertilization by nitrogen oxides that reach the forest land by precipitation (P. O. Nilsson, 1999). Accordingly, in physical terms there is room for a future increase in biomass withdrawal. The Swedish annual net felling of 74 Mm\(^3\) standing volume (National Board of Forestry, 2001) can be categorised into industrial roundwood, logging residues and fuel wood.

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\(^6\) Increment and felling are often given in standing volume, which corresponds to stem volume over bark from stump to top (m\(^3\)sk). Volumes of industrial roundwood, wood chips and fuel wood are given in the unit solid volume excluding bark (m\(^3\)ub).
Swedish forests are owned to 49% by non-industrial private owners and to 40% by companies. The state owns only 3%, see Figure 4.3. The remaining 8% constitutes “other public forests” owned by the church, municipalities etc. Between 1906 and 1964 the Swedish pulp and paper industry was prohibited from acquiring forest land. During that time and most of the 20th century the industry owned about 25 percent of the forest area, a figure that rose in 1994 to 40 percent, when most of the state-owned forest was transferred to a state-owned company, which was subsequently partly privatised. The size of the state-owned and company-owned forest holdings are predominantly large, i.e. larger than 1000 ha, while most of the non-industrial private holdings are between 20 and 400 ha in size.

Non-industrial, private forest owners form a very heterogeneous group with respect to holding size, age of the owner and whether the property is the main source of income or not (Bergman and Nilsson, 1999). About one third (92,000) of these owners belong to forest owner associations.

These associations own sawmills and paper and pulp plants, and act in many ways similarly to the large forest-industry companies. The large industrial companies and forest owner associations have played important roles in the development of the biomass market in Sweden.

![Figure 4.3 The ownership structure of forest land. The figures in parentheses show the owner’s share of gross felling (National Board of Forestry, 2001).](image)

4.1.2 Forest industry

Historically, the forest industry has contributed greatly to the Swedish economy and in 1998 its value added corresponded to 12% of the total value added of the manufacturing industry in Sweden (National Board of Forestry, 2001). The share of wood and paper products in Sweden in 2000 was 5% of the GDP (Statistics Sweden, 2000b), which is only surpassed by Finland when comparing the OECD countries. Both Sweden and Finland are major producers and exporters of wood products.

Roughly 90% of the Swedish felled stem wood, including bark, is consumed by the forest industry as industrial round wood. The remaining 10% is fuel wood. About half of the industrial round wood is made up of sawlogs and the other half of pulpwood. Approximately 40% of the timber and pulpwood eventually become residues and are used for energy purposes. At the sawmills half of the input volume ends up as by-products: wood chips, bark and sawdust. Nearly all wood chips are sold as pulp wood. Sawdust is used in the wood material industry and as fuel. In Sweden, most of the sawdust that reaches the commercial biofuel market has been upgraded to pellets or briquettes.

Despite vast national resources, the forest industry also imports large quantities of roundwood, in 2000 approximately 11.7 million m³ ub. Most is imported from Russia and the Baltic states. Sweden, however, is a major exporter of forest products with high value added. One example is paper, of which 84% of the total production is exported. Market pulp and sawn wood are also exported. Figure 4.6 shows the figures for production, export and import in detail.

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7 The State’s small share is somewhat misleading. 37% of company forest land is owned by Sveaskog AB, which is a state-owned company.
4.1.3 Use of biomass in the forest industry

The forest industry accounts for about 54% of the total energy used in Swedish industry and is the largest user of biomass in Sweden. In chemical pulp mills most of the process steam is produced from black liquor, which in total amounted to 39.2 TWh in 2000 (Table 4.1). Besides serving as steam producers, the black liquor boilers are part of a recycling loop. The chemicals that are added to the boilers in order to extract the cellulose fibres from the pulp wood by dissolution of lignin, are retrieved from the ash. In chemical and mechanical pulp mills, as well as at sawmills, bark and sawdust are used as fuels, while logging residues are rarely used.

Table 4.1 Use of biomass (TWh) for energy purposes in the forest industry (National Board of Forestry, 2001).

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose industry, black liquor</td>
<td>26.0</td>
<td>27.6</td>
<td>39.2</td>
</tr>
<tr>
<td>Cellulose industry, other by-products*</td>
<td>4.6</td>
<td>8.2</td>
<td>6.9</td>
</tr>
<tr>
<td>Sawmill industry, by-products</td>
<td>4.8</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td>Biofuels for electricity production</td>
<td>0.7</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Total in Swedish forest industry</td>
<td>36.9</td>
<td>45.2</td>
<td>59</td>
</tr>
</tbody>
</table>

* Including 0.6 TWh of pitch fuel (fuel from tall oil).

After the oil crises in the 1970s the forest industry engaged itself in reducing its dependence on oil by economizing on energy and using internal by-products to a greater extent. Part of the increase in use of by-products in the industry, however, is related to increased pulp production. In 2000 the consumption of oil was a quarter of that in 1973 (Figure 4.4). During the same period, the use of electricity almost doubled due to the increased production of mechanical pulp and paper (Swedish Forest Industries’ Federation, 2001). Today, mechanical pulp, which is mainly used for newsprint, makes up 29% of the pulp produced in Sweden but accounts for 56% of the electricity consumed in pulp production, see Figure 4.5.
Tall oil has been used as a fuel since the 1960s. Current use amounts to about 2 TWh, where district heating accounts for 1.4 TWh and pulp mills for the remaining part. When evaporating black liquor before combustion, crude tall oil is collected as a by-product. Previously, the crude tall oil was usually burned directly at the mill. A few years ago, however, a tax was imposed on tall oil if it was used directly for energy purposes without being processed. This tax aimed at protecting the supply of tall oil as a raw material for the chemical industry. Today all crude tall oil is transported to Sandarne, where Sweden’s only wood distillation plant is located. Three main products are refined by distillation: (1) tall oil rosin, which is the most valuable, used in the production of paint, glue and varnish, (2) tall oil fatty acid with a similar field of application to tall oil rosin, and (3) pitch fuel, composed mostly of the heaviest fraction with similar burning qualities to heavy fuel oil. Tall oil is also imported from Finland, Norway, the USA and the UK. About one third of the pitch fuel used in district heating plants and pulp mills is indigenous (Ljungblom, 1999).

Thirty-five of the 60 pulp mills in Sweden are equipped with backpressure turbines. In total the equivalent of 851 MW was installed at the end of 2000, annually producing 4.0 TWh power, 2.3 TWh of which from biofuels (Swedish Forest Industries’ Federation, 2001; Wiberg, 2001). The forest industry has estimated the overall power production potential to be 5-6 TWh, using installed boiler and turbine capacity, based on current heat demand (Wiberg, 2001).

Implementing the new technique of black liquor gasification (BLG) or gasification of solid biofuels would provide even greater opportunities for electricity production due to the increased electricity-to-heat ratio. Näsholm and Westermark (1997) indicate a potential to double the power output for an integrated BLG combined cycle system, compared to conventional recovery system. Several BLG processes have been studied (e.g. Warnqvist et al., 2000). At the research laboratory of the Energy Technology Centre (ETC), Piteå, Northern Sweden, a demonstration plant for BLG with a capacity of 20 ton dry black liquor per day is under construction.

4.1.4 Supply of biomass by-products and waste heat to district heating systems

In Sweden the use of biomass is largely integrated with the forest industry, which, apart from its own consumption, supplies the district heating sector with low-cost wood fuels, see Figure 4.6. The wood fuels include logging residues (see section 4.1.5) and forest industry by-products, such as wood chips,

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8 Situated in Gävleborg län.
bark and sawdust. Sometimes these by-products are refined to pellets, briquettes or powder before delivery to a heating plant.

