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RESEARCH
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REPORT

IRRADIATED WOOD-PLASTIC MATERIALS
COMMERCIALIZATION
IN THE PACIFIC NORTHWEST
AND GREAT LAKES REGIONS

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By
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PACIFIC NORTHWEST AND GREAT LAKES REGIONS

By

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CHEMISTRY DEPARTMENT

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A B S T R A C T

This study of the potential for commercialization of irradiated wood-plastic materials in the Pacific Northwest and Great Lakes areas concludes that the selling price under large scale production will range from about \$2.10 to \$2.60 per board foot. The examination of a variety of local wood species shows that Pacific Northwest hardwoods, red alder and big leaf maple, as well as the following softwoods are most suitable for this treatment process: Douglas fir, western hemlock, ponderosa pine and Engelmann spruce. The problem of monomer loss at surfaces and particularly at the end grain of treated wood sections indicates that only uses involving a minimum of trimming losses are potentially commercial. The most attractive application for completely impregnated wood is for flooring. Of course, any use that can tolerate the cost and waste losses can be considered, but such uses appear to be limited. The present process does not appear to be practical for veneers or complex pre-shaped wood pieces.

In view of the high cost of the product a strong case can not be made for a specific site location for a plant.

Further research and development work is suggested to solve the surface depletion problem so that the process can be applied to veneers and pre-shaped wood pieces. Work to impart fire retardency and cross linking or grafting of polymer to the cellulose fraction of the wood was also proposed.

There was found to be appreciable interest throughout the wood production industry in the development of the process and the need to obtain additional research and development to assure its practical application.

IRRADIATED WOOD-PLASTIC MATERIALS
COMMERCIALIZATION IN THE PACIFIC NORTHWEST
AND GREAT LAKES REGIONS

INTRODUCTION

As part of a national program on the investigation by the Division of Isotopes Development of the U. S. Atomic Energy Commission on the industrial applications for radiation, the Pacific Northwest Laboratory (operated by the Battelle Memorial Institute for the AEC) was asked to conduct this study^[1] on the commercialization of irradiated wood-plastic materials in the Pacific Northwest and Great Lakes Regions.

The study was to be based on existing technical data and marketing information. No laboratory work, product evaluation, or testing was to be performed. The Pacific Northwest Laboratory entered into a cooperative contract with the Washington State University, Engineering Research Division, on this study. This report is the result of this joint effort.

The subject of wood-plastic combinations has been an area of investigation both in this country and abroad, privately as well as under government sponsorship. In the United States the major portion of the process research has been done by Dr. James A. Kent at the West Virginia University Engineering Experiment Station, Morgantown, West Virginia.^[2,3,5] However, other research has been done by the Dow Chemical Company,^[6,7] The Koppers Company, and by others in Canada^[8] and overseas.^[9] The significant results of the research and development has been detailed and summarized by others and will not be repeated here. References [4], [10,11 & 12] adequately cover the progress of such work.

OBJECTIVE

The objectives of this present study are to review the work of others and evaluate the prospects for commercialization of the process for the manufacture of irradiated wood-plastic material in the Pacific Northwest and Great Lakes

Regions. To accomplish these objectives required: (1) the consideration of likely wood species suitable for the process in these areas, (2) the selection of a few likely candidate products based on known properties provided by the process, (3) development of production cost data for such production, and (4) conclusions as to likely producers, and geographical sites for such production.

SUMMARY OF RESULTS

This report acknowledges the many impressive improvements in the mechanical, structural, durability, and decorative qualities of irradiated wood-plastic materials as demonstrated by many investigators on selected specimens of the material.

This report concludes that the wholesale price of irradiated wood-plastic material will range from about \$2.10 to \$2.60 per board foot (1/12th of a cubic foot) for soft and hardwoods, respectively.

The problem of depletion of monomer from surfaces and particularly wherever end-grain is exposed by an intersecting surface inhibits the development of a number of applications.

On the basis of the process as presently applied and as evidenced by the quality of a number of samples of treated wood species obtained in the course of this study, it is also concluded that cost and process problems will limit the potential large scale application to only a few products at the present time. Although a wide range of potential products was considered in this study, the process appears to justify consideration at present of large scale manufacture of flooring. This is especially prospective, if the improved strength and durability properties permit uses at thicknesses substantially below that of conventional wood flooring. Although flooring is the most apparent near future use suggested by this study, a more general area of use could be said to include all applications involving simple flat shapes from which a minimum of waste is generated in converting the treated wood to the final used form.

The process as represented by specimens of treated wood supplied in the course of the study does not appear to be practically applicable either to veneers or to pre-shaped wood which is characterized by curves, scroll work, or carving which

exposes end grain. However, although the shaping of treated bulk wood in such forms is suggested, such use is practical only where the loss of costly treated wood in shavings, trimmings and turnings can be tolerated. The magnitude of such a business in the near future is not believed to be sufficient to support a plant to provide this sort of raw material.

The process appears to be most feasible with top grade wood - a grade with which the lumber industry already has few marketing problems. Low grade wood containing cracks, knots, surface damage or imperfections, or nonuniform grain does not appear to be economically justified for use with this process since the scrap losses involved in getting sufficient suitable material from such stock would be prohibitive. However, top grade wood of low valued species may be suitably treated by the process, western hemlock, for example.

For large scale manufacture of material for flooring no strong case can be visualized for a site location since the shipping costs would be such a small fraction of the total cost of this expensive product. It is reasonable to consider that the site would be integrated with an existing wood products producer, but not necessarily a present flooring producer.

DISCUSSION

The Process and Product

The process which serves as the basis for this study is that as developed by others^[2,3,5] for the impregnation of wood with a liquid monomer, specifically methyl methacrylate, and the complete polymerization of the monomer in the more or less saturated wood with ionizing radiation, specifically gamma radiation from an isotope source such as Co⁶⁰ or Cs¹³⁷. The product is wood which has a large fraction of its volume filled with polymethyl methacrylate.* The product then has the appearance and fibrous nature of wood combined with some of the typical properties of the polymer. Such treatment gives a product which has

*Polymethyl methacrylate is commonly available in a variety of forms (cylinders, sheets, tubing, and cast articles) called by the trade names of "Lucite", or "Plexiglas".

markedly improved toughness, strength, abrasion resistance and dimensional stability, and does not need to be surface coated with varnish, lacquer, etc., for protection of the improved surface appearance. With regard to dimensional stability it should be noted that this property generally has to do with major and rapid changes in moisture content. This product does not completely resist penetration by moisture but the rate of this moisture pick-up is markedly reduced such that for practical purposes the material can be claimed to present dimensional stability to a satisfactory degree for most uses. The treated wood needs only to be planed, sanded and buffed to provide a finished surface. The principal unfavorable characteristic developed by the treatment is that the new product can not be nailed without splitting. However, among those accustomed to using high quality wood, nailing is regarded as a primitive method of attaching such material.

The process appears, therefore, to be one of rather impressive simplicity - impregnate, irradiate, and mechanically prepare the surfaces. However, like any impregnation process as applied to wood, the usual problems exist such as penetrability of the wood species, uniformity of impregnation, and limitations in dimensions which can be practically processed. Actually all of these problems have existed for more than a hundred years in the wood preserving industry. Even the polymerization of monomers within the wood structure is neither unique, nor a recent development. Such polymerization has been done with heat and the use of catalysts. However, the use of radiation for this step is relatively new and unique in its application and does have distinct advantages.

In addition, the cost factors obviously limit the utilization of the products to those applications which can justifiably make good use of the improved properties. Although up to now little practical data on costs are available, it is quite obvious that the treated wood which is well over fifty per cent polymer by weight can't be a cheap product so long as the monomer costs in the range of about twenty cents a pound. A board foot of typical soft wood (one-twelfth of a cubic foot) will weigh about two and a half pounds. After treatment the weight will be about five and one-half pounds, of which three pounds are plastic which, in the raw form (monomer), would then cost about sixty-five cents in this board foot of new product. With quality soft woods available for about fifteen cents

per board foot, the raw material costs alone for the new product can't be less than about eighty cents per board foot. Such a cost basis will obviously and readily exclude a number of product applications. A more realistic consideration of costs (and prices) is covered later.

A review of many wood products as sold to the ultimate consumer shows many that are quite costly, even in their unfinished state. Fine hardwood plywood, high quality flooring, specialty woods, and parts for furniture are examples of these. It appears that in these areas, as will be developed later, lie the principal outlets for high quality irradiated wood-plastic materials. It is noted that these uses are those which preserve and emphasize the beauty and texture of natural selected woods. It is soon concluded that structural uses, even those where the improved physical and mechanical properties can best be applied can be satisfied with less costly materials such as ordinary wood of greater cross-section or metals.

Results of inspection of western wood species submitted by Battelle-Northwest, and treated at West Virginia University and Lockheed-Georgia Co., are shown in the following tabulation. Although sampling was very limited, these results provided some background impressions of the general applicability of the process to the more common types of western woods.

Observations on Treated Wood

Wood species mostly in the form of 2" x 4" were submitted for treatment, both to the West Virginia University and the Lockheed-Georgia Company. The 2" x 4" lumber was selected because it appeared to be the largest practical thickness that could be readily accommodated by the process and also because, if this dimension could be processed, all dimensions smaller than this could be handled to cover a wide range of lumber thicknesses.

On the basis of observations on the returned treated wood specimens the following comments are made.

1. Unsatisfactory wood species:

Western Red Cedar (only the sapwood was impregnated)

Western Larch (wood was essentially completely nonimpregnated)

Lodgepole Pine (only the sapwood was impregnated)

REVIEW OF RESULTS ON VARIOUS WOOD SPECIES IN THE FORM OF
IRRADIATED WOOD PLASTIC COMBINATIONS

Wood Species	Dimensions	Processed By	Weight Gain %	Comments and Observations
Douglas Fir	2"x4"x5' long	W. Va. Univ.	110-118	Very good impregnation.
Western Hemlock	2"x4"x5'	W. Va. Univ.	85-102	Nonuniform.
Engelman Spruce	2"x4"x5'	W. Va. Univ.	148	Very good impregnation.
Western Red Cedar	2"x4"x5'	W. Va. Univ.	34-49	Very poor impregnation.
Sugar Pine	2"x4"x5'	W. Va. Univ.	129-176	Fair but "grainy".
Idaho White Pine	1/2"x3"x5'	W. Va. Univ.	155-156	Good.
Incense Cedar	1/2"x3"x5'	W. Va. Univ.	155	Good.
Sitka Spruce	2"x4"x3-1/2" rough	W. Va. Univ.	52	Unsatisfactory impregnation.
Redwood	2"x4"x5'	W. Va. Univ.	100-105	Unsatisfactory, contains unimpregnated streