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WOOD PELLET PRODUCTION COSTS UNDER AUSTRIAN FRAMEWORK CONDITIONS

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ABSTRACT: Both the production and the demand of wood pellets in Austria as well as in several other European countries show a strong increase since several years. Many companies, mainly from the wood industry, which have appropriate raw materials available for the production of wood pellets, are already active in this field or are planning to enter this market. Moreover, companies which have to buy the raw materials for the wood pellet production as well as companies with drying capacities are interested and partly also already active in the market for wood pellets. Even wood chips and log wood are gaining increasing interest as raw materials for pellet production plants, due to the further rising pellet demand and the limited availability of sawdust. To start a pellet production plant it is essential to calculate the pellet production costs in advance in order to consider, investigate and optimize the specific framework conditions of the producer for an economic operation. Respective calculations performed for different scenarios under Austrian framework conditions show that a wood pellet production is possible both in small-scale (production rates of some hundred tons per year) as well as in large-scale plants (some ten thousand tons per year) from different raw materials (dry wood shavings, wet sawdust, wood chips, log wood). However, it is very important to take care of the specific framework conditions of the producer – in particular for small-scale units, because the risk of a non-economic pellet production is considerably higher than for large-scale systems. Sensitivity analyses performed to evaluate the influence of different parameters on the total pellet production costs indicated, that the most important influencing factors are the pellet throughput, the plant availability, the annual full load operating hours, the raw material costs and the specific heat costs. The costs for raw material and for drying can cover up to almost 80% of the total pellet production costs.
Keywords: pellet, pelletization, wood pellet, cost analysis, economics, round wood.

1 INTRODUCTION AND OBJECTIVES

Both the production and the demand of wood pellets in Austria as well as in several other European countries show a strong increase since several years. Many companies, mainly from the wood industry, which have appropriate raw materials available for the production of wood pellets are already active in this field or are planning to enter this market. Moreover, companies which have to buy the raw materials for the wood pellet production as well as companies with drying capacities are interested and partly also already active in the market for wood pellets. Even wood chips and log wood are gaining an increasing interest as raw materials for pellet production plants, due to the further rising pellet demand and the limited availability of sawdust. To start a pellet production plant it is essential to calculate the pellet production costs in advance in order to consider, investigate and optimize the specific framework conditions of the producer for an economic operation.

Comprehensive investigations and calculations of the production costs of wood pellets under consideration of all relevant parameters and for different framework conditions have been performed within the project presented [1]. The calculations are based on data from planned and already realized pellet production plants and consider the whole production chain from the raw material till the pellet storage.

A further objective of the work was the performance of sensitivity analyses of important cost factors in the pellet production process.

2 METHODOLOGY

An economic evaluation of the steps of the manufacturing process was made using the full costing method based on the guideline VDI 2067 [2]. According to this guideline, the different types of costs are divided into four cost groups. These are

- the costs based on capital (capital and maintenance costs),
- the consumption costs,
- the operating costs
- and the other costs.

The costs based on capital consist of the annual capital and maintenance costs. The annuity (annual capital costs) can be calculated by multiplying the capital recovery factor (CRF, see Equation 1) with the investment costs. The annual maintenance costs are calculated in percent of the whole investment costs on the basis of guiding values and are evenly spread over the years of the utilization period. The capital and maintenance costs are calculated for each unit of the overall pelletization plant, taking the different wear and utilization periods into consideration. The total capital and maintenance costs can be calculated by addition of these subtotals.

Equation 1: $$CRF = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$

Explanations: CRF…capital recovery factor; i…real interest rate [% p.a.]; n…utilisation period [a]

No investment subsidies are considered for the calculation of the pellet production costs. The interest rate considered is generally 6% p.a. (no difference between own and borrowed capital).

All costs in connection with the manufacturing process, e.g. the costs for the raw material, the heat for drying and the electricity demand are included in the group of consumption costs. The operating costs comprise costs originating from the operation of the plant, e.g. personnel costs. The other costs include costs

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such as insurance rates, overall dues, taxes and administration costs and are calculated as a percentage of the overall investment costs. These cost data are based on already gained experiences from pellet production plants planned or already in operation.

The following parameters must be considered in a detailed calculation of the pellet production costs:

- The investment costs of all units of the pellet production process (including the raw material pre-treatment, which depends on the raw material used), of construction, infrastructure and planning as well as the utilization periods and maintenance costs of all units and facilities.
- The raw material costs as well as the water content and the bulk density of the raw material used.
- The price for electricity and the own electricity demand of the production plant usually calculated based on the electrical power required for all electrical installations and a simultaneity factor, which considers the fact that not all electrical installations operate on full load at the same time.
- The interest rate.
- The availability of the plant, which considers both scheduled and unscheduled shutdowns.
- In case a raw material drying is necessary, the specific heat costs and the heat demand for drying.
- The costs and the demand of bio-additives that may be used and the corresponding dosing system.
- If a conditioning unit is for the raw material used, the demand and the costs of the hot water or the steam used for conditioning.
- The storage costs for wet and dry raw materials as well as for pellets, depending on the storage capacity and the kind of storage system used (open-air storage, storage building, silo storage), taking an average storage filling level and average days sales outstanding (gap between pellet delivery and incoming payment) into account.
- The kind of shift work (plant utilization).
- The personnel costs both for production, marketing and administration.
- The annual pellet production rate as well as the water content and the bulk density of the pellets produced.
- Other costs.