In the 1980s the development of a biomass market met resistance from the forest companies who feared competition for the raw material. To ensure the future supply of wood to the forest industry, the government regulated the use of roundwood for heating purposes in the Wood Fibre Act, which was passed in 1987 (SFS 1987:588). The fear of a shortage of wood fibre proved, however, to be exaggerated. In 1993 the Act was repealed and the wood fuel market was thus administratively deregulated (SFS 1993:564). Today it is the forest sector that administers a large part of the wood fuel market. The value of integrating the production of biofuels with the forest industry lies in the opportunity to use skills and structures that already exist in the forest industry. Generally, the biofuel companies that supply the municipal heating plants coordinate their field operations with normal forestry operations. Thus, the cost of machinery and forest roads can be shared between both users. Also, several of the forest companies own specialized wood-fuel trading companies (Roos et al., 1999).

The different sectors of the forest industry are themselves often integrated, for instance pulp and paper are usually produced at the same plant. Sawmills may also favourably be located in the vicinity of the pulp and paper mill. When located together, long transportation of pulp and pulpwood is avoided. Furthermore, the different sectors can be connected to the same steam grid, which makes lower use of energy possible through optimisation.

Apart from the supply of by-products to district heating plants, there are at the moment 16 pulp and paper mills that deliver waste heat or steam (in 2000 this amounted to 630 and 800 GWh, respectively) to municipal district heating grids. About 120 GWh of steam are delivered to other neighbouring industries (Wiberg, 2001).

A new phenomenon in energy-intensive industries, and in particular the forest industry, is outsourcing of the energy conversion plants to an energy company. Hereby, capital is released and may instead be invested in the core business. An example is SCA Packaging Munksund, a pulp and paper plant in Piteå, which in 2001 signed a long-term contract with Vattenfall, a major power and heat producing company in Sweden. From 2002 onwards Vattenfall’s CHP plant will provide the mill with steam and power, using bark as fuel, half of which will come from the mill (Vattenfall, 2001).
Figure 4.6. Material flows of forestry raw material in 2000 - manufactured products, recycled products and by-products used as fuel. The grey lines mark flows of material used solely as fuels (National Board of Forestry, 2001, FAO forestry database, Swedish Woodfuel Association, Nilsson, P.O., ed. 1999; Swedish DH Association, 2001)

Conversion factors used: (1) roundwood: 0.93 ton/m³f ub, (2) sawn wood: 0.51 ton/m³, (3) wood chips: 0.8 ton/m³f ub, (4) fuel wood: 0.8 ton/m³f ub
n.a. = not available
* Uncertain figure
4.1.5 Supply of logging residues from forestry

At the beginning of the 1980s, a new type of forest fuel was introduced into the Swedish energy system. Logging residues from tree felling (tops and branches) were introduced for heat production in district heating systems. The market for logging residues has grown steadily during the past two decades, and now accounts for about 7 TWh of the fuel supply in district heating systems. Important driving forces were a continuous reduction in production costs and increased prices of fossil fuels, mainly due to taxes (see Figure 3.3). The nominal price of forest fuels is about the same as in the mid-1980s, leading to a reduction in real terms of almost 50% (see Figure 3.4). As a result, the cost of biomass-based heat production in district heating is about 50% lower than fossil-fuel-based heat (see Figure 3.3). The reduction in production costs of logging residues has been made possible by the continuous development of technology and administration based on commercial experience gained in the recovery and handling of forest fuels. During recent years, the importation of cheap wood fuels has put pressure on the price of forest fuels (see Section 4.3).

The most cost-efficient harvesting chain in Sweden today is based on roadside chipping of logging residues collected from final felling of mature spruce stands (Figure 4.7). This chain includes: (i) cutting and processing trees with a harvester which simultaneously bunches the residues, (ii) terrain transportation of residues by a modified forwarder to a storage site at the roadside, (iii) chipping residues at the roadside using a chipper, and finally (iv) transporting the chips to the heating plant in a truck-trailer unit. On average, the recovery rate of logging residues in mature spruce stands varies from 65 to 75%. A prerequisite for achieving a high recovery rate is the development of logging methods supporting logging residue harvesting. Working methods have been modified such that the logging residues are piled up beside the harvester. In this way, the logging residues will not get crushed by the harvesting machine or the forwarders, and the risk of contamination by undesirable stones, soil and humus material will be reduced. This new logging method has only a minor impact on the productivity of the timber harvest and haulage (Savolainen and Berggren, 2000).

Transporting the residues from the cutting site to a storage site located at the roadside normally takes place during the summer season with a normal type of a forwarder with an enlarged load capacity. The storage piles, which should be as large as possible, are normally covered with tarred paper, since this results in approximately 10% drier wood chips than those produced from uncovered logging residues (Savolainen and Berggren, 2000). In addition, covering logging residues is an effective way to prevent decomposition by microorganisms during prolonged storage (the covering paper can then be
chipped with the logging residues). During storage from summer to winter, the water content is normally reduced from 50% (fresh biomass) to 25 to 35%.

The logging residues are then processed into wood chips by a mobile chipper during the winter. The chipper often consists of a drum chipper on a lorry chassis with a capacity of between 40 and 80 bulk m$^3$ per effective working hour (Savolainen and Berggren, 2000). The wood chips are transported to the heating plants by trucks, typically equipped with either detachable containers or a side tipper, and the size of the load is usually between 90 and 120 m$^3$. Good management of the logistics of the chipper and the chip trucks significantly affects the cost. Thus, full occupation of both machines with as little waiting time as possible is crucial for an effective roadside chipping production chain.

Under current Swedish conditions, the energy input per unit biomass produced, including transportation, is about 4% for logging residues, of which transportation to the heating plant is equivalent to about one fourth (Börjesson, 1996). The transportation distance is today, on average, about 70 km. In general, the energy input per unit biomass is lower for residues from forestry and agriculture, such as logging residues and straw, than when growing energy crops, especially annual crops (see Section 4.3). There is also the potential for further energy efficiency improvements in the logging residue production chain by, for example, improved harvesting machines and new concepts of harvesting and transport (see below in this section).

The current cost of forest fuels is about 100 SEK (10 USD) per MWh (see Fig. 3.4). This cost is derived from harvesting and processing operations, ≈60%, administration and compensation to the land owner, ≈15%, and transporting operations, ≈25%. This cost of logging residue recovery does not include costs of nutrient compensation. A prerequisite for the long-term sustainable utilisation of logging residues is, however, that nutrient losses due to the removal of tree tops and branches are compensated for, by e.g. recirculation of wood ash after combustion. Wood ash recirculation is expected to increase future forest fuel costs by approximately 5% (Börjesson, 2000).

The economic compensation to forest owners for logging residues is low (between 0 and 10% of the forest fuel cost). This is equivalent to an increased income of only one or two percent from final felling, compared with the harvesting of stem wood alone. The economic compensation to the forest owner has therefore never been an important driving force in the increased utilisation of forest fuels in Sweden during the 1980s and 90s. Thus, factors other than economic compensation may have affected the willingness of forest owners to sell logging residues. One example is easier replanting when residues are recovered after final felling. The attitude of local foresters towards logging residues may also significantly affect the prerequisite for logging residue harvest. Local foresters normally hold a strong position within the local production network, and the degree of integration of forest fuels into local forestry operations may vary considerably depending on whether the attitude of local foresters towards forest fuel is positive, negative or indifferent (Ling, 1996). A future increase in forest fuel harvest may therefore depend on the attitudes of forest owners and foresters towards logging residue harvest, and the economic compensation to the forest owner. This may have to be increased to avoid becoming a barrier to the expansion of forest fuel utilisation.

New concepts of logging residue harvest and transport are under development in Sweden and Finland, which could lead to future reductions in production costs. One example is baling of logging residues and chipping at the end-use facility. Baling logging residues is one way of compacting raw material in order to improve the productivity of long-distance transportation, and to gain advantages of scale in the chipping process. It has been estimated that the cost of producing wood chips from logging residues using this method could be reduced, on average, by 20 to 30%, compared with conventional roadside chipping (Glöde, 2000).

