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GUIDELINES FOR THE DEVELOPMENT OF FOREST CHIPS SUPPLY CHAIN MODELS: THE ITALIAN EXPERIENCE IN THE EASTERN ALPS

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Abstract: *The exploitation of forest biomass may offer important benefits in terms of environmental protection and local employment, but the development of an effective forest biomass chain is hindered by the lack of techniques for tapping the resource at reasonable costs.*

In 2003 the National Council for Research (CNR) launched a vast research program with the goal of testing the best available technologies for harvesting forest biomass under Alpine conditions. The project has received support from the most important Agencies operating on this territory, including the Forest Service of the Trento Province, the Regional Forest Service for Friuli Venezia Giulia, the LAG Prealpi e Dolomiti, the Forest Owners Association of Carnia, the Fiemme Community, the Mountain Communities of Feltre, Belluno, Gemona, Tolmezzo, Barcis and Tarcento, the Forest Owners Association of Mt. Grappa.

The Project 1) explored the wood biomass market, 2) characterized forest chips as a commercial product and 3) devised and tested supply strategies to make forest chips more competitive. Overall, 18 harvesting trials were conducted within the scope of the project, covering maturity cuts, thinning, management of new forests and riverbed cleaning operations.

The project team included a number of experts from different Countries: besides the CNR core group, it counted researchers from the Technical University of Munich, the FVA in Freiburg, the University of California and Virginia-Tech.

The trials conducted in 2004 focused on salvaging logging residue from maturity cuts, which has become increasingly interesting with the introduction of processors, resulting in the accumulation of considerable volumes of slash at yarder landings. Directing this residue to the biomass market translates a disposal problem into a profit opportunity: four treatments were tested on yarder terrain, and four on tractor terrain. Trials conducted in 2005 focused on the thinning of spruce stands (five treatments) and pine stands (four treatments). Patch thinning seems very promising, and profits can be made under favorable terrain conditions. Selection thinning is more difficult, but data processed so far indicate that biomass production allows reducing thinning cost to 1/3 compared to the traditional method. The management of new "invasion" forests and of riverbeds was studied in 2006. Several treatments were applied, including: shred to waste, clear-cut, thinning from below and thinning from above. Inter-active, computerized Decision Support Systems been developed for all the operation types described above.

The results of the projects have also been gathered in a "Handbook for the development of forest chips supply chain models", which is available in Italian and English and can be requested free of charge from the Authors of this paper.

1. Introduction

Many foresters watch at the development of the bio energy sector with a mix of hope and fear: hope that it may offer a rewarding outlet to the low-grade wood presently abandoned in the forest; fear that in time the hunger for fuel may motivate the overexploitation of the forest resource. To date, the Italian biomass plants have confirmed neither expectation, as they can still obtain large quantities of wood fuel through the commercial channels of import and recycling (Spinelli and Secknus, 2005). In this instance, transport represents the main cost that varies with the distance to be covered and the quality of the available road network.

However, the plants commissioned to date have bound almost all the residue generated from industrial activities: in Italy as well as in Austria or in Germany, any further development of the bio energy sector depends on the ability to tap primary wood, growing in forests and fields. This is a real challenge, as the mobilization of primary wood is much more complex and far less profitable than the recycling of industrial wood residue, once disposed for free. Any intervention on forest ecosystems requires specific skills and competence, in order to achieve economic and environmental sustainability.

Today in Northern Italy one can count at least 43 district heating plants and 11 power stations, all currently in operation and fuelled exclusively with clean wood (Table 1). These plants generate an annual wood fuel demand in excess of 1 million tonnes, to which one should add the further amount required by the hundredths of small plants built in private households. For plant managers, the choice between alternative fuel products is dictated by delivered price, product quality and supplier service. Today, sawmill residue wins over forest chip on all three fronts, because it is cheaper, it is cleaner and it is supplied from an industry to another industry, with a clear advantage in logistic and administrative terms.

Table 1: Wood-fired district heating plants and power stations in Northern Italy

Region	District Heating Plants			Power Stations		
	n°	MWt	t/year	n°	MWe	t/year
Valle d'Aosta	2	10	11200	-	-	-
Piemonte	4	24	26880	3	27	270000
Lombardia	3	35	39200	4	30	300000
Veneto	3	2	2240	2	23	230000
Trento	2	17	19040	-	-	-
Bolzano	30	107	119840	-	-	-
Friuli V.G.	1	0,5	560	1	3	30000
Emilia-Romagna	-	-	-	1	23	230000
Total	43	196	218960	11	106	1060000

Fuel consumption is estimated for 35 % wood moisture content.

Forest enterprises must learn a lot in order to compete on quality, price and service. Deliveries must become quick, regular and guaranteed: no plant can afford a temporary shut-down for the lack of fuel.

Therefore, appropriate technical know-how must be developed for organizing local supply chains, managed by local actors and able to tap the resource abundantly available on the land, within the terms of economical and environmental sustainability. To date, research and dissemination have proved the best tools for generating such know-how and transferring it to the end-users.

2. The "Eastern Alps" project

Starting in 2003, CNR has launched a large research programme with the goal of testing the best technologies for the optimization of biomass harvesting in the Alpine forests. Such effort will help mobilize the forest resource, allowing forest owners to benefit from the opportunities currently offered by the biomass market, which until now has brought little advantage to those who work in the forest.

The work is being conducted by the Timber and Tree Institute (IVALSA) from its centre in San Michele all'Adige, near Trento. It consists of an articulate test programme that covers all the Italian Eastern Alps. Tests are conducted with the support of the most important organizations in this territory, including the Regional Forest Services of Trentino, Veneto and Friuli, and the Local Action Group (GAL) Prealpi e Dolomiti. A key role is plaid by Watershed Authorities in Feltre and Belluno, and in all of Friuli. Forest owners have also joined the project through their most important associations, such as the Consorzio Boschi Carnici, the Magnifica Comunità di Fiemme and the Associazione Monte Grappa – who started with the first test in the summer 2003.

The project includes several activities, and namely: 1) a survey of the wood chip market in the Eastern Alps, 2) an evaluation of forest chip quality and of the factors affecting it and 3) a number of harvesting trials to identify the most effective techniques for reducing delivered cost and increasing product quality. To date, results have been disseminated through 11 publications and 9 demo days. CNR personnel have also presented the main findings of the project in 10 Seminars or Conferences, 4 of which held outside Italy. However, this report represents the only comprehensive English summary of the results obtained from the 20 harvesting trials, carried out by CNR between 2003 and 2006. It contains essential information about the quantity of biomass that can be obtained from different operations, about its harvesting cost and about the key elements for choosing the best technology under a given set of conditions.

The complexity of close-to-nature forestry suggested a systematic approach, in order to handle each case with the deserved attention. Given the difficulty of dealing with all possible situations, priority was given to cases with the following characteristics:

1) widespread coverage of the territory, so that the knowledge generated by the project could be widely applied to real practice; 2) urgent need for some management, due to an ongoing rapid evolution that must be directed towards the desired silvicultural prototypes; 3) relatively favourable harvesting conditions, in order to facilitate the achievement of economic sustainability; 4) lack of commercial outlets for the product obtained from the treatment, difficult to market for its poor quality.

A 20-test experimental plan allowed checking a number of different situations, and in particular: the recovery of forest residue after regeneration cuts – small clear-cuts or group selection; the thinning of young softwood plantations; the management of pioneer forests; the cleaning of riparian stands (Table 2)

Table 2: Harvesting tests performed by CNR on the Eastern Italian Alps: 2003-2006

Stand – treatment	Trials n°	Surface. ha	Log Vol. m^3	Biomass green t	Study hours
Mature spruce – even aged	3	10.1	3018	445	442
Mature spruce – uneven aged	2	11.3	720	155	349
Young spruce – thinning	5	4.3	121	270	288
Young pine – various	5	5.4	72	397	362
Pioneer forests – various	2	1.6	0	141	176
Riparian stands - cleaning	3	5.2	102	197	119
Total	20	38.0	4033	1605	1735

The trials covered 38 hectares and were directed by CNR personnel, who designed the operations and the working methods, in order to avoid the use of sub-optimal procedures. The constant presence of CNR personnel on all test sites guaranteed the accurate execution of all prescriptions contained in the original plans. The actual harvesting work was carried out by hired professionals, preferably local, but also coming from outside the area or even from abroad, if the equipment prescribed could not be obtained otherwise.

During each trials, CNR researchers conducted detailed time-studies, stopwatching all work cycles by time elements (Bergstrand 1991). To this purpose, they used *Husky Hunter* handheld computers, loaded with the dedicated *Siwork 3* software (Kofman 1995). All loads produced were taken to a certified weighbridge, and their bulk volume was measured with a tape. The individual weight of each harvest tree was calculated by building a dedicated diameter-weight tariff for that species and site, or by using the tariffs recently developed by ISAFA in Trento (Fattorini et al. 2005), after calculating a diameter-height curve for each stand. The values returned by the tables were corrected on the basis of the mass actually scaled on the weighbridge. Individual tree weights were used for modelling work cycle time, in order to relate its duration to tree size. Wood moisture content was measured according to the CEN/TS 14774-2 European standard, on 20 samples per site – 10 collected at felling and 10 at chipping. Wood density was calculated after measuring the volume and the weight of 10 samples per site. Landing space and wood stack volume were measured with the usual topographic gauges: compass, tape, hip chain and laser rangefinder.

Overall, detailed stopwatching sessions lasted 1735 work hours, during which the teams produced 1600 green tonnes of wood chips and 4000 m^3 of saw logs.

3. Results

Concerning regeneration cuts in pure or mixed spruce stands one can discriminate between two different cases: clear cuts and selection cuts – the latter applied to single trees or tree groups. On steep terrain, (small) clear cuts are preferred, because the removal is intense enough to justify the installation of a cable yarder. Selection cut is often prescribed in tractor terrain, where one may easily reach scattered trees.

Clear cuts yield from 150 to 300 m^3 of saw logs per hectare, depending on cut surface, tree size and topping diameter. Under these conditions, the recovery of residue may generate a further 30 to 90 green tonnes of chips per hectare. As a rule of thumb, the recovery of residue yields an additional 200-300 kg of green biomass for each cubic meter of saw logs actually harvested. Recovering tops only reduces this additional harvest to 100 kg of biomass per cubic meter of saw logs. Selection cuts yield from 60 to 80 m^3 of saw logs per hectare, and a further 10-20 green tonnes of chips if residue is recovered.

The trials showed that separate recovery of logging residue from the stump site is never profitable under mountain conditions: if trees are processed before extraction it is best to leave the residue in the forest, because an eventual recovery will cost more than it will earn (Spinelli et al. ,2006 a). Successful examples from Northern Europe have little application in the Alpine forests: residue collection at the stump site does work when applied to large clear cuts accessible to forwarders, but this is seldom the case in the Alpine mountains.

On the contrary, whole-tree harvesting is generally profitable. The models developed within the scope of the project allowed calculating a 10 to 30 % profit increase on the traditional short wood system. The more mechanized the operation, the higher the gain, which is directly linked to the replacement of motor-manual processing with its mechanized version: depending on the model, the introduction of a processor will decrease processing cost by 10 to 25 %. In this context, residue recovery represents an additional source of revenue, which improves the overall economy of the operation without dramatically changing it. Only when processing is carried out with motor-manual methods, biomass plays a key role and makes the whole-tree system preferable: in this case, if logging residue cannot be sold, it is best to stay with the traditional short wood system, which offers more or less the same revenue, but it is simpler to deploy and requires lower investments.

Overall, the study demonstrated that recovering logging residue generates an additional income of about 4 € per m^3 of saw logs, motivating whole-tree extraction. Of course, that depends on the efficiency of biomass processing and transportation. Chipping at the landing and transportation of the chips is always the most effective solution, with a cost of approximately 20-25 €/green tonne (Spinelli et al. 2006 b). However, if the biomass must be stored at the end-user, one may consider the production of bundles or tree sections: both techniques are more expensive than direct chipping, but under present market conditions remain profitable until transport distance does not exceed 45 km. Beyond that distance, delivered cost is higher than the top price currently paid by most biomass plants, equal to 14 €/m^3 loose volume. These figures are only valid for truck transportation: if semi-trailer or truck-and-trailer units can be used, the economic transportation range increases accordingly.

Thinning trials of young spruce plantations concerned 30 to 40 years-old artificial stands, established on ex-farmland and generally accessible to extraction vehicles. Here, whole-tree chipping allows harvesting 50 to 100 green tonnes of biomass per hectare, depending on stand fertility and thinning intensity. When tree size is large enough to favour integrated harvesting, these stands can yield up to 70 m^3 of saw logs and 40 green tonnes of biomass per hectare (Spinelli et al., 2006 c).

The average stand may present the following characteristics: a 30 % slope gradient, a 400 trees/ha removal and a 18 cm breast height diameter of the average tree harvested. The average tree will then weigh about 200 kg and the thinning will yield 80 green tonnes of biomass per hectare. If the transport distance is 35 km and the price paid for the chips and the small saw logs is respectively 40 €/green tonne and 45 €/m^3 (Rossi, 2005), the thinning will result in a loss between 300 and 2000 €/ha. The cheapest option is represented by mechanized harvesting, where trees are felled and processed by a harvester and the biomass is delivered in log form to the plant: however, that works well only if the plant is equipped with an highly-efficient electric chipper. If a mobile chipper must be used, then it is best to extract whole trees and chip them at the landing, at a cost of 800 €/ha (second cheapest option). As a general rule, the more mechanized the harvesting chain, the cheaper the thinning: best results are obtained with harvesters, forwarders, industrial chippers, truck-and-trailer units. Every step towards a lower level of mechanization involves a proportional growth of thinning costs. Hence, the crucial role of the infrastructure – roads and landings – which must be adequate to the deployment of advanced mechanization.

At any rate, we are not too far from the target: ends can meet at a chip price between 50 and 60 €/green tonne delivered, which today does not seem impossible. All of this stands in the absence of public subsidies, which have been totally excluded from our calculations. In fact, the models produced in this study may provide a useful tool for the releasing of subsidies, which could be tailored to the actual harvesting costs of individual cases. That would prevent the risks inherent to a flat-rate subsidy equal for all situations, which may just increase the gain of profitable operations, without filling the gap in those cases that are actually disadvantaged.

Selection thinning and premature regeneration cuts were tested on young pine stands (P. nigra and P. sylvestris) – both aimed at advancing the natural regeneration of indigenous hardwoods in the dominated layer. Tests were conducted in artificial stands with an age between 40 and 70 years, and with a breast-height diameter between 15 and 30 cm. Here, selection thinning may yield about 70 green tonnes of biomass per hectare, and premature regeneration cuts (patches or strips) twice as much.

Premature regeneration cuts must be applied with much care, and are justified only by the urgent need for some management, when less drastic solutions are ruled out by technical or economic factors. Premature regeneration cuts favour the economic sustainability of management, by making operations easier and by producing better assortments than those normally obtained from a selection thinning. The difference is dramatic, as premature regeneration cuts yield some profit where thinning would have caused important losses (Spinelli et al., 2006 d).

While selection thinning will only offer chips, premature regeneration cuts allow choosing among different product strategies and namely: chips only, saw logs only and associated saw logs and chips. The best choice depends on the price obtained for the different assortments: under the conditions of the tests, a delivered price of 50 €/green tonne would cover the cost of the chips, and a landing price of 40 €/m^3 that of the saw logs. Any further price difference would shift the balance towards one or the other assortment, eventually justifying the chipping of saw log material.

In tractor terrain, premature regeneration cuts generally turn some profits, while thinning may break even. On the other hand, cable extraction always results in financial losses, estimated between 600 and 2000 €/ha (Spinelli and Magagnotti, 2006 a). Better results can be obtained by stepping to a higher level of mechanization, as these stands offer ideal conditions for introducing the classic harvester-forwarder team. Of course, foresters are concerned with the impacts of heavy machine traffic, and especially with the risk of soil damage: however, pine plantations grow on very stony soils, where skeleton is the best protection against soil compaction (Matthies et al., 2007).

The silviculture of pioneer stands can follow two opposite goals, depending on stand quality and on the surrounding landscape. In densely forested landscapes and when the quality of the stand is poor, foresters may opt for renewing the original pasture by applying small-size clear cuts. On the contrary, an open landscape and a good stand quality favour forest improvement through selection thinning.

Under the conditions of the study, harvesting pioneer stands always results in financial losses, estimated between 1000 and 2500 €/ha: theoretically, clear cuts may offer some profit, which is soon written off by the need for suppressing the thick hazel understorey. Despite all rationalization efforts, this job alone fetches a cost of approximately 1500 €/ha. In this instance, conventional mechanization can provide little help, and may even result the least effective option, probably because it was designed for very different harvesting conditions. In the future, it may be worth developing a dedicated mechanization for harvesting hazel stands, by adapting already existing machines and techniques (e.g. feller-bunchers).

Chip price has a marked effect on harvesting economics: its present level of 40 €/green tonne delivered does not allow reaching economic sustainability, and favours the associated production of firewood and chips, against whole-tree chipping. Under the condition of the tests, product balance is reached at a chip price of 45 €/green tonne, beyond which whole-tree chipping is preferable. Operations will break even for a chip price of 50 and 60 €/green tonne delivered, respectively for the clear cut and the thinning. Anyway, it is encouraging that the performance of the operations tested within the scope of this project was markedly superior to that documented in previous studies (Cavalli et al., 2002), which demonstrates the ongoing progress in this field.

Riparian stands present extremely variable work conditions, justifying very different approaches. Although very common, mastication to waste is the most expensive option by far, and should be avoided whenever possible. The present price of industrial chips does not offer much economic margin, yet it justifies biomass recovery, as that allows a factor 10 reduction of operation losses compared to mastication. For this same reason, best results are obtained with the associated harvesting of saw logs and chips, when tree size and quality allow for that. This approach results in better value recovery and is favoured by selection cuts of the dominating layer, easily justified under both silvicultural and hydrological terms (Spinelli and Magagnotti, 2006 b).

Riparian stand maintenance requires suitable mechanization, based on feller-bunchers, harvesters and forwarders: mechanization allows cost cutting and offers a better work environment, improving operator safety and comfort. The main weakness of mechanized operations is their relocation cost, hence the interest in consolidating work lots in large enough units to favour the only operational choice that allows cost-effective maintenance. Rational techniques, adequate planning and modern management strategies may dramatically improve the economic performance of riverbed maintenance, resulting in a more efficient hydrologic network and a higher availability of wood biomass.

4. Conclusions

The CNR trials covered a number of operational situations typical of the Italian Alps, where biomass recovery may help increasing the economic sustainability of silviculture. The large variability of forest environments prevents the formulation of general conclusions, and that is why CNR developed a number of dedicated calculation models that return punctual cost estimates for the specific conditions offered by each operation (tree size, extraction and transportation distance, cost of the production factors etc.). This said, one can still make some general considerations, to provide a few reference points.

First of all, it must be stressed that forest chips obtain a very modest price, and their production can hardly generate large profits: therefore, product integration is the best strategy, as it maximizes value recovery. If a significant proportion of the harvest can be converted into more valuable assortments, the operation must be geared to produce them, as the income they will generate may bear part of the cost of chip production. A typical example is provided by residue recovery: with whole-tree extraction, the main product (saw logs) will bear the cost of felling, extraction and processing, so that chips will need to pay for chipping and transportation only. Nor this excludes that the main product may draw some benefits from a collateral chip production: whole-tree extraction and processing at the landing allows using highly-efficient processing equipment that cannot access the trees directly in the forest. Often, mechanized processing is prevented by difficult slash disposal, to which biomass production offers a cost-effective answer.

Chip harvesting requires changing the traditional logging systems, and involves a general re-organization of harvesting operations. In general, one should reduce iterative handling to the bare minimum. All manual processes should be mechanized, and when that is not possible they should be replaced with alternative processes that can be mechanized. This is typically the case of chipping, a mechanical process that replaces the inefficient motor-manual delimbing-bucking of small trees. Harvesters have a large potential in improving the efficiency of associated harvesting: they should be used whenever tree size allows the production of saw logs and when the wood lot is large enough to absorb relocation costs. Depending on terrain conditions, harvesters can work in the forest or at the landing: their benefits go beyond cheaper processing, and include a better presentation of wood to extraction units and the possibility to perform wood sorting, handling and stacking. The use of harvesters in regeneration cuts allows cutting harvesting cost by 30 % compared to traditional motor-manual operations. In thinnings, saw log production is only profitable when using harvesters: here mechanized felling-processing is more expensive than motor-manual felling, but allows for easier extraction, eventually resulting in a lower harvesting cost. Furthermore, most harvesters can be used to produce undelimbed tree sections or roughly delimbed logs that are easier to handle and produce better chips.

Logistics are a key issue when re-organizing and mechanizing harvesting operations, especially in mountain areas that are often penalized by poor infrastructure. Logging firms must plan all moving and transport with much attention. For example, if the nearest landing is too small for accommodating industrial equipment, operators must be able to correctly evaluate whether they should move the wood to an intermediate storage or adopt a lower level of mechanization. The choice depends on the efficiency of intermediate transportation and on the distance to the end user, which in turn determines the advantage of using larger vehicles for road transportation. In general, intermediate transportation adds a further 10 €/green tonne to the total harvesting cost, and it pays only when the original landing is not accessible to road transport vehicles. Resorting to intermediate transportation just for moving from a good landing to a better one is seldom profitable. In general, it is best to look for sites with good infrastructure, even if they are located further away from the end user. If transportation distance remains within 80 km, transport by truck-and-trailer units will cost less than double handling. At any rate, CNR has produced a calculation model for assisting professionals in this choice, as it compares the overall performance of logistical options under the conditions specified by the end-users.

Whenever possible, the operational plan should include a seasoning period before chipping, in order to reduce fuel moisture content. However, under Alpine conditions it is unlikely that open-air storage will determine a moisture content reduction higher than 10 percent points (table 3). Best results are obtained with spruce and hardwoods after 2-4 months of summer storage. A further extension of the storage period does not yield better results and can make things worse, as wood can absorb winter moisture and eventually rot. Pine is a particularly difficult customer: none of the storage trials resulted in a significant moisture content drop, regardless of storage duration and form (whole trees, logs, branches). In general, it is very difficult that natural air-drying may bring wood moisture content below 35-40%: this must be borne in mind when designing a plant that must be fed with forest chips.

The results of the work conducted so far have been gathered in a "Handbook for the development of forest chips supply chain models", which is available in Italian and English and can be requested free of charge from the Authors of this paper.

Table 3: Results of the CNR storage trials in the Italian Eastern Alps

Placename	Province	Stock	Species	Place	Days	Initial %	Final %	Δ %
Lumini	VR	Whole trees	P. nigra	Landing	201	49,1	48,1	-1,0
Lumini	VR	Whole trees	P. nigra	Landing	350	49,1	48,4	-0,7
Santa Viola	VR	Whole trees	P. nigra	Landing	112	52,2	49,2	-3,0
Santa Viola	VR	Logs	P. nigra	Landing	694	52,2	54,8	**2,6**
Marzone	UD	Logs	P. silvestris	Landing	83	51,3	45,5	-5,8
Nurtiseas	UD	Logs	P. silvestris	Landing	80	48,3	48,8	0,5
Verzegnis	UD	Slash	P. silvestris	Landing	84	49,8	38,8	**-11,0**
Gemona	UD	Logs	P. silvestris	Yard	117	52,3	42,5	**-9,8**
Sovramonte	BL	Whole trees	P. abies	Landing	8	55,7	54,9	-0,8
Seren del Grappa	BL	Whole trees e	P. abies	Landing	60	58,1	49,4	**-8,7**
Belluno	BL	Sections	P. abies	Landing	67	50,1	48,3	-1,8
Andreis	PN	Tops	P. abies	Landing	102	50,8	51,5	0,7
Monte Pertica	BL	Tops	P.abies	Landing	20	55,1	50,1	**-5,0**
Rigolato	UD	Bundles	Softwoods	Yard	116	50,9	40,6	**-10,3**
Cavalese	TN	Tops	P.abies	Landing	66	45,3	39,3	**-6,0**
Cermis	TN	Sections	P.abies	Yard	68	45,3	35,3	**-10,0**
Lagorai	TN	Tops	P.abies	Landing	427	46,1	47,0	0,9
Andreis	PN	Tops	Hardwoods	Landing	123	45,6	40,1	**-5,5**
Taipana	UD	Tops	Hardwoods	Landing	25	40,6	41,5	0,9

Bold underlined Δ values have resulted significant to ANOVA testing

However vast and ambitious, a four-year research work cannot address all cases, or devise all solutions. The same concept of progress implies that each arrival point is the starting point of a new endeavour. New questions that took form during the study are now the subject of ongoing work, whose results will be available in the next coming years.

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