From these data both the total pellet production costs as well as the costs caused by each unit or cost factor of the pelletization process can be calculated. This has in a first step been done for a base case scenario under Austrian framework conditions, including the performance of sensitivity analyses for important influencing parameters. Subsequently, the pellet production costs for eight different scenarios have been calculated and compared to the base case scenario.

All costs calculated are based on the year 2008. Distribution costs (by an own distribution system from the producer or by retailers) and taxes are not considered, following the costs calculated are pellet production costs loco factory before taxes.

3 BASE CASE SCENARIO

The total pelletization process has been separated into drying, grinding, pelletization, cooling, storage and peripheral equipment and is based on sawdust as raw material. The personnel costs as well as construction costs have been calculated for the whole plant (only the storage costs include the investment costs related to construction directly). Finally, the raw material costs have been determined.

The framework conditions for the calculation of the base case scenario are shown in Table I and are discussed in detail in the following sections.

Table I: Framework conditions for the calculation of the pellet production costs for the base case scenario

Parameters	Unit	Value
General conditions		
Price for electricity	€/MWh	100
Specific electricity consumption	kWh/$t_{pellets}$	113.9
Interest rate	% p.a.	6.0
Other costs	% p.a.	2.8
Equipment availability	%	91.3
Simultaneity factor (electrical installations)	%	85
Utilization period construction	a	50
Service and maintenance costs construction	%	1.0
Utilization period infrastructure	a	15
Service and maintenance costs infrastructure	%	1.0
Utilization period planning	a	20
Average service and maintenance costs of dryer, hammer mill, pellet mill, cooler, peripheral equipment	%	2.4
Raw material data		
Raw material		Sawdust
Water content	wt.% (w.b.)	55
Bulk density (d.b.)	kg (d.b.)/m^3	120
Raw material price	€/m^3	7.8
Drying data		
Dryer type		Belt dryer
Specific heat costs	€/MWh	35.0
Required electric power (including feeding)	kW	140
Heat demand for drying	kWh/$t_{ev.w.}$	1,200
Utilization period	a	15
Grinding data		
Grinding unit type		Hammermill
Required electric power	kW	110
Utilization period	a	15
Pellet mill data		
Pellet mill type		Ring die
Required electric power	kW	300
Hot water consumption for conditioning per ton pellets produced	wt.%	1.0
Specific heat costs (hot water)	€/t	2.7
Bio-additive demand	%	1.0
Costs for bio-additives	€/$t_{pellets}$	2.3
Utilization period	a	15
Cooling data		
Cooler type		Counterflow cooler
Required electric power	kW	12.0
Utilization period	a	15
Storage data		
Open-air storage for wet sawdust		
Utilization period	a	50
Service and maintenance costs	%	1.0
Storage capacity (in % of the annual demand)	%	1.9
Silo storage for dried sawdust		
Utilization period (silo 15 a, construction 50 a)	a	22.3
Service and maintenance costs	%	1.5
Storage capacity (in % of the annual demand)	%	0.4
Pellet storage		
Utilization period (silo 15 a, construction 50 a)	a	22.2
Service and maintenance costs	%	1.5
Storage capacity (in % of the annual pellet production)	%	2.3
Average storage filling level (in % of the storage capacity)	%	50
Average days sales outstanding	days	14
Peripheral equipment data (conveying systems, steel construction)		
Required electric power	kW	108
Utilization period	a	15
Pellet data		
Pellet troughput	t (w.b.)/h	5.0
Annual pellet production	t (w.b.)/a	40,000
Water content pellets	wt.% (w.b.)	10.0
Bulk density pellets	kg (w.b.)/m^3	625
Diameter pellets	mm	6.0
Retail price for pellets (exclusive VAT)	€/t (w.b.)	162.8
Kind of shift work		
Shifts per day		3
Working days per week		7
Annual full load operating hours	h p.a.	8,000
Personnel data		
Hourly rate	€/h	25.0
Persons per shift		1.0
Persons for deputyship per shift (holidays, illness)		0.25
Personnel for administration and marketing	€/a	73,000

3.1 General conditions

The number of 8,000 annual full load operating hours are based on the assumption of a continuous plant operation on 7 days per week and 24 hours per day, taking an equipment availability of 91.3% into account (based on practical experiences of pellet producers), and follows the actual trend of continuously operated pellet production plants. Based on the throughput of 5 $t_{pellets}$/h chosen, an annual pellet production of 40,000 tons results.

An average price for electricity for medium-sized enterprises in Austria amounts to about 100 €/MWh. The electricity price for small-sized enterprises would be higher.

The simultaneity factor for electricity demand (= electric power needed on average / nominal electric power of all units × 100) has been assumed to be 85% and is based on experiences of plant operators.

The interest rate chosen is an average real interest rate currently achievable.

The utilization period and the maintenance costs chosen for construction according to the guideline VDI 2067 are 50 years and 1% of the investment costs per year, respectively. Investments in infrastructure are calculated with an utilization period of 15 years and maintenance costs of 1% of the investment costs per year. The utilization period for planning has been calculated with 20 years (without maintenance costs).