Besides future reductions in direct costs, logging residue recovery and recirculation of wood ash can lead to a reduction in environmental costs. Examples of additional local environmental benefits achieved are reduced soil acidification and, primarily in southern Sweden, also improved nitrogen balance and reduced nutrient leaching from forest land (Börjesson, 2000). Recovery of residues leads to a slight increase in the net emission of carbon dioxide, compared with on-site decomposition, but this increase is small compared with the net emission of carbon dioxide from fossil fuel cycles. The impact
of toxic compounds is estimated to be insignificant, as is that on biodiversity, provided current
guidelines for forestry management methods are followed. When the value of potential local
environmental benefits is included in cost calculations, the total cost of logging residues in southern
Sweden, is estimated to be reduced by more than two thirds of the current direct cost (Börjesson,
2000).

4.2. Importation of wood fuels
During recent years the importation of wood fuels has increased rapidly, while export is insignificant.
One consequence of this is that the previous trend of increasing logging residue harvest from Swedish
forests has been broken and the harvest has started to decline. This, in return, has a negative effect on
the domestic forest fuel market since many local forestry entrepreneurs find themselves under high
economic pressure, which leads to damaged confidence in the logging residue market and thus reduced
willingness to invest in new machines etc. It has been estimated that imported wood fuels make up
about 40% of the total forest fuel supply to the district heating sector today, and account for about 6
TWh per year (Börjesson, 2001). The largest exporters are, in decreasing order, the Baltic region,
Germany and the Netherlands. From the Baltic region Sweden mainly imports roundwood and wood
chips, while from Germany and the Netherlands mainly recycled wood waste is imported. The Baltic
countries also export large quantities of roundwood and pulp wood to sawmills and pulp and paper
mills in Sweden, some of which later finds its way into the heating sector.

The increase in the import of wood fuels, as for domestic wood fuels, is mainly due to high
taxes on fossil fuels in Sweden, which provides the domestic heating plants with greater incentive for
biomass use in relation to foreign competitors whose use of fossil fuels is not so heavily taxed. Yet
another contributing factor is the more extensive waste legislation in some European countries. The
deposition of waste in landfills, for example, is much more costly in Germany and the Netherlands than
in Sweden. Germany and the Netherlands are also burdened with a tax on waste combustion, which
Sweden lacks. This makes it profitable for waste handling enterprises in Germany and the Netherlands
to export wood waste free to Swedish heating plants whose only cost will be that of transportation. If
sea transport is used, the cost of transporting wood waste from northern Europe, or wood chips from
the Baltic region, corresponds to about one third of the total cost of domestic forest fuels (Börjesson,
2001). The competitiveness of imported wood fuels is thus highest for district heating plants located
along the Swedish coast with good access to harbours, since reloading costs (from boats to trucks) can
be avoided.

4.3 Agriculture
There are several biomass resources within the agriculture sector, which could be used for energy
purposes, such as traditional food crops, residues from their cultivation, and dedicated energy crops.
These biomass resources differ regarding cost, energy and land-use efficiency, and impact on the local
environment, and thereby in fulfilling the demands for physical sustainability. Residues, such as straw,
and dedicated perennial energy crops, such as short-rotation forestry (Salix) and energy grass, are
generally more cost- and energy-efficient than traditional annual crops, such as cereals and oil seed
plants. The energy efficiency of a biomass production chain based on straw is about the same as for one
based on logging residues, i.e. the energy input per unit biomass produced, including transportation, is
about 4% (Börjesson, 1996). The corresponding figure for Salix is about 5%. The energy efficiency of a
biomass production chain based on annual energy crops such as cereals (e.g. wheat) and oil seed plants
(e.g. rape seed) is significantly lower. Here, the energy input is about 15-20% of the energy content of
the biomass produced.

The production cost per unit energy is also normally much lower for straw and Salix than for
traditional annual crops when existing cultivation subsidies are excluded. The production cost per unit
energy for straw and Salix may, for example, be up to 3 to 4 times lower than for rape seed and cereals (Gustavsson et al., 1995). In addition to these benefits, the cultivation of dedicated perennial energy crops will have a much smaller negative impact on the local environment than the cultivation of annual crops. For example, if Salix replaces rape seed and wheat, the risk of nutrient leaching and erosion will decrease, as the requirement of commercial fertilisers and pesticides is less. Thus, perennial cropping systems can fulfill the demands for long-term sustainable use of arable land in a much better way than annual cropping systems.

Biomass from agriculture, such as straw and energy crops, plays a minor role in the current Swedish energy system, despite efforts in research and development and in the creation of economical incentives. The annual harvest from short-rotation forest plantations amounts to around 0.1 TWh today (Swedish National Energy Administration, 2001d). The total use of straw as fuel is also approximately 0.1 TWh per year.

4.3.1 Salix

Research into short-rotation forest (Salix) was initiated in the early 1970s, and the programme expanded until late 1990s. It was not until the beginning of the 1990s that expansion of full-scale Salix plantations for energy occurred, and a market for Salix was established. This expansion was driven by a combination of various factors. One important factor was the introduction in 1991 of a new agricultural policy in Sweden which, through deregulation, led to lower grain prices and simultaneously introduced compensation for set-aside land as well as subsidies for Salix plantations on surplus arable land (Rosenqvist et al., 2000). The subsidies for planting Salix, existing between 1991 and 1996, amounted to 10,000 SEK/ha. These subsidies were part of the transition programme for the new deregulated agricultural policy, which was aimed at converting 500,000 ha from price-regulated food production to other uses, e.g. energy production.

Another driving force behind the expansion of Salix plantations during the 1990s was the increased tax on fossil fuels in 1991, which resulted in the increased competitiveness of biomass (see Section 3.2). A third important prerequisite for rapid growth was the existing infrastructure for the coordination and transport of forest fuel to district heating plants, which could also be utilised for Salix. This combination of driving forces contributed to the dynamic development of Salix plantations; the area of Salix increasing from almost zero to above 15,000 ha between 1991 and 1996 (Figure 4.9). Most of the willow plantations were administrated by Agrobränsle AB and SL Energy, two bioenergy companies owned by the Federation of Swedish Farmers, through contract cultivation. Dedicated planting machines were developed, as well as harvesting machines, leading to a 50% reduction in planting costs in a few years, and increased harvesting capacity; the current chipping capacity being about 60-70 tonnes per hour (Rosenqvist et al., 2000).

![Figure 4.9. Salix plantation area in Sweden from 1989 to 2000 (data from Agrobränsle AB, 2002).](image-url)
Since 1997 the expansion in Salix plantation has ceased. One reason for this is reduced subsidies. The governmental plantation establishment grant of 10,000 SEK per hectare Salix was reduced to 3,000 SEK/hectare in 1997, which seriously affected the economy of Salix cultivation. Planting Salix can be considered as a long-term investment as the cultivation time is estimated to be 20-25 years, and the crop is harvested every three to five years. The establishment cost amounts to, on average, 13,000 SEK per hectare (Rosenqvist, 1997). The establishment cost normally amounts to about 20% of the total cost of Salix production. The former subsidy of 10,000 SEK per hectare established Salix between 1991 and 1996, almost neutralised the negative liquidity during the first rotation period, leading to higher profitability and reduced economical risk for the farmer. In 1999, the governmental plantation establishment subsidy was increased to 5,000 SEK per hectare, the aim of which was to restimulate expansion in Salix cultivation. This new subsidy is, however, still not high enough to avoid significant negative liquidity during the first rotation period.

