TERMINAL COST ANALYSIS FOR FOREST FUEL SUPPLY IN FINLAND

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ABSTRACT: As forest fuel demand increases, new logistical solutions are needed. Most of the increase in use is expected to take place in large heat and power (CHP) production units which set special requirements for the supply as both procurement volumes and transport distances increase. Biomass fuel terminals broaden the spectrum of available supply options by offering cost-effective large-scale biomass storage and processing options for securing the fuel supply in all conditions. This study aimed to study different costs of a satellite terminal and to produce important concept and cost information for developing forest fuel logistics based on future terminals. The figures indicate that terminals do not create direct cost benefits per se: direct supply chains are more economical compared to supply through terminals. However, there are several indirect benefits that can be reached via fuel supply through terminals: regional fuel procurement can be widened to a national scale, security of supply increases through easily available storages, large supply volumes can be delivered by an individual operator, prices remain more stable and a more even quality of delivered fuel can be achieved.

Keywords: Forest fuel supply, biomass terminal, cost analysis, terminal operations

1 INTRODUCTION

According to the Finnish energy and climate strategy [1] the goal of the use of forest chips in heat and power production by 2020 is 90 PJ which corresponds to 13 million solid cubic metres of wood. In comparison, 8 million solid cubic metres of forest chips were used for heat and power production in Finland in 2013 [2]. Additionally, there are plans to increase the use of industrial timber (pulpwood) by over 4 million cubic meters in Central Finland [3]. This increase in wood felling will bring more logging residue and stumps to market, but as the new bio refinery installation focuses on pulpwood use, the market will tighten on pulp wood and possibly partly on small wood used for energy production too [4].

The increasing use of forest fuels inevitably makes transport distances longer because new bioenergy capacity is built in densely populated areas while untapped fuelwood resources are in rural areas, mainly in the northern part of Finland [5]. Traditionally direct supply chains from forest to plant have been used in forest fuel procurement [6] [7] [8]. As fuelwood volumes are increasing and long distance transport distances are increasing more effective logistic solutions are needed.

Timber and fuelwood terminals for timber storage, periodical biomass fuel storage and fuel manufacturing are already widely used in the Nordic countries to improve pulpwood and wood energy logistics [9] [10] [11]. Terminal chains have an important function when the fuelwood supply is studied in a broader context. There were 202 fuelwood terminals with a minimum annual supply volume of 300 GJ forest fuels, totalling 1.8 PJ in 2015 in Finland [28]. Correspondingly in Sweden there were 270 terminals supplying totally 2.2 PJ of fuelwood in 2013 [10] [26].

The terminal offers security of supply for a fuel user: it can also even out fuel quality fluctuation and by utilising a terminal supply wood fuel harvesting season and utilization of production machinery heavily burdened by high investment costs can be distributed more evenly over the traditionally quieter seasons [10]. During the peak load the focus is on the easily accessible terminal storage facilities.

On the other hand, it is obvious that additional handling and storage times add costs to supplied wood fuel compared to direct supply chains [12] [13]. These costs are partly offset by cost savings on more economical material handling in terminals, energy content increment during storage and more efficient logistical solutions in transportation. Detailed studies on possible terminal operations and costs involved have not been conducted in Finland so far.

Based on existing examples of operating terminals, three different developing terminal types, satellite terminal, feed-in terminal fuel and upgrading terminal, can be identified [14]. The satellite terminal was selected for a cost analysis due to its complex structure that exhibits all required work phases and sources of terminal supply costs that must be considered, and also due to the satellite terminal's key role in long haul wood fuel supply chains. In this study the satellite terminal refers to a biomass fuel processing and storage terminal near fuel raw material resources and far away from the fuel users. It can also function as a transport hub of biomass fuels between large end-users and biomass resources [15].

The main aim of this study was to study different cost factors of fuelwood terminals and to compare fuelwood supply cost with direct supply.

2 MATERIAL AND METHODS

Cost and technology information used in this study was gathered from recent research studies. The data were completed with interviews and data obtained from real life operations. All presented values are theoretical and data for calculations were collected mostly from previous terminal related studies [12] [16] [17] [18] [19] [20]. No time studies were executed. Values for material handling were not available and thus the cost and productivity analysis on material handling is based on values supplied by Mantsinen Ltd.