The service and maintenance costs for the dryer, the hammer mill, the pellet mill, the cooler and the peripheral equipment are calculated as an average of these units and are based on experiences from pellet producers.

Insurance rates, overall dues, taxes and administration costs are summarized under other costs. These costs are taken into consideration with an amount of 2.8% of the overall investment costs per year and are based on experiences of pellet producers.

3.2 Drying

The most important raw material for pellet production plants in Austria is sawdust, which is usually available with a water content of 55 wt.% (w.b.) from sawmills. Therefore, sawdust has been taken as a basis for the calculation of the base case scenario and consequently, the raw material must be dried from 55 to 10 wt.% (w.b.).

For the calculation of the drying costs the most important drying technology used in pellet production plants in Austria, i.e. belt dryer, has been considered.

The utilization period has been chosen based on producer experiences.

The heat demand for drying of belt dryers amounts to about 1,200 kWh per ton evaporated water. The required electric power includes control system, belt washer, screw for product spreading on the belt and feeding system. These data are based on information from dryer manufacturers.

The specific heat costs for drying are based on hot water with a feed temperature of 90°C from a biomass hot water boiler [3].

3.3 Grinding

Raw material grinding in the pelletization process is usually done with hammer mills. The utilization period has again been chosen based on information from pellet producers. The required electric power is based on data for a hammer mill suitable for this plant size from a respective manufacturer.

3.4 Pelletization

The costs for pelletization itself also include costs for conditioning and biological additives. Two main technologies are available for pelletization, i.e. ring die and flat die pellet mills. Most of the pellets produced in Austria are produced with ring die pellet mills, which form therefore the basis for this calculation.

The required electric power includes not only the main drive of the pellet mill but also the raw material feeding system and the mixing screw of the conditioner.

Biological additives are, if any, usually added in an amount of about 1 wt.% of the pellet mass and are therefore of minor importance for the total pellet production costs. Moreover, also the costs for conditioning (if applied) are of minor relevance concerning the total pellet production costs.

The utilization period of pellet mills is assumed to be 15 years.

3.5 Cooling

Due to the upstream conditioning (with hot water or steam) and the friction in the pellet mill, the pellets leave the mill with 100°C and more. Therefore, they have to be cooled before they are stored. The coolers commonly used are counterflow coolers. For very small pellet mills with low throughputs a subsequent cooler is not necessary.

Utilization period and required electric power are based on information from pellet producers and cooler manufacturers, respectively.

3.6 Raw material and pellet storage

Wet raw material (sawdust) is usually stored at paved open-air storages. In order to ensure some flexibility in storage and transport logistics, a storage capacity of about one week has been considered. Intermediate storage for dried raw materials is usually done in silos. Their storage capacity can be kept comparatively small, as both dryer and pellet mill usually operate continuously and only short shut-downs must be buffered. A storage capacity of only 36 hours has therefore been taken into account. Also pellets are usually stored in silos. The pellet storage capacity has been chosen to be approximately 8 days, which ensures some flexibility in the distribution of pellets.

The utilization periods have been chosen with 15 years for the silos itself and with 50 years for constructional parts of silo storage systems and open-air storages with maintenance costs of 1.0% for open-air storages and 1.5% of the investment costs for silo storage systems.

3.7 Peripheral equipment

Peripheral equipment includes the costs of investments and electrical power required for motors of feeding systems, the sieving machine, fans, cell air locks, etc. which have not been considered directly in one of the main components described before. The utilization period of these systems has been chosen with 15 years.

3.8 General investments

The general investments (see Table II) include investments for construction, infrastructure (asphalt, transformer, water supply) and planning. The general investment costs are dominated by the planning costs.

3.9 Personnel

Personnel costs include both costs for personnel in the production as well as in marketing and administration.

In the production usually one person is needed for the whole pelletization plant per shift. In addition to the personnel needed per shift, a quarter person has been calculated for deputyship (holydays, illness). This means, that 1.25 persons are needed to operate the plant. Due to an operation around the clock throughout the year operating staff is needed at 8,760 hours per year leading to 10,950 annual working hours (corresponding to 6.25 full time equivalents). Based on a hourly rate of 25 €/h personnel costs amount to 273,750 €/a. Two full time persons are calculated for marketing and administration with annual costs of 73,000 € leading to total annual personnel costs of 346,750 €/a.

3.10 Raw material

Wet sawdust with a water content of 55.0 wt.% (w.b.) and a bulk density of 267 kg (w.b.)/m^3 formed the basis for the calculations of the base case scenario. The raw material price for wet sawdust loco pellet producer taken into consideration is 7.82 €/m^3 (or 65.2 €/t (d.b.)). The price is an average price for the year 2008 under Austrian side constraints (softwood, prices loco pellet producer including transportation costs). This price leads to annual raw material costs of about 2.3 million €.

3.11 Total pellet production costs

The results of the calculation of the total pellet production costs are shown in Table II. They amount for the base case scenario to 136.6 €/$t_{pellets}$. Figure 1 shows the composition of the pellet production costs according to the guideline VDI 2067. It can be seen, that the specific pellet production costs are dominated by the consumption costs, followed by the costs based on capital and the operating costs (personnel costs). The other costs are of minor relevance. The consumption costs are dominated by the raw material and heat costs (see Figure 2).