One reason why the government subsidises for planting Salix were reduced was regulations in the EU area subsidy system within the Common Agriculture Policy (CAP). It is here stated that the maximum level of the government subsidy may not exceed 50% of the planting cost, which has been estimated to, on average, 10,000 SEK per hectare. Swedish membership in EU in 1995, and thereby in the CAP, also affected the prerequisites for Salix cultivation in other ways. For example, one regulation, which was lifted in 1999, stated that a farmer could grow Salix on a maximum of 50% of his farmland, to be eligible for land subsidies. One result of this regulation was that some farmers were forced to abandon newly planted Salix plantations between 1996 and 1999, see Figure 4.9. Another example is that the amount of mandatory set-aside land, or the area that may not be used for food production in order that area subsidies may be granted for grain and oil seed cultivations, has varied considerably during recent years, or from 12% in 1995 to 3% in 2000. This led to the reduced willingness of some farmers to establish long-term Salix plantations, especially grain producers with a high equipment capacity for grain cultivation for whom Salix production gives the highest profitability on mandatory set-aside land but not on other land (Rosenqvist, 1997).

For farmers with low equipment capacity for grain cultivation, Salix cultivation could be competitive also on land other than set-aside land, especially on average grain soils (but not on the poorest or the best grain soils) (Rosenqvist, 1998). Here, the competitiveness of Salix versus grain is mainly affected by the prices of grain and Salix chips. Grain prices have become more volatile during recent years. One reason for this is changing world market prices of grain, but also annual changes in the level of subsidies for grain production within the CAP. Such uncertainty leads to a reduced willingness of farmers to invest in long-term energy plantations. The price of Salix chips has fallen during recent years, as it follows the average price of wood fuels (see Figure 3.4). The price of Salix chips is normally somewhat lower than that of forest fuel chips, due to the higher water content in Salix chips (around 50% compared with 25-35%). The current price of Salix chips is 80 to 90 SEK per MWh, which can be compared with the assumed prices of 110 to 120 SEK per MWh in Salix profitability calculations during the mid-1990s. Thus, the income from Salix plantations that are harvested today is somewhat lower than the expected income when the plantations were established in the mid-1990s. In order to attain positive land rental costs, the price of Salix chips is required to be at least 95 to 100 SEK per MWh, according to calculations by Rosenqvist (1997). The pressure on the price of domestic wood fuels has increased even further since 1999, due to a rapid increase in the importation of wood fuels, such as waste wood from northern Europe. This is affecting Salix growers, especially in the south part of Sweden where the population density is high and many cities are located along the coast, thus providing good conditions for importing biomass by sea.

One negative effect of the high government establishment grant in the early 1990s was that some Salix plantations were established on poor soils not suitable for Salix cultivation and that the plantations were not managed properly. This was the case when the farmer’s main interest in Salix cultivation was to receive the subsidy, not to produce high biomass yields. As a result, early harvest yields were often much lower than expected, i.e. about 4 to 5 tonnes dry matter per hectare per year instead of around 10 tonnes. The biomass yield after the first rotation period is also normally only 60% of that in following rotation periods since the plant is developing its root system during the first few
years. Today, harvest yields in properly managed plantations on good soils are typically around 8 to 10 dry tonnes per hectare per year (Agrobränsle, 2002). Biomass yields are also expected to continue to increase in the future due to improvements in plant breeding and management methods. For example, new Salix clones commercially available today are expected to give, on average, 30-40% higher biomass yields than Salix clones sold during the mid-1990s (Larsson, 2002).

Apart from strictly economical factors other factors affect the willingness of farmers to grow Salix. A study by Rosenqvist et al. (2000) of Salix growers in Sweden showed that willingness is influenced by factors such as geographical location, the age of the farmer, farm size and farm type. For example, a much higher concentration of Salix growers was recorded in central Sweden than in southern Sweden. One explanation of this is more suitable soil conditions for Salix cultivation, since agricultural land in central Sweden consists largely of moderately good grain-producing land, which gives the highest profitability in Salix cultivation (see above). However, local and regional variation in Salix plantation intensity might also be due to variation in the interest among local agricultural cooperatives and advisers. Salix growers are more often in the age range 50-60 years and compared with non-Salix growers, have larger farms. This may be because farmers running large-scale enterprises are better able to assess and diversify risks associated with new crops, and are better informed about the economy and subsidies available (Rosenqvist et al., 2000). Salix growers are less often focused on animal and milk production, and more often on cereal and food crop production, compared with other farmers.

Through appropriate design, location and management, Salix plantations have the potential to generate several local environmental benefits, which could increase the value of the production systems thereby improving future market conditions for biomass. Examples of such multi-functional biomass production systems are vegetation filters for purifying municipal wastewater, buffer strips along open streams preventing nutrient leaching, and shelter belts preventing soil erosion (Börjesson, 1999a). A previous study showed that up to 19 TWh perennial crops could theoretically be produced annually in Sweden at a reduced cost of more than 50%, when the multi-functional potential is fully utilised (Börjesson, 1999b). Purification of municipal wastewater is estimated to have the highest economic value, and this concept is currently being tested in large-scale trials in Sweden. Thus, the economic incentives for farmers to establish multi-functional Salix plantations, is another factor affecting the introduction of energy crops.

4.3.2 Straw

Sweden has three straw-fired district heating plants (>1.0 MW) and a few hundred straw-fired farm boilers utilising only a few percent of the estimated fuel straw potential (Nilsson, 1999). In Denmark, fuel straw is used in around 10,000 boilers on farms, and in 58 district heating plants, some of which are combined heat and power plants (Nikolaisen, 1998). Thus, the current use of fuel straw is about 30 times higher in Denmark than in Sweden while the straw potential is estimated to be only 3 times higher. One reason why the use of fuel straw is low in Sweden is the weather during the harvesting period. Due to the wet autumn climate the number of days with suitable straw harvest conditions is relatively small in Sweden. For example, calculations by D. Nilsson (1999) show that years of incomplete straw harvest could amount to 70% in central Sweden while the corresponding figure for southern Sweden is only around 10%.

Poor reliability in straw supply leads to increased costs since straw is often harvested with specially designed and highly effective machines with heavy investment costs. Thus, the fixed harvesting costs may be considerable (D. Nilsson, 1999). Since straw is harvested during a short period in the autumn it has to be stored until the winter when the heating plants need the fuel. This leads to additional costs which, for example, Salix is not burdened with since Salix is harvested during the winter. The costs of harvesting, transportation and storage of straw may account for about 85% of the total straw fuel cost in district heating plants. Calculations by D. Nilsson (1999) show that the straw fuel delivery costs at heating plants in southern and central Sweden will be, on average, around 110-115
and 135-145 SEK/MWh, respectively. Thus, the cost of fuel straw in southern Sweden is about the same as for forest fuels, while it is some 25% higher in central Sweden.

Another factor restricting the use of fuel straw in heating plants, is the low ash melting temperature and its unfavourable slagging, fouling and corrosion characteristics. These problems can be alleviated to a certain degree by the handling system employed. In Denmark, for example, some harvesting of leached, “grey” straw is carried out during the winter. This leached straw has lower contents of alkali metals and chlorine, which increases the ash fusion temperature and reduces fouling problems (Jenkins et al., 1996). It may also be possible to adopt this method in Sweden.

In conclusion, there are various reasons why such a small fraction of the total fuel straw potential is utilised in Sweden today. Examples are a poor reliability in straw supply, especially in central Sweden, the need for storage from autumn to winter, and problems associated with slagging, fouling and corrosion during combustion. Similar problems are much smaller considering forest fuels, which is why Swedish heating plants use forest fuels rather than straw today. However, in the future if the supply of cheap forest fuels should be limited in a region with large fuel straw resources, the use of fuel straw has the potential to increase significantly.

4.4. District heating systems

Biomass of various origins is currently the dominating fuel in district heating (DH) systems, following steady growth since the early 1980s and now supplies more than 15 TWh of heat per year. Currently, biomass constitutes more than a third of the total energy input to district heat production, and consist mainly of wood residues from forestry and the forestry industry, imported wood chips or roundwood, and domestic or imported wood waste (see Figures 4.10 and 4.11).