Four different annual fuel outputs were selected for analysis: 0.36 PJ (0.1 TWh), 1.08 (0.3 TWh), 2.52 PJ (0.7 TWh) and 3.60 PJ/year (1 TWh/year) of supplied fuel. The three largest size classes are based on a train transport sequence. For 3.60 PJ/a there are two daily chip train departures, for 2.52 PJ/a one daily chip train departure is sufficient and for 1.08 PJ/a a train departs every second day. The 0.36 PJ/year was selected to reflect the effect of terminal size to fuel treatment and handling costs. A conversion factor of 7.20 GJ/solid-m^3 is applied in the following calculations in case no other value is given.

2.1 Costs related to terminal area and logistical connections

Costs related to the terminal area consist mainly of terminal land acquisition costs and land construction costs. The land cost varies from one site to another and it is very hard to give even a regional average on the purchase cost of land area. In addition to purchasing land, terminal sites can also be rented or leased.

Land construction is also a significant cost element. For example, the asphalting cost for an existing gravel surface costs around €20-30/m^2. If additional land construction work has to be done before paving the area, the total cost can be over two or three times higher compared to mere paving cost of the area. [21]

In this study a terminal site acquisition cost was expected to be €5,000/ha, paving cost €30/m^2, service life of the area 15 years, interest rate 10% and the residual value of the area €5,000/ha. 50% of the total terminal area was expected to be paved with asphalt. No road, railway or other land construction costs were included in the calculation. Similar values for terminal area costs have been presented e.g. by Karttunen [12].

2.2 Fuelwood storage costs

In addition to area requirement of raw fuel material storage piles, other auxiliary areas for example for chipping and grinding are needed. Table 1 presents the area requirements for different terminal outputs. Space requirements for connecting road and railways are not included due to their case specific nature.

Table 1. Area requirements for different terminal outputs in hectares. Connecting roads and railways are not included in the calculation. (Values modified from Impola & Tiihonen [22])

Out-put, PJ	Season storage area, ha	Near storage area, ha	Grinder/ chipper + auxiliary areas, ha	Chip storage, ha	Total area, ha
3.60	4.30	0.40	1.30	0.20	6.20
2.52	2.90	0.20	1.30	0.20	4.60
1.08	1.70	0.10	0.70	0.10	2.60
0.36	0.50	0.00	0.30	0.10	0.90

In this study it was estimated that 31% of the material is processed though season storage (long term storage), 43% of the material is processed through near storage (short term storage close to the comminution area), and 26% of the material is fed directly to comminution from trucks or train carriages. This distribution is based on actual case experiences from a pulpwood terminal, cost optimization of material handling between different storage options and estimations on requirements of security of supply for a biomass fuel terminal (1).

The applied rotation times for season storage and near storage are 2 rotations/year and 100 rotations/year respectively. Table 2 presents the average annual fuel flows. It should be noted, however, that the material supply-delivery-distribution varies season to season due to actual fuel needs of the end-user. Similar material storage breakdown was applied for all terminal sizes for achieving comparable results.

Table 2. Annual material flow breakdown for different terminal outputs between season storage, near storage and direct feed to comminution.

Output, PJ	Through season storage, PJ/year	Through near storage PJ/year	Directly from trucks, PJ/year	Total PJ/year
3.60	1.12	1.60	0.93	3.65
2.52	0.75	1.06	0.62	2.43
1.08	0.37	0.59	0.31	1.21
0.36	0.11	0.16	0.09	0.36

2.3 Machine investments and operational costs

Grinding is a comminution solution for all solid biomasses (Rinne 2010). A chipper is a good option for all “clean” materials such as uncommercial stem wood, delimbed stem, whole tree and logging residues (Spinelli et al. 2012). Generally, when stationary and mobile machinery are compared, stationary machinery becomes more economical with large scale use [18] [23].

Like chippers, grinders are available both in mobile and stationary units. Here, a mobile grinder was selected because in addition to being a solution for all raw fuel materials, it is a valid option for all terminal output sizes. For this study the selected combination gives a possibility for comparing stationary and mobile machines as well as chipper and grinder technology.