Table II: Calculation of the pellet production costs for the base case scenario

	Investment costs €	Capital costs € p.a.	Maintenance costs € p.a.	Consumption costs € p.a.	Operating costs € p.a.	Other costs € p.a.	Total costs € p.a.	Specific costs €/$t_{pellets}$
Drying	950,000	97,815	23,180	1,775,200		26,410	1,922,605	48.1
Grinding	206,000	21,210	5,026	74,800		5,727	106,764	2.7
Pelletization	467,000	48,084	11,395	295,080		12,983	367,541	9.2
Cooling	32,000	3,295	781	8,160		890	13,125	0.3
Storage	1,083,000	87,284	15,680	20,836		30,107	153,907	3.8
Peripheral equipment	435,000	44,789	10,614	73,440		12,093	140,936	3.5
Personnel					346,750		346,750	8.7
Raw material				2,346,000			2,346,000	58.7
General investments	570,300	47,818	2,300			15,854	65,972	1.6
Total	3,743,300	350,294	68,976	4,593,516	346,750	104,064	5,463,599	136.6
Specific costs in €/$t_{pellets}$		8.8	1.7	114.8	8.7	2.6		136.6

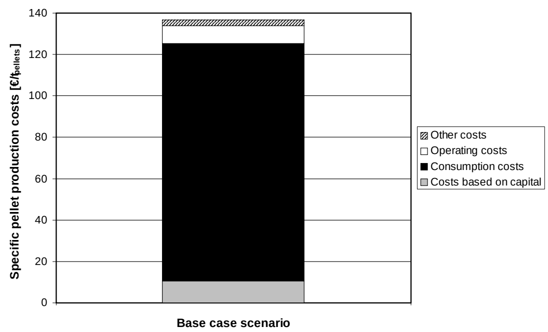

Figure 1: Pellet production costs and their composition according to the guideline VDI 2067 for the base case scenario
Explanations: specific pellet production costs loco factory 136.6 €/$t_{pellets}$; the calculation is based on the framework conditions according to Tables I and II; data source [1]

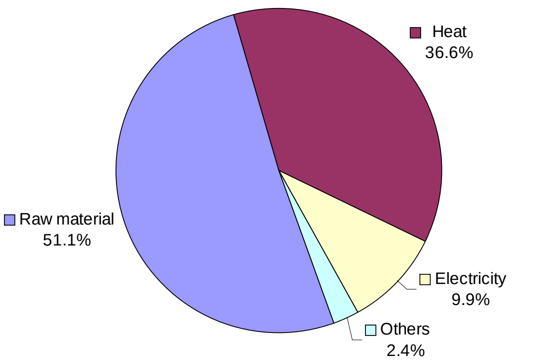

Figure 2: Composition of the consumption costs
Explanations: specific consumption costs loco factory 114.8 €/$t_{pellets}$; the calculation is based on the framework conditions according to Tables I and II; data source [1]

Figure 3 shows the composition of the pellet production costs according to the different cost factors. It can be seen, that the main cost factors are the raw material and the drying costs, covering together almost 80% of the total pellet production costs.

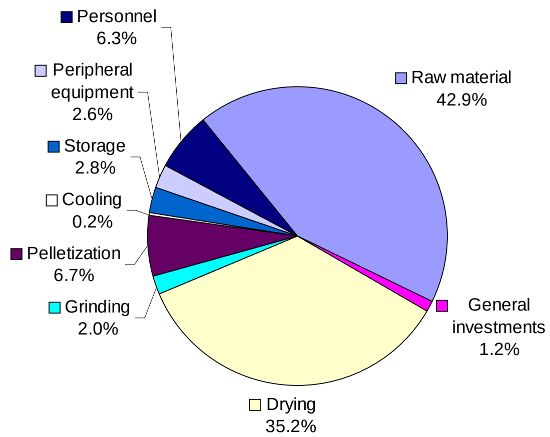

Figure 3: Pellet production costs and their composition according to the different cost factors
Explanations: specific pellet production costs loco factory 136.6 €/$t_{pellets}$; the calculation is based on the framework conditions according to Tables I and II; data source [1]

The grinding unit is the second largest electricity consumer in the pelletization process (behind the pellet mill). However, the influence of the grinding costs on the total pellet production costs is comparatively low.

Behind raw material and drying the pelletization itself is the main cost factor of the overall pelletization process. The most relevant cost item of the pelletization step itself is the electricity consumption, followed by the investment costs.

In spite of quite high investment costs for the storage system, the influence of the storage costs on the total pellet production costs is relatively low.

The influence of the costs caused by peripheral equipment, cooling and by general investments on the total pellet production costs is low. Only the personnel costs are a further relevant cost factor.

3.12 Sensitivity analyses

In order to determine the impact of different parameters on the total pellet production costs, sensitivity analyses have been performed by varying each parameter one by one by plus or minus 10%. The respective results are summarized in Figure 4.

The specific pellet production costs are mainly influenced by the pellet throughput, the availability of the plant, the annual full load operating hours, the raw material costs and the specific heat costs.

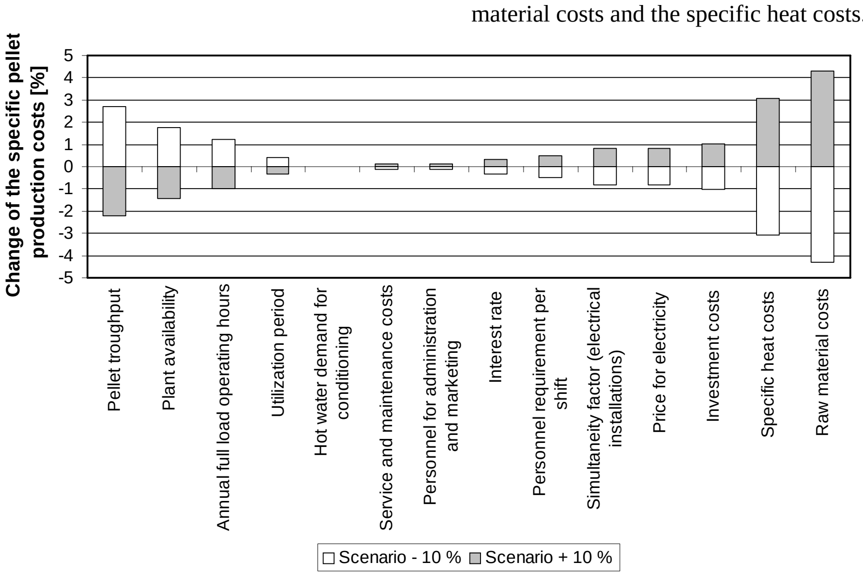

Figure 4: Influence of different parameters on the total pellet production costs
Explanations: the calculation is based on the framework conditions according to Tables I and II; sensitivity analyses performed by varying each parameter one by one by plus or minus 10%

The pellet throughput can e.g. be increased by using appropriate bio-additives (e.g. maize or rye flower), which act as a lubricant in the pellet mill. As it is shown in Figure 5 this is a good possibility to decrease the total pellet production costs. On the other hand, a low throughput (e.g. caused by a raw material which is too dry) leads to strongly increased pellet production costs.

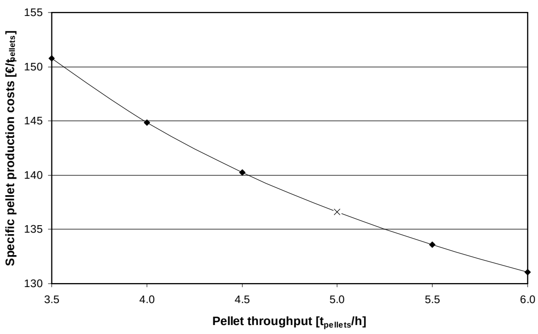

Figure 5: Dependency of the total pellet production costs on the pellet throughput
Explanations: x…base case; specific pellet production costs loco factory; the calculation is based on the framework conditions according to Tables I and II

The dependency of the total pellet production costs on the raw material price (wet sawdust) is shown in Figure 6. Considering a possible variation of the raw material price from about 7.0 to 11.0 €/m^3, the resulting pellet production costs variation amounts to almost 23%. Thus, it becomes obvious that the economy of a pellet production plant is strongly dependent on the raw material price. In this context it is important to take the advantage of a proper selection of the plant location into account. If transportation costs of the raw material can be avoided by combining raw material producer (i.e. a sawmill) and the pellet producer at one site, a substantial economic advantage could be achieved.

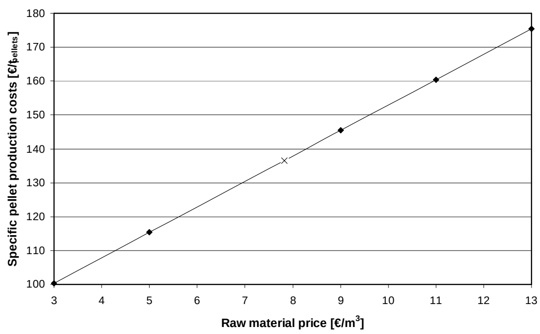

Figure 6: Dependency of the total pellet production costs on the raw material price
Explanations: x…base case; specific pellet production costs loco factory; the calculation is based on the framework conditions according to Tables I and II

The annual full load operating hours are a further important influencing factor on the total pellet production costs. Based on the results shown in Figure 7 it becomes obvious, that reduced annual full load operating hours rapidly lead to an uneconomic operation. A low plant availability leads to a similar effect. In this context it must also be taken into account, that it is not meaningful to operate the plant only one or two shifts per day, because a daily start up and shut-down of the dryer cannot be recommended. Therefore, at least three shifts per day at five days per week are recommended for an economic production of wood pellets. The optimum would be a seven-day per week operation.

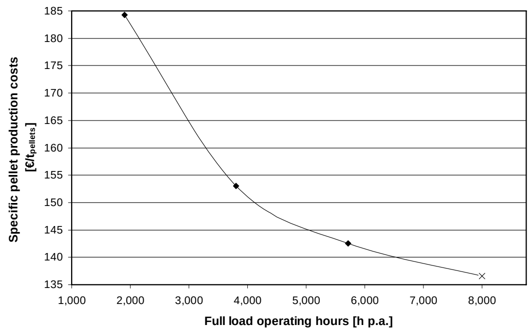

Figure 7: Dependency of the total pellet production costs on the annual full load operating hours
Explanations: x…base case; specific pellet production costs loco factory; the calculation is based on the framework conditions according to Tables I and II

The influence of the specific heat costs on the total pellet production costs is substantial and is shown in Figure 8. They have been assumed to be 35.0 €/MWh for the base case scenario, taking a heat supply by a biomass hot water boiler into account. The result shows the great potential for cost reduction by cheap heat as well as the great danger of increased costs in this field. By suitable combination of pellet production plants with biomass CHP plants specific heat prices as low as 25.0 to 30.0 €/MWh could be achieved under appropriate framework conditions, which would lower the specific pellet production costs by 4.4 to 8.8%.

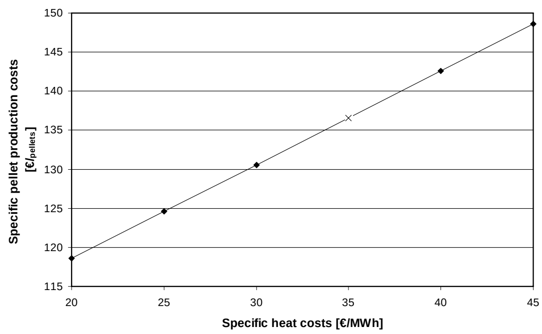

Figure 8: Dependency of the total pellet production costs on the specific heat costs
Explanations: x…base case; specific pellet production costs loco factory; the calculation is based on the framework conditions according to Tables I and II

4 DIFFERENT SCENARIOS UNDER AUSTRIAN FRAMEWORK CONDITIONS

The pellet production costs calculated in the previous section refer to an average case under Austrian framework conditions. Depending on the specific framework conditions of different producers, the pellet production costs can, however, vary in a broad range. In order to investigate the influence of different parameters on the pellet production costs comprehensive sensitivity analyses have been performed (see section 3.12). In this section the influences of site-specific framework conditions and of different plant sizes on the economy of pellet production plants are shown and discussed.

Table III gives an overview of all relevant parameters differing from the base case scenario. The pellet production costs of each scenario have been calculated applying the same methodology as described in section 3.

Scenario 1 is based on the assumption, that wood shavings are used as a raw material instead of sawdust. Compared to the base case scenario only a silo storage for the raw material is used in this case, as the outdoor storage of dry wood shavings would not be meaningful due to the danger of re-humidification. The storage capacity for the dry raw material is assumed to be the same as for the intermediate storage of the base case scenario, which can be done, if the raw material production is at the same location as the pellet production plant and the raw material storage can therefore be designed as an intermediate storage. Moreover, in this case also the raw material transportation costs can be avoided. Due to the use of dry raw material, the drying step can completely be avoided. This results in a reduced electricity and mainly heat demand and the total investment costs are reduced substantially. In this scenario the specific pellet production costs can be lowered by about 25% compared to the base case scenario. The cost reduction effect is partly compensated by the more expensive raw material. The costs of wood shavings are about 27% higher compared to the costs of sawdust (related to dry substance). The composition of the pellet production costs for scenario 1 is completely different (see Figure 9 compared to Figure 3). Due to the use of dry raw material no drying costs occur and the share of raw material costs increases to almost 73% of the total pellet production costs. The other cost factors are changed accordingly.

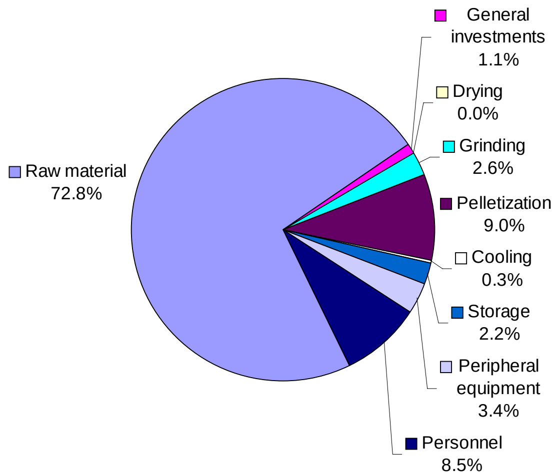

Figure 9: Pellet production costs and their composition according to the different cost factors for scenario 1
Explanations: specific pellet production costs loco factory 102.5 €/t$_{pellets}$; the calculation is based on the framework conditions according to Table III

Scenario 2 is an upscale of the base case scenario, based on the threefold annual pellet production (i.e. 120,000 t$_{pellets}$/a) and the same annual full load operating hours. Therefore, the different units of pellet production (drying, grinding, pelletization, cooling, peripheral equipment and construction) must be designed for the threefold throughput. The storage capacity must be increased accordingly. An economy-of-scale effect has been considered to be between 15% and 20% for the different units. Due to this upscale, the specific pellet production costs can be decreased by about 6.4%

(compared to the base case scenario). This result confirms the economic reasonability of the current trend in Austria to large pellet production plants.

A small-scale pelletization is shown in scenario 3. This is an example for a small pellet producer who produces pellets according to the raw material availability from his own industrial plant. The raw material is dry wood shavings and is pelletized at a second-hand pellet mill from the animal feed industry. The pellet production amounts to 430 $t_{pellets}$/a. This scenario shows, that an economic pellet production can be achieved in small-scale plants if good framework conditions are available (in this case extremely cheap electricity due to an own hydropower station, existing storage facilities, dry raw material without drying and grinding demand, no cooling demand due to the low throughput and extremely cheap raw material based on the maximum achievable sales price in the respective region).

The throughput of scenario 4 (0.5 t/h) is even below of that of scenario 3. However, due to the assumed one-shift operation at 5 days per week the annual pellet production is higher. The raw material is also dry wood shavings. Consequently, drying, grinding and cooling can also be saved in this scenario. The investment costs are based on new equipment and electricity price as well as raw material costs are based on an average Austrian prices for this framework conditions. Consequently, investment, electricity and raw material costs are higher, which leads to increased pellet production costs of approximately 181 €/$t_{pellets}$, which is higher than the limit for an economic operation (which is approximately between 140 and 155 €/$t_{pellets}$, depending on the distribution system) [1]. A pellet mill with a throughput of 1.2 t/h as considered in scenario 5 can lower the pellet production costs under the same framework conditions as for scenario 4 to about 162 €/$t_{pellets}$. However, they are still higher than the limit for an economic operation.

Table III: Main differences in the framework conditions of the scenarios considered compared to the base case scenario
Explanations: 1)…related to the annual demand; 2)…log wood in solid cubic meter; IWC w. bark…industrial wood chips without bark

Parameters	Unit	Base case	Scenario 1 Dry raw material	Scenario 2 Upscale	Scenario 3 Small-scale	Scenario 4 Small-scale	Scenario 5 Small-scale	Scenario 6 Small-scale	Scenario 7 Wood chips	Scenario 8 Log wood
General conditions										
Price for electricity	€/MWh	100	100	100	45	120	120	110	100	100
Total electricity consumption	GWh/a	4.56	3.60	12.93	0.03	0.08	0.27	0.11	5.75	7.79
Specific electricity consumption	kWh/$t_{pellets}$	113.9	90.1	107.8	75.3	88.4	119.4	100.1	143.7	194.7
Total investment costs	€	3,743,300	2,112,000	9,176,200	53,424	184,440	809,840	178,164	4,596,900	7,485,500
Raw material data										
Raw material		Sawdust	Wood shavings	Sawdust	Wood shavings	Wood shavings	Wood shavings	Wood shavings	IWC w. bark	Log wood
Raw material price	€/m³ 2)	7.82	9.95	7.82	1.34	9.95	9.95	9.95	11.84	40.80
Raw material storage										
Kind of storage for wet raw material		paved open-air storage	none	paved open-air storage	none	none	none	none	paved open-air storage	paved open-air storage
Storage capacity 1)	%	1.92		1.92					1.92	8.33
Kind of storage for dried raw material		Silo	Silo	Silo	Silo	Silo	Silo	Silo	Silo	Silo
Storage capacity 1)	%	0.41	0.41	0.41	existing	0.41	0.41	0.41	0.41	0.41
Drying data										
Dryer type		Belt dryer	none	3 Belt dryers	none	none	none	none	Belt dryer	Belt dryer
Required electric power	kW	140.0		420.0					140.0	140.0
Grinding / sieving data										
Unit type		Hammermill	Hammermill	Hammermill	none	none	Sieving machine	included	Hammermill	Hammermill
Required electric power	kW	110.0	110.0	330.0			2.5		110.0	110.0
Pellet mill data										
Required electric power	kW	300.0	300.0	900.0	50.0	40.0	154.0	42.0	300.0	300.0
Cooling data										
Cooler type		Counterflow cooler	Counterflow cooler	3 Counterflow cooler	none	none	none	included	Counterflow cooler	Counterflow cooler
Required electric power	kW	12.0	12.0	36.0					12.0	12.0
Pellet storage										
Kind of storage		Silo	Silo	Silo	Storehouse	Silo	Silo	Storehouse	Silo	Silo
Storage capacity 1)	%	2.30	2.30	2.30	25.00	12.00	50.00	10.00	2.30	2.30
Peripheral equipment data (conveying systems, steel construction)										
Required electric power	kW	108.0	108.0	216.0	12.0	12.0	12.0		108.0	108.0
Pellet data										
Pellet production rate	$t_{pellets}$/h	5.0	5.0	15.0	0.7	0.5	1.2	0.3	5.0	5.0
Annual pellet production	$t_{pellets}$/a	40,000.0	40,000.0	120,000.0	430.7	952.4	2,285.7	1,142.9	40,000.0	40,000.0
Kind of shift work										
Shifts per day		3	3	3	1	1	1	2	3	3
Working days per week		7	7	7	1.5	5	5	5	7	7
Annual operating hours	h p.a.	8,000	8,000	8,000	615	1,905	1,905	3,810	8,000	8,000
Personnel data										
Hourly rate	€/h	25.00	25.00	25.00	8.94	25.00	25.00	25.00	25.00	25.00
Persons per shift		1.00	1.00	1.00	1.00	1.00	1.00	0.25	1.25	2.00
Persons for deputyship (holidays, illness)		0.25	0.25	0.25		0.25	0.25	0.25	0.25	0.25
Personnel for administration and marketing	€/a	73,000	73,000	73,000	3,700	2,800	8,200	1,990	73,000	73,000
Specific pellet production costs	€/$t_{pellets}$	136.6	102.5	127.8	50.8	180.5	162.2	135.0	148.9	196.8

A specific case is scenario 6. A Swedish manufacturer offers complete pellet production plants for dry raw material with throughputs of 300 kg/h, where hammer mill, pellet mill and cooler are included [4]. The personnel demand is limited to about 2 hours per shift. Based on a two-shift operation at five days per week specific pellet production costs of about 135 €/$t_{pellets}$ can be achieved. Therefore, this system is well suited to produce pellets in small-scale operation, if good framework conditions are available. This system is in particular favored from Italian pellet producers [5]. Scenarios 3 to 6 show, the danger of an uneconomic operation of a pellet production plant is in particular given in the small-scale pellet production. Only special framework conditions allow an economic operation.

Industrial wood chips (without bark) are used as a raw material in scenario 7 under the same framework conditions as in the base case scenario. This raw material is of increasing importance, as a further increase of the use of sawdust is almost impossible due to a shortage of sawdust. Industrial wood chips with bark would also be a potential raw material for pelletization and even cheaper. However, due to the bark content and consequently the higher ash content a production of pellets according to ÖNORM or DIN standards would not be possible. Only the production of pellets for industrial use, e.g. in power plants, would be possible. Industrial wood chips without bark are more expensive than sawdust (by about 7%). The investment costs of a pellet production plant able to use wood chips are higher, as additional investments in coarse grinding (size reduction from wood chips to sawdust) before the dryer, increased construction costs and additional peripheral equipment are necessary. A slight saving can be achieved in raw material storage due to the higher bulk density of wood chips compared to sawdust. The additional grinding unit causes additional electricity costs. In total, the pellet production costs under this framework conditions amount to about 149 €/$t_{pellets}$.

Due to increasing shortage of sawdust many pellet producers think about or have already realized pellet production plants able to use log wood as a raw material [6; 7]. Such a plant is taken into account in scenario 8, based on fresh log wood with a water content 55 wt.% (w.b.). The price of log wood loco pellet production plant is based on an average Austrian price for pulpwood [8]. Based on dry substance, log wood is about 50% more expensive than sawdust. The additional equipment already mentioned for scenario 7 is also necessary for scenario 8. Moreover, a debarking unit is necessary for pellet production plants producing ÖNORM or DIN pellets. A stationary chipper has been taken into account to produce wood chips from the log wood. Additionally, conveying systems as well as a log wood storage have also been considered. Compared to scenario 7 the total investment costs increase by 63%. The electricity consumption increases by about 70% compared to the base case scenario. The resulting pellet production costs amount to about 197 €/$t_{pellets}$, which is clearly higher then the limit for an economic operation. However, pellet production from log wood should, regardless this result, be a relevant future option, as pellet prices will increase in the near future (the actual pellet prices are comparatively low). Moreover, pellet production plants using log wood should be designed for higher annual pellet production rates so that a relevant economy-of-scale-effect could be achieved. An additional cost reduction potential could be realized by utilization of stored log wood. In this case the natural drying effect would reduce the heat demand for drying and consequently the drying costs.

5 CONCLUSIONS

Full cost calculations of pellet production costs under Austrian framework conditions for a base case scenario and for different scenarios have been performed in order to evaluate the pellet production economically.

The results for the base scenario show, that the main shares of the pellet production costs are the costs for raw material and for drying. These costs can cover up to almost 80% of the total pellet production costs. Pelletization itself and personnel are further relevant cost factors, covering together about 13% of the total costs. The remaining cost factors general investments, grinding, cooling, storage and peripheral equipment cover together less than 10% of the total costs and are therefore of minor relevance.

Sensitivity analyses performed to evaluate the influence of different parameters on the total pellet production costs indicated, that the most important influencing factors are the pellet throughput, the plant availability, the annual full load operating hours, the raw material costs and the specific heat costs.

As the pellet production costs may vary in a broad range under different framework conditions, eight different scenarios regarding site-specific framework conditions and plant sizes have been investigated. It could be shown, that a wood pellet production is possible both in small-scale (production rates of some hundred tons per year) as well as in large-scale plants (some ten thousand tons per year) from different raw materials (dry wood shavings, wet sawdust, wood chips, log wood). However, it is very important to take care of the specific framework conditions of the producer – in particular for small-scale units, because the risk of a non-economic pellet production is considerably higher than for large-scale systems.

By the use of dry raw materials such as wood shavings the specific pellet production costs can substantially be reduced, as drying costs can be saved (even if the raw material is significantly more expensive).

Due to an increasing shortage of sawdust (due to increasing demand of the pellet industry as well as the reduced availability because of a reduced cutting volume of the sawmill industry), the raw materials wood chips and log wood gain increasing importance. Compared to the base case scenario the production costs of pellets increase by about 9%, if wood chips are used and by about 44%, if log wood is used. In this context it must be pointed out, that a price increase of pellets must be expected in the near future, as the current price level is comparatively low, which would make the pellet production from these raw materials more economic. Moreover, such pellet production plants should be designed for higher annual production rates in order to benefit from an economy-of-scale-effect.

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7 LOGO SPACE