DH systems are of strategic importance in the Swedish energy system, producing more than 40% of all low-temperature heat supplied to non-industrial (residential and service) buildings, see Figure 4.10 (in addition some 4 TWh/y are delivered to industry (Swedish District Heating Association, 2001a). Such centralized heating systems have the advantage of relative fuel flexibility, and also provide opportunities for efficient electricity production in combined heat and power (CHP) plants. Although there are some 170 companies producing and/or distributing district heat, most of the heat is delivered by relatively large systems (Figure 4.12). This gives sufficient economy of scale for efficient CHP plants, or, for that matter, e.g., plants for cogeneration of heat and methanol. Furthermore, the scale of DH systems is in general consistent with reasonable conditions for efficient biomass supply (Börjesson and Gustavsson, 1996).

Until now CHP generation in Swedish DH systems has not been as important as in, for example, Denmark, Finland and Eastern Europe. The conditions for the future development of CHP generation will be discussed below.

In addition to conventional district heating systems, smaller heating centrals (“block centrals”) supply heat, for example, to office buildings, schools and apartments, some of which use biomass as fuel. Technically, the dividing line between DH systems and block centrals is not clear, since some of the latter produce more heat than small DH systems. In 1985 10 TWh of oil were used in such centrals, and in addition some 10 TWh in similar centrals in industry (National Energy Board, 1987). Most of this heat is now taken from DH systems or is supplied by, e.g., pellets firing, but a significant amount of oil is still used. Figure 4.12 shows the heat supply to multi-dwelling buildings, houses, and non-residential premises, thus comprising the entire non-industrial low temperature heat market.
Figure 4.12. Low-temperature heat supply (TWh) in Sweden 2000 (excluding industry), distributed over DH systems; and multi-dwelling buildings, non-residential premises, and single houses not connected to DH systems. The sum of all heat loads is 92.5 TWh. (Data for DH systems from the Swedish District Heating Association, 2001b; other: Statistics Sweden, 2001a.

(*) For DH systems the values refer to delivered heat. If CHP generation were installed in these systems the approximate electricity production capacities in the three classes of DH systems would be: >50 MW; 10-50 MW; and <10 MW (assuming 50% of the heat were produced in CHP mode; an electricity-to-heat ratio of 0.75; and a capacity factor for electricity of 60%).

(**) No data available on biomass use for heating in multi-dwelling buildings and non-residential premises.

4.4.1 Historical development and ownership issues

The first Swedish publicly owned district heating system was in operation in 1948, but more rapid development started in the 1960s (Werner, 1989). Growth rates with regard to heat delivery have begun to decline only in recent years. In many cases the development of DH systems was facilitated by close contacts and good communication between local government and potential large customers, such as privately or publicly owned housing companies (Summerton, 1992). In addition, public buildings such as schools and hospitals also provided an initial basis for heat deliveries. District heating was consistent with a prevailing acceptance of centralized, community-wide technical solutions.

Centralized systems inevitably mean heat losses and high investments associated with the distribution system, but the following positive factors motivated investments in district heating (adopted from Werner, 1989):

- Economy and fuel flexibility (cheap heavy oil could be used instead of expensive light oil; otherwise unusable heat sources, such as industrial waste heat, could be utilized; the specific investment in production units was smaller due to scale effects)
- Efficiency (professional maintenance is affordable at large plants; technological scale effects)
- Environment (obviously easier to control a few emission points than tens of thousands)
- The opportunity to produce electricity cheaply and efficiently in CHP plants.
Initially, local, publicly owned utilities were formed to manage district heating. The financial stability offered by local authorities made it possible to enlist new customers by pricing out competing fuels, thereby essentially irreversibly compelling them become and stay customers. As important, however, were formal and informal networks and contacts between, e.g. local housing companies and city employees/officials (Summerton, 1992). Public ownership still dominates, although DH systems in most cities have been transferred to publicly owned companies, rather than being run by the municipal administration. Quite recently, a structural shift with regard to ownership has begun (see below).

Early DH systems almost exclusively used heavy fuel oil, which was cheaper than the light oils used by smaller boilers, but since the early 1980s profound changes have taken place with regard to energy inputs to DH systems. After the oil crises in the 1970s, DH systems were ideal objects for the rapid replacement of oil. During the 1980s the use of coal increased significantly, but the tax reform in the early 1990s led to the phasing out of coal. Large heat pumps utilising surface water and waste water, large electric boilers and some biomass also came onto the scene in the 1980s. The earlier transition to a solid fuel (coal), made the transition to biomass less complicated.

The considerable expansion of district heating in the 1960s and onwards could have led to a significant increase in electricity production from CHP. However, CHP units were installed only at the beginning of this period, as the political decision to build up a large nuclear capacity in a very short time effectively blocked such investments (Hård and Olsson, 1994, Werner, 1999).

The energy/environment tax reform in the early 1990s caused a massive increase in the use of biomass in DH systems, as biomass became the cheapest fuel. However, the nature of the new taxation system only favoured the use of biomass for heat production, as electricity was taxed when consumed (regardless of the generating fuel). Thus, the development of new CHP systems was poor, and with low electricity prices starting with the 1996 deregulation of the electricity market, biomass CHP plants have been constructed during the past ten years only in response to government subsidies (see Section 3.3).

The expansion of biomass use in district heating has not only resulted from changes in the tax system. The development of DH systems, and the decision regarding investment in CHP or not, also depends on system ownership and local/regional political preferences. In some cities, the use of biomass for heat and electricity generation is part of long-term social and/or environmental commitments (see, e.g., Växjö Municipality (2002) and Kristianstad Municipality (2002)), while in other cases the changeover to biomass primarily represents a rational short-term economic decision, for example Sydkraft’s investment in “biomass-for-heat” in Malmö (Bardouille, 2001).

District heating was first developed in densely populated city centres and areas with many multi-family dwellings. Over time, however, areas with a lower heating density have been connected. Currently a high percentage (75%) of multi-family dwellings is connected, as well as public and commercial buildings (60%) (Werner, 1999). Virtually all towns/cities in Sweden have DH systems. The potential for expansion in these original markets is rather limited. Also, the period from the early 1970s up till the mid-1980s showed continuous development in heating efficiency of buildings (Swedish National Energy Administration, 2000c), leading to a relative decrease in heat densities and thus heat delivery. This process may, however, be balanced by the connection of new customers, but the Swedish building stock, particularly that of multi-family dwellings, has grown very slowly since the 1980s.

In recent years national policy instruments and local initiatives have promoted the connection of smaller customers to DH systems, such as single houses. Depending on the source of heating replaced, the advantages of this would be better urban air quality, lower CO₂ emission, or less pressure on the electricity supply. Also, a larger number of customers and thus a greater heat demand on DH systems would increase the potential for CHP. This argument has, however, not been valid during the previous five years due to low electricity prices.

Another recent development is an ongoing transformation in the ownership of DH systems. Originally, most local district heating utilities were run by the municipal administration. Most cities have now transformed these into city-owned companies (see Figure 4.13), which act more freely and with less political control. The political planning process related to the development of the heating
market thus lies more in the surveying and planning process than in the direct control of the energy supply.

Furthermore, a growing share of district heating companies is being sold to large national (and international) utilities, representing a variety of energy services – electricity, gas, and now district heat (Andersson and Werner, 2001, Swedish National Energy Administration, 2001d). This may have implications for the future price and infrastructure development. Although heat markets are local, they interact with the larger markets for electricity and gas.

![Figure 4.13. Distribution of ownership of DH systems in Sweden 1999, in terms of heat delivered (Andersson and Werner, 2001).](image)

### 4.4.2 District heating & CHP

In the early years of Swedish district heating, CHP was in often installed in the systems. The first ten DH systems all included oil-fired CHP units, constructed in the 1950s and 1960s (Werner, 1999). Between 1965 and 1980 thermal power from condensing plants or from industrial or district heat cogeneration was needed to complement hydro power. With the very rapid increase in nuclear power generation from 1975 to 1985, and the oil price increases of the 1970s, the proportion of cogenerated electricity in DH systems and industry in the national electricity balance fell from almost 10% in 1980 to less than 5% in 1985 (Werner, 1999) (see also Figure 4.14).

After the oil crises in the 1970s many oil-fired CHP units were converted to coal, and during the 1990s the production of CHP electricity has slowly increased, still contributing, however, a very small fraction of the total electricity production.

During the whole district heating era conventional steam turbines have dominated in the production of electricity, although boiler technologies have also been developed. Fluidized beds of various designs are now the preferred technology in large-scale DH systems, mainly due to fuel flexibility. In the 1980s and 1990s several very large development projects were launched, aiming at attaining higher electric efficiencies with biomass. These projects involved the gasification of biomass and the use of the synthesis gas in combined cycle systems. Only one of these projects resulted in a full-scale demonstration unit (Bioflow, 6 + 9 MW\textsubscript{thermal} + electric). Several factors led to reduced interest in the further development of biomass gasification and the subsequent use of the gas in gas turbines namely; low electricity prices; the complexity, and thus the cost, of the systems; and competition with still developing steam turbine systems.
Since 1990 almost all new CHP units have been constructed for wood fuels, using conventional technology, and drawing on targeted biomass CHP subsidies. Biomass-based CHP has increased during this period, although only up to about one per cent of the total electricity production. More than ten major Swedish DH systems have large biomass CHP units (Swedish District Heating Association, 2001b).

During the past decade the capacity to produce electricity in Swedish DH systems has been poorly utilised (see Figure 4.14). This can be explained, at least in recent years, by low electricity prices in the Nordic market.

![Figure 4.14. Combined heat and power (CHP) in Sweden 1970-2000: installed capacity, and actual and potential electricity production (Swedish National Energy Administration, 2001b; Hård and Olsson, 1994; Swedish District Heating Association, 2001b).](image)

(*) Insufficient data for the years 1990 and 1992-1997 (linear approximation)

(**) Potential electricity production from CHP has been assumed based on a 60% capacity factor for installed electric capacity (corresponding to 5250 equivalent full load hours).

### 4.4.3. District heating pricing

District heating prices rose in real terms with oil prices in the 1970s, reaching a maximum in the early 1980s. After that they decreased, and have been fairly constant with an average slightly below 400 SEK/MWh since 1985 (in terms of prices, 1999 SEK, calculated as total income from district heat sales according to Andersson and Werner, 2001). Price differences between different district heating companies are not particularly large, with 80% of the companies having prices between 350 and 500 SEK/MWh. Municipally owned district heating utilities tend to have slightly lower heat prices than facilities owned by larger utilities, although the differences are not great (Andersson and Werner, 2001).

In principle, there is a risk of cross-subsidies when both heat and electricity are produced in CHP plants and sold by the same organisation/company. Some attempts have been made to analyse this situation by Swedish authorities, but no cases of cross-subsidizing of heat or electricity were found (Swedish National Energy Administration, 2000d). On the contrary, another study showed that district heating companies with CHP production seem to offer similar district heating prices to companies with no electricity sales (Andersson and Werner, 2001). District heating companies/CHP operators have, however, been criticised for non-transparency in their annual reports etc., and more transparent book-
keeping and better price information is desirable (Swedish National Energy Administration, 2000d; Andersson and Werner 2001).

4.5 Small-scale biomass for heating

Small-scale use of biomass for the heating of single houses has a long history, and the dominating technology has been conventional burning of firewood in boilers connected to a hydronic heat distribution system. A relatively large fraction, about 10%, or approximately 10 TWh/y, of the total low-temperature heat demand of buildings has been supplied in this way for several decades (Swedish National Energy Administration 2000a). These systems are particularly common in sparsely populated areas, and in small towns and villages. Single houses represent a total heat/hot water energy use of some 40 TWh/y (see Figures 4.12 and 4.15).

Over time, combination boilers have been extensively installed, allowing for heating by means of oil, wood or electricity, thus making different heating strategies possible in different seasons, and responding to relative price changes.

In the case of firewood, only a very small part is traded on a conventional market. Most of the wood is collected by the house-owners themselves, or traded through informal channels, often through contacts with forest owners. Direct heat costs for wood firing, excluding the manual labour associated with wood collecting and handling, but including capital costs, have in general been lower than those of competing fuels. The total cost including manual labour is, of course, very sensitive to the assumed labour cost. On the other hand, wood burning is a way of life preferred by many house-owners, providing exercise and fresh air. The future size of this, today, relatively large niche market is unclear, but it will probably not grow.

Conventional firewood heating systems are problematic with regard to health-related emissions, such as tar and other hydrocarbons, in addition to sanitary problems associated with soot emission. These problems occur particularly with low-quality or moist wood and/or with part-load/intermittent firing. Most of these problems could be overcome (although NO\textsubscript{x} formation may increase), if wood of good quality is burned under full load conditions, preferably storing the heat in a hot-water accumulator. Such a system still requires manual firing, but less time is needed.

Technologies have developed over the past decade to overcome environmental problems and to reduce manual labour. Refined biomass, typically wood pellets, is used in systems with varying degree of automation. Either dedicated pellet boilers are used, or a conventional oil boiler converted to pellets by changing the burner. In both cases, fuel could automatically be fed to the boiler by, e.g., screw feeding systems. Emissions from such well-maintained pellet boiler systems could be kept at acceptable levels (Swedish Institute of Agricultural and Environmental Engineering, 1997).

A market for these systems is currently slowly developing, but suitable fuels are not available everywhere. Still much of the distribution is carried out by house-owners themselves, involving, e.g., sack deliveries. Larger scale bulk transport (similar to fuel oil systems) of pellets is available regionally, making these systems similar to oil systems with regard to maintenance and comfort. The house-owner must, however, care for the removal of a small volume of ashes.
Figure 4.15. Energy carriers (TWh/y) used for the production of heat and hot water in single houses in Sweden 1970-1998 (from the Swedish National Energy Administration, 2000c).

Figure 4.16. Energy carriers and technologies for the production of heat and hot water in single houses in Sweden in 2000 in TWh (adopted from Statistics Sweden, 2001b; National Board of Forestry, 2001; Lagheim, 2002). To the category “Firewood, pellets (only)” 2.2 TWh have been added to correct for single houses in the agriculture sector.

Figures 4.15 and 4.16 show the distribution according to energy carrier for heat/hot-water energy use in single houses. The current market share of fuel oil (12 TWh/y) can technically be replaced by biomass, and this is also, in general, economically advantageous with the current price/tax structure.
A fairly large part of the total electricity use takes place in houses with electric radiators only (5.6 TWh/y) and those with hydronic systems for electricity only (5.1 TWh/y), where a shift to biomass would be technically and/or economically complicated. Here, however, e.g., pellet furnaces could be installed.

Over the whole period 1970 - 2000 firewood firing, and in the past decade also pellets, has had lower variable costs (including taxes) than electricity and oil (for electricity and oil prices, see, e.g., Swedish National Energy Administration, 2001d), especially if the labour cost of the house owner is neglected. The margin has varied, however, according to changes in oil and electricity prices and taxes. In Figure 4.17 typical total costs (including taxes) are shown for the heating of a single house with different energy carriers. This case is representative mainly of houses more than 30 years old, having a chimney and a hydronic heat distribution system. Newer houses are in general more energy efficient, and are thus not suitable for capital-intensive systems such as heat pumps or pellet boilers. Note also, that after 1970 more than half of all single houses were constructed for electric heating only (Statistics Sweden, 2001b).

Technologies now on the market (pellet burners for converting oil boilers or dedicated pellet boilers) seem to be economically rational choices for house owners, but these technologies still have a small market share. The further development will depend, amongst other things, on (technical) experience of the existing systems as well as attitude/lifestyle-related factors. Another limiting factor could be storage capacity for pellets, typically a few cubic metres. The prices of competing alternatives such as electricity and oil will also affect development, especially as heat pumps seem to be an attractive alternative to pellet burners (see Figure 4.17).

![Figure 4.15. Total annual costs in SEK/year, including taxes, for the production of heat/hot water in single houses with different heating systems. The left-hand bars indicate a heat load of 20,000kWh/y, and the right-hand bars 30,000 kWh/yr (data on investment costs, fuel prices and efficiencies are taken from Gustavsson and Karlsson, 2002, see also notes below). (*) Capital costs calculated with a real interest rate of 6%, and a lifetime of 20 years, except for the pellet burner, which has an estimated lifetime of 10 years. Investment costs are taken from Gustavsson and Karlsson, 2002, except for the pellet burner (assumed to 25 000 SEK). (**) Efficiencies and fuel prices taken from Gustavsson and Karlsson, 2002, except for oil and electricity prices (Swedish National Energy Administration, 2001d). Prices: electricity: 735 SEK/MWh; oil: 560 SEK/MWh; wood: 111 SEK/MWh; pellets 302 SEK/MWh. (***) A pellet burner is installed in an existing and functioning oil boiler. The technical lifetime of this set-up is assumed to 10 years (see also (*)).](image-url)
5. Integrated assessment of the development of biomass use from 1980 to 2000

A number of factors of various kinds have interacted to bring about the increased use of biomass in Sweden during the past twenty years. These factors can be divided into three categories: structure, policies and actors. The geographical, industrial and technical structures allowed a rapid response to the policies decided by the political institutions, while actors were able to respond to those policies. These factors will be briefly discussed below. In Table 5.1 events and trends affecting the supply of and demand for biomass are summarised.

Structure. The widespread forests of Sweden (227 000 km², 2.5 ha/capita) have been a prerequisite for forestry and the forest industry and thus for the expansion of biomass use. Forestry and the forest industry handle biomass resources (used in forest products or as energy sources) corresponding to an energy content of 150 TWh/y. This is equivalent to one fourth of the current Swedish primary energy supply. This has resulted in the technical capacity to handle large biomass flows in an efficient manner. The energy used for space and hot water heating accounts for a significant fraction (approximately one fourth) of the total Swedish energy demand. The use of biomass to replace fossil fuels in this application is the most cost-effective alternative for replacing fossil fuels (Gustavsson et al., 1995). The existence of district heating systems has facilitated the rapid growth in biomass demand in response to policy changes. The increased consumption of biomass is due to both fossil fuel replacement in existing plants and the construction of new plants dedicated to biomass combustion. District heating systems provide low-temperature heat corresponding to approximately 40% of the heat demand in Swedish buildings. These systems are quite energy efficient with distribution losses of about 10% (which are largely compensated for by the higher conversion efficiency in the heating plants compared with separate boilers).
Table 5.1 Events and trends contributing to the development of biomass. Information is based on various official documents and Hillring (1998). The comments and evaluation in the last column are, however, based on the authors’ own assessments.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Comments and evaluation</th>
</tr>
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<tbody>
<tr>
<td>1903</td>
<td>The Forestry Act</td>
<td>Provided the basis for measures that improve forest productivity and thus increasing the resource base for biomass.</td>
</tr>
<tr>
<td>1930s and onwards</td>
<td>Restructuring of the Swedish agriculture</td>
<td>Since the 1930s the area of arable land has decreased as higher productivity has reduced the area needed for food production. This freed land for forestry and energy crop production.</td>
</tr>
<tr>
<td>1960s and onwards</td>
<td>Expansion of district heating systems</td>
<td>The first district heating system was in operation in 1948 but more rapid development started in the 1960s. The network of DH systems is still growing.</td>
</tr>
<tr>
<td>1975</td>
<td>Energy policy decision</td>
<td>States that the energy supply should be based, as far as possible, on domestic resources.</td>
</tr>
<tr>
<td>1975-1987</td>
<td>The Building Act (136a)</td>
<td>Government approval needed for handling large amounts of wood fibre.</td>
</tr>
<tr>
<td>1975-</td>
<td>Energy research programme</td>
<td>Provides subsidies for bioenergy research.</td>
</tr>
<tr>
<td>1981-1986</td>
<td>Investment grants for peat combustion plants</td>
<td>Plants are also suitable for biomass</td>
</tr>
<tr>
<td>1982-1994</td>
<td>The Solid Fuel Act</td>
<td>Plants producing more than 50 GWh must be designed so that they can use solid fuels</td>
</tr>
<tr>
<td>1986-</td>
<td>The National Board of Forestry’s guidelines for regulating extraction of tree parts etc.</td>
<td>Concerned with the removal of nutrients from forest land. Different restrictions on biomass extraction are stipulated for different types of soils and stands.</td>
</tr>
<tr>
<td>1988-</td>
<td>Energy Technology Fund</td>
<td>Grants for the development of technologies for biomass-based transportation fuel production, biomass gasification and biomass production.</td>
</tr>
<tr>
<td>1989</td>
<td>Vattenfall (The State Power Board) announces that 1,000 million SEK will be devoted to bioenergy R&amp;D</td>
<td>Development of cogeneration technology initiated but after a few years this is redirected to exploring environmental implications and market opportunities for biomass.</td>
</tr>
<tr>
<td>1991</td>
<td>Three-party agreement on energy policy</td>
<td>Leads to new forms of financial support for renewable energy. The ensuing deregulation of the electricity market resulted in reduced interest in high electricity-to-heat ratios and gasification technologies.</td>
</tr>
<tr>
<td>1991-1995</td>
<td>Investment grants for biomass-based cogeneration plants are introduced</td>
<td>Leads to increased establishment of Salix plantations thanks to financial aid for planting and subsidies related to the areas used for energy crop cultivation.</td>
</tr>
<tr>
<td>1991-1996</td>
<td>Investment grants for the expansion of district heating systems.</td>
<td>District heating systems form a solid basis for biomass expansion.</td>
</tr>
<tr>
<td>1991</td>
<td>Reformation of the energy taxation system with the introduction of a CO₂ tax</td>
<td>Results in improved competitiveness for biomass used for heating purposes.</td>
</tr>
<tr>
<td>1995-</td>
<td>Sweden joins the EU and is obliged to follow the CAP (Common Agricultural Policy).</td>
<td>Leads to a halt in the establishment of Salix cultivations as a result of lower and unpredictable subsidy levels.</td>
</tr>
<tr>
<td>1998-</td>
<td>FABEL is transformed into a system for supporting the introduction of new energy technologies.</td>
<td>State-financed local investment programmes were introduced resulting in investments in expansion of district heating systems and conversion to biomass-based heating.</td>
</tr>
<tr>
<td>1998-</td>
<td>LIP-KLIMP</td>
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There are, however, also structural factors in Sweden that hamper bioenergy expansion for heating purposes. The most important of these is the extensive use of electric space heating which was a consequence of the large quantities of electricity available at low cost at the end of the 1970s and the beginning of the 1980s. This was a result of the rapid expansion of nuclear power, which coincided
with radical increases in the price of oil, which had totally dominated the heating market during the 1970s. Substituting electric heating with biomass is often difficult and expensive as in many cases water-based heating distribution systems, access to district heating systems, and chimneys are lacking (the latter is of relevance only when individual biomass heating is the option of interest). Some buildings are heated with electricity employing water-based distribution systems and these are therefore easier to convert to biomass-based heating systems.

The existence of a high electricity production capacity in northern Europe has restricted the expansion of biomass-based electricity since this has led to too low electricity prices for biomass to be able to compete. The existing policy instruments, mainly investment grants, have not been sufficient to fully compensate for these low electricity prices.

No significant growth of biomass-based systems in individual private buildings has been experienced as a result of the rather high investment costs and a reluctance to replace well-functioning existing heating systems. In addition, after 1970 more than 50% of the new houses were not constructed for individual boilers and many of them for that reason lack chimneys, hydronic systems and sufficient space for boilers and fuel storage. Conventional individual biomass burning in built-up areas is generally not recommended for air pollution reasons. The market for pellets for individual heating systems seems, however, to have good potential in the near future due to increasing taxation on competing energy carriers. Pellet systems are, furthermore, simpler to handle and produce significantly lower emissions of soot and VOCs than do conventional biomass boilers.

Geographical factors have restricted the feasibility of straw use in the Swedish energy system. The weather conditions, with a wet autumn climate, result in relatively few days suitable for straw harvest and the reliability of straw supply is thus poor.

Policy. A sustained commitment to renewable energy has existed in Sweden since the referendum on nuclear power and the biomass sector has expanded since then. The perhaps single most important decision that spurred the expansion of biomass was the tax reform in 1991 that radically improved the economic competitiveness of biomass, especially compared with coal. The use of coal expanded at the expense of oil during the 1980s when oil substitution was the main issue. During the following ten years the carbon tax continued to increase and the general level is today 2.5 times higher than when it was introduced in 1991. Other policy initiatives, such as investment grants for electricity production, as well as more general policy statements, have all contributed to establishing confidence that biomass will be supported in one way or another in the future. In addition, bioenergy R&D, which has been ongoing for over more than two decades, has facilitated improvements throughout the fuel chain. In the even longer perspective, a century-long political commitment to developing the productivity of forest resources has been essential in building up the large forest resources currently available in Sweden.

However, there are also policies that counteract potential biomass production in Sweden. Most important is perhaps the common agricultural policy (CAP), which, through the construction of its subsidy system, supports conventional annual food crops in preference to perennial energy crops. The mere existence of an unpredictable subsidy system makes long-term investments in perennial short-rotation forestry (which would have a lifetime of approximately 25 years for best economy) unattractive. The promising development of short-rotation forestry on Swedish surplus land has almost stagnated at a level corresponding to 0.5-1% of the total Swedish biomass supply.

The difference in regulations regarding the handling of waste wood between Sweden on the one hand and Germany and the Netherlands on the other, has led to increased importation of waste wood, which competes with domestic logging residues in Sweden. The use of domestic logging residues has declined during the last years while simultaneously the total amount of biomass used has increased.

Actors. Efficient logistics are essential for competitive bioenergy systems. The vertically integrated forest industries and forest owner’s organisations (that also own several large forest industries) have qualifications for handling new systems that include an energy assortment. The engagement of different companies and organisations has, however, varied between and within organisations (Ling, 1999).
Especially in the 1980s and the beginning of the 1990s, the forest sector as a whole showed some reluctance to promote the rapid expansion of biomass use due to the fear of feedstock competition in their core area, namely paper and pulp production. On the whole, the existence of strong, and efficient actors, responsive to new market areas, has, however, facilitated an increase in the use of biomass.

In Sweden there are companies engaged in the construction of heat and power plants as well as forest machinery. In response to the increasing biomass demand, these groups of companies have been engaged in developing new modern technologies for biomass combustion and technologies for logging residue extraction. The expansion of biomass in district heating has led to the introduction of flue-gas condensation, which has enabled efficiency gains in biomass plants of 10-25% (Johansson, 2000). Sweden, together with Finland, is one of the leading producers of forestry machinery. R&D organisations, machinery producers and forestry organisations together form an innovative environment for the development of technologies that enable the extraction of logging residues at lower, competitive costs. The real price of logging residues has fallen by 50% during the recent decades. This reduction is partly the result of technological development and partly an effect of more efficient administration and lower revenues for land owners.

District heating companies have responded very quickly during recent decades to new policy signals. During the 1980s, high taxation led to the rapid replacement of oil by an expansion of coal and electric heating. In response to new economic conditions in the 1990s interest turned to biomass. District heating companies, in contrast to households, are professional organisations that analyse the production costs of their plants much more carefully and compare them to alternatives. They can therefore be expected to react more quickly to changes in the taxation system. The fact that many of the companies are, or have until recently been, publicly owned has probably increased their sensitivity to local political environmental goals, which has led to investments also in such biomass technologies which, from a strictly business economic point, appears questionable.

Power-generating companies have also reacted to the new political signals and devoted considerable fractions of their RD&D spending to biomass. Traditional power companies have also played an increasing role in the biomass market through the acquisition of district heating systems and the starting up of new business areas in the heat supply sector.

Domestic consumers have so far not been as active actors as those on the municipal district heating market. The growth of companies supplying refined biofuels (e.g. wood pellets) for domestic heating, however, increased towards the end of the 1990s. In some cases, municipalities have reduced the expansion of small-scale firewood heating for environmental reasons. Small-scale firewood heating is not recommended in built-up areas unless modern combustion technologies (including water accumulator tanks) are used.

6. Lessons Learned for the European Arena

The main prerequisite for biomass supply is, of course, available biomass resources. Countries with large forest resources will probably have good opportunities to use some of these resources for energy purposes. The existence of a forest industry and professional organisations for handling large biomass flows will probably allow a low cost biomass supply. The geographical locations of the forest resources in relation to the demand will strongly affect the competitiveness of biomass. The economy of long-distance biomass transport (>150 km) depends on the existence of sea or rail transport systems.

For many countries agriculture will be the main potential producer of biomass. Key factors such as high productivity and low production costs will determine which biomass resource is competitive in the energy sector. Agriculture throughout Europe is highly dependent on subsidies, which generally promote conventional labour-intensive products such as cereals, corn and oil seed crops. These crops are not likely to be competitive on the energy market due to their high production costs. If subsidies are excluded, the most competitive crops in Europe regarding energy would be perennial crops that are less labour-intensive than conventional crops. Radical changes in agricultural subsidies and in many
countries, in agricultural structure would be required for an expansion of such crops. Achieving coherence in agricultural and energy policies is perhaps the greatest challenge facing biomass in Europe. Even with current policies, however, considerable energy sources could be provided by agricultural land in the form of straw. Although the climatic conditions in Sweden are not favourable for straw harvest, this is not necessarily the case in other countries. For example, straw is much more widely used in Denmark than in Sweden.

The existence of centralised heat production systems has been a central factor in the rapid expansion of biomass in Sweden. Large industrial consumers and centralised systems are therefore strategic resources for successful and cost-efficient biomass exploitation. Several studies show that the use of biomass for heating purposes (in boilers, or if possible in combined heat and power plants) provides the most efficient way of utilising biomass in a strategy for reducing the emission of greenhouse gases. Major district heating systems exist in, for example, central and eastern Europe, Denmark and Finland. The expansion of centralised systems in other countries could probably be motivated as a means of improving air quality and providing a basis for efficient electricity production in the form of CHP.

The introduction of high taxes on fossil fuels was essential for the biomass expansion in Sweden. Sweden has no fossil fuel sources of its own which has made this strategy less controversial than may be the case in countries with large fossil fuel resources, employing many. The reformation of energy taxation was part of the restructuring of the whole tax system, which is based on high taxes. The possibility to apply high energy and environmental taxes in other countries will probably depend on the structure of the existing tax system and the general attitude towards taxation per se. Sweden has also only minor problems associated with low-income households not being able to afford heating costs. This is partly due to high energy efficiency standards in Swedish buildings and the way in which the social security system is constructed. There are also some important exemptions from high taxes on fossil fuels in the industrial sector\(^9\) and electricity sector, which reduce the effect on the competitiveness of Swedish industry.

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\(^9\) Although the energy and carbon taxes are much lower for industry than for other sectors they are still rather high compared with competing countries.
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