The costs are presented for different terminal output sizes (0.36, 1.08, 2.52 and 3.60 PJ) of delivered fuel per year and for different raw fuel materials (uncommercial stem wood, delimbed stem, whole tree, stumps and logging residues). Comminution with both a stationary chipper and grinding with a mobile grinder was studied for the 2.52 and 3.60 PJ terminals. Comminution by a mobile grinder was studied for all other terminals.

For presenting the comminution costs, a cost analysis of 2 different machine options for 2.52 and 3.60PJ terminals was executed. The options were a trailer-mounted high-capacity horizontal grinder and a stationary chipper. For stumps the grinder was the only studied comminution machine option.

The grinder investment includes the grinder unit and a 15 meter discharge conveyor. The chipper unit consists of a feed-in conveyor, metal detector, chipper, discharge conveyor, foundation, protective buildings and all required installation costs for making the unit operative after it has been delivered by the manufacturer. Applied investment costs were €550,000 (grinder) and 2 million euros (stationary chipper), service lives 3.4 and 15 years respectively: Residual value in the end of service life for both machines was expected to be zero. Calculated and applied hourly costs were 186.6 €/working hour for grinder and 238 €/working hour for chipper. Annual effective working hours were expected to be 4,000 hours, based on a year-round 2-shift operation. A work force cost of €25.00/hour was applied (40% overheads included). Major machine service and maintenance was expected to take place outside effective hours. Table 3 presents the applied productivities for different fuel materials. Other applied unit costs of comminution are displayed on Table 6. For 0.36 and 1.08 PJ terminals, a grinder was the only studied comminution option.

Table 3. Applied productivities (Pr) per utilization hour including interruptions shorter than 15 minutes (€/h-15) and unit costs (UC) for comminution machinery. Data collected from machine users and manufacturers and from Rinne [18]. SW=Uncommercial stem wood, DS=Delimbed stem wood, WT=Whole trees, S=Stumps, LR=Logging residues.

	SW	DS	WT	S	LR
Pr GJ, mobile grinder	382	382	382	252	432
Pr solid-m^3, mobile grinder	53	53	53	35	60
Pr GJ, stationary chipper	590	590	590	N/A	648
Pr solid-m^3, stationary chipper	81.9	81.9	81.9	N/A	90
Unit costs, €/GJ, mobile grinder	0.49	0.49	0.49	0.74	0.43
UC, €/solid-m^3, mobile grinder	3.5	3.5	3.5	5.3	3.1
UC, €/GJ, stationary chipper	0.39	0.39	0.39	N/A	0.37
UC, €/solid-m^3, stationary chipper	2.8	2.8	2.8	N/A	2.7

The large 2.52 and 3.60 PJ terminals provide full work load for comminution machinery. In smaller 0.36 and 1.08 PJ terminals the machines were expected to work periodically on a contract basis, meaning that the machines were moved from one terminal to another depending on their schedule. Thus, compensating for the additional costs incurred from shifting from one work site to another, 10% cost increment was applied for comminution operations in 1.08 PJ terminal. In 0.36 PJ terminal the expected cost increment was 30%. In 2.52 and 3.60 PJ terminals all comminution machines were expected to be electrically powered. In smaller terminals, a diesel powered grinder option was applied.

Table 4. Other costs of comminution for a mobile grinder and a stationary chipper. [18]

	Mobile grinder	Stationary chipper
Insurance, €/GJ	0.003	0.033
Workforce, €/GJ	0.06	0.06
Admin, €/GJ	0.03	0.03
Blades and sieves, €/GJ	0.06	0.08
Maintenance, €/GJ	0.06	0.06
Fuel/energy, €/GJ	0.14*	0.08
Unexpected & budgeted surplus, €/GJ	0.03	0

*Energy cost with diesel powered grinder 0.15 €/GJ

2.4 Material handling machines

In the two larger 2.52 and 3.60 PJ terminals, material handling machines were expected to be used in the unloading of trucks, storage pile management and feeding of the comminution machine. The feed-in machine in 2.52 and 3.60 PJ is an electrically powered 90 tonne material handler (2.5m grapple opening) with 26 meter reach and a rail undercarriage. The season storage material handler (2.52 and 3.60 PJ terminals) is a 60 tonne diesel powered material handler (1.2m grapple opening) with 17 meter reach and a track undercarriage. In the smaller terminals, all loading and feeding was expected to be executed by the loaders of trucks (2014 email from M. Kari to M. Virkkunen, unreferenced; see “Notes”).

For all terminals, two parallel material management options were studied: feed through season storage and direct feed to comminution. The feed through season storage option consists of the following actions: unloading from truck/train to storage, loading from storage, terminal transport, unloading from terminal transport (possibly simultaneously feeding to comminution), handling at near storage (optional) and feeding into comminution. Direct feed consists of the following actions: unloading from truck/train (possibly simultaneously feeding to comminution), handling at near storage (optional) and feed to comminution.

The cost of material handling at near storage was expected to be included in feeding to comminution, based on the argument that avoiding this additional unload-feed operation is the desired option and this can be achieved by optimizing the terminal operations (2). Additionally, the near storage is managed by the feeding material handling machine.

The main cost drivers for material handling are, density of the material, the size of individual grapple load (cross-section of the grapple opening multiplied by the length of the load) and work rotation (time from collection of the grapple load to release of the load) of the machine (2). The applied work rotation lengths have been determined in experiments of the handling of pulpwood in terminals.

A wheel loader was used in the loading of ready-made fuel for transport and for cleaning and other maintenance work in the terminal. The estimated annual effective hours for the wheel loader were 4,300 hours, service lifetime 5.5 years, investment €210,000 and hourly productivity 160 solid-m^3/E-15h. The hours of the wheel loader were dedicated to the loading of fuel for transport (3,300h) and maintenance and cleaning work in the terminal (1,000h). The calculated applied hourly cost was €56.64/h.

The internal terminal transfers were executed with a special terminal truck. The load capacity of the truck was 90 frame-m^3. The applied work rotation for the truck was 27 minutes (2) from unloading to unloading. Table 5 summarizes the productivities and unit costs of handling and terminal transfer machinery for different materials. The presented values represent the technical maximum productivities, assuming that, for example, the comminution machine's capacity does not limit the productivity of the feeding. Two parallel comminution machines were expected to be used at 2.52 and 3.60 PJ terminals. Based on the presented feeding productivities it was assumed that one feeding machine could feed two comminution machines, excluding the feeding of stumps and logging residue. All excess time was expected to be used for near storage management and unloading of arriving trucks and trains.

Table 5. Productivities (solid-m^3/h-15) and unit costs (€/solid-m^3) of handling and terminal transfer machinery for different materials. (2) MH=Material handler, TTT=Terminal truck transport, WL=Wheel loader, FG=Feed to grinder, SW=Uncommercial stem wood, DS=Delimbed stem wood, WT=Whole trees, S=Stumps, LR=Logging residues.

	SW	DS	WT	S	LR
MH, storage, solid-m^3/h	346	247	173	74	90
MH, feed in, solid-m^3/h	373	266	186	80	63
TTT, solid-m^3/h	140	100	70	60	40
WL (chips/hog fuel), solid-m^3/h	160	160	160	160	160
FG, €/solid-m^3	72	106	33	21	21
MH, storage, €/ solid-m^3	0.4	0.4	0.4	0.5	0.5
MH, feed in, €/ solid-m^3	0.5	0.5	0.5	0.7	0.8
FG, €/solid-m^3	0.9	0.9	1.9	1.4	1.4
TTT, €/ solid-m^3	0.5	0.7	1.0	1.2	1.8
WL (chips/hog fuel), €/ solid-m^3	0.4	0.4	0.4	0.4	0.4

2.5 Measuring

In the smaller 0.36 and 1.08 PJ terminals studied, all measurements were expected to be executed with loader scales (trucks and wheel loaders) (3). In the larger terminals 2.52 and 3.60 PJ, all arriving and departing material was expected to be weighed with a weigh bridge [24]. In addition to this, in larger terminals, a special volume and mass measurement device was expected to be used in connection with comminution, for possible moisture content determination. The applied investment cost of the weigh bridge was €150,000 and the expected investment period was 15 years. The mass and volume measurement device was expected to have an investment cost of €300,000 and a lifetime of 15 years (4).

2.6 Terminal supply chain compared to direct supply chain

In order to compare fuelwood supply costs through terminals, direct supply costs were calculated as well. The direct chain costs consisted of the standing wood price, capital costs landing area, felling and forwarding costs, chipping costs, and long distance transportation costs for 100km truck transportation.

In this comparison, the terminal supply chain consisted of the roadside price of wood (similar to standing price + harvesting costs), transportation costs to the terminal, terminal costs including capital costs, and long distance transportation costs including 600km train transportation. A long train transportation option was chosen to correspond with an actual terminal case study within a large study programme (BEST) (see Acknowledgements).

3 RESULTS

3.1 Fuel production costs at all terminals

Figure 1 presents the terminal fuel production costs for wood chips from uncommercial stem wood, delimbed stem, whole tree, stumps and logging residues based on the grinding of the material in direct feed and season storage options.

The results indicate that the direct feed fuel supply costs through large terminal units are 21–24% lower in 3.60 PJ terminal compared to 0.36 PJ terminal (Figure 1). In supply through season storage the respective difference is 19–34%. Also, direct feed is more economical in all size classes (costs are 22 to 78% higher in the storage option), as fewer loading-unloading and terminal transfer sequences are required. Materials with a low density are not well suited for a season storage option as the loading, unloading and terminal transfer costs are high. It can be concluded that in terms of terminal storage and handling only uncommercial stem wood and delimbed stem are viable options for supply that includes long term storing of the material.

When different raw materials are compared against each other the terminal processing cost of stumps stands out. The high cost of stump processing is due to the relatively high handling and grinding costs. Grinding costs of stumps were 0.75 to 0.98 €/GJ compared to 0.50 to 0.64 €/GJ of uncommercial delimbed stem grinding costs.

The cost benefit of large terminal units accumulates from more efficient storage space use (6m high storage instead of 5m high piles) and higher utilization rate of machines. The use of comminution machinery is especially important in this respect. In large units the machinery use is uninterrupted by transfers from one work site to another, and the machines are fed by purpose built material handlers, with enough capacity to feed even the challenging loose materials efficiently to comminution.

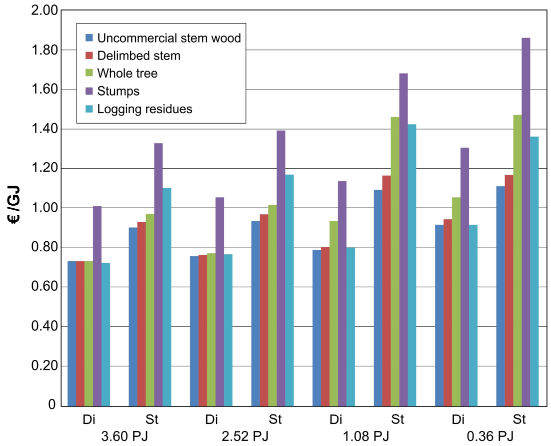

Figure 1. Terminal wood fuel production costs (€/GJ) in different terminal sizes for all raw materials based on grinding of the material in direct feed (Di) and season stored options (St).

In 0.36 and 1.08 PJ terminals feed to comminution is more expensive due to the assumption that trucks are used for feeding of the comminution. Based on the cost analysis, the truck operated feeding is more expensive compared to large scale feeding of the raw fuel material with material handlers. The small annual fuel supply of the two smaller terminals studied does not however enable the economical use of material handling machinery.

3.2 Comparison of direct supply chain and terminal supply chain costs

Figure 2 summarizes an example of the total supply cost of delimbed stem in a traditional supply chain and a terminal supply chain. The applied terminal costs are based on fuel supply through a 3.6 PJ terminal direct feed supply option (€0.72/GJ) and season storage supply (€0.94/GJ) option. This represents the most economical terminal supply option for delimbed stem.

The presented cost at plant is €5.4/GJ in the direct supply chain and €6.1–6.3/GJ in the terminal supply chain (direct feed/season storage options through a 3.6 PJ terminal). The figures indicate that fuel supply through a terminal is 13 to 16% more expensive compared to direct fuel supply and 5–9% more expensive compared to the current average price of forest fuel in Finland (€5.8/GJ, Bioenergia-lehti 04/2014). However, the studied terminal supply case is dedicated to long haul (600km by railway) biomass supply from, for example, North-Eastern Finland to a large cogeneration facility located in Finland's Metropolitan area, and thus large scale wood biomass supply can be expected. With a 50% shorter supply distance (300km) and with an estimated 45% transport cost reduction (applied cost €0.95/GJ) the cost of fuel supplied through terminals would be €5.3–5.5/GJ, roughly equal to the supply costs of a direct supply chain.

It is important to note that in the smaller terminals, the terminal costs are significantly higher (up to 34% difference between the total supply costs in a 3.6 PJ and 0.03 PJ terminal).

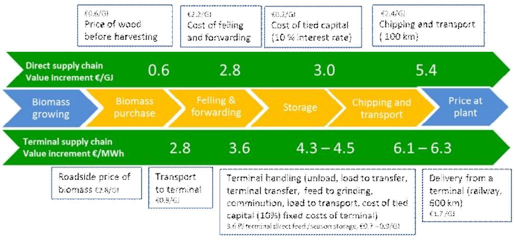

Figure 2. An examplar summary of the total supply cost of delimbed stem in a traditional supply chain and a terminal supply chain

4 DISCUSSION

The main driver for the introduction of new biomass terminals is the expected significant increase in the wood fuel use in heat and electricity production in Finland [1]. Similar trends are seen in many other European countries too [25] [26]. As forest fuel use increases, regional availability may exceed forest fuel availability in certain areas of Finland [5]. This increased demand can be met with long haul biomass terminals. Due to the lack of previous research, especially lack of empirical data and existing points of comparison on biomass fuel supply through terminals, the presented results are theoretical, based on data collected from several individual publications. In real life each terminal is unique and for reaching more accurate cost values, each terminal requires specific case studies and careful planning. Unfortunately the complexity of real life terminal conditions means that the results cannot be fully generalized, as the operation environment changes from one terminal site to another.

However, the understanding of the cost factors behind terminal supply costs for different materials and different terminal size classes provides an excellent starting point for more case specific studies. Therefore it should be taken into consideration that there is no universal terminal cost but instead a cost per each raw fuel material and each machine combination for each terminal size.

The results also point out the annually supplied wood fuel volume should be over 2.52 PJ in order to meet the break-even volume point of different machine options. Especially this is the case with stationary machines. This corresponds to a minimum terminal area of 5 hectares. Similar observations were made in Sweden by Kons [26], where < 5 ha terminals have been found to utilize mobile machinery and have less measuring options available. In this study the 3.60 and 2.52 PJ terminals (4.62 and 6.24 ha correspondingly) were expected to utilize stationery machinery and to be equipped with weigh bridges and online mass/volume measuring devices whereas the two studied smaller terminals were expected to have no stationery installations.

Assessing temporal changes of the expected biomass deliveries to and from the terminal were excluded from this study on purpose but it is evident that seasonal fluctuations, typically affected by climate and weather conditions, should be taken into account in case-specific studies. This can be done, for example, by analysing the entire supply-logistics system in a discrete-event simulation environment (e.g., for one year), where the material input is scheduled according to time series data about biomass harvests and the output according to the estimated fuel consumption of terminal customer(s) [27]. The selection of several fuel types and uncertainty related to the logistics chains increase the complexity in the supply-demand alteration. A sufficient amount of pre-studied fuel terminal concepts with documented flowthrough amounts is useful for case-specific simulation studies, in order to find cost-optimal solutions for the whole network of supply chains.

In conclusion, the largest studied terminal (3.60 PJ/a) and large stationary fuel handling and processing machines were found to be the most cost effective. It should also be noted, however, that direct supply chains are more economical than supply though terminals, particularly if delivered volumes are small. It is likely that the increase in terminal size will not happen overnight, without a break-in and learning period for the terminal operators and without long and secured fuel supply contracts between fuel supplier and users. Also, it is likely that until a large scale operation has been set up, mobile machinery will form the core of the applied machinery in terminals. The higher unit costs of mobile machinery is compensated for by smaller risks for the investor as the mobile machinery can be easily transported from one work site to another. In addition, smaller capital requirement will mean an easier start for the terminal business.

5 NOTES

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9 ACKNOWLEDGEMENTS

This work was supported by the Sustainable Bioenergy Solutions for Tomorrow (BEST) programme coordinated by CLIC Innovation Ltd., and co-funded by the Finnish Funding Agency for Innovation (Tekes). The authors wish to thank Mantsinen Ltd. for contributing to the contents of this article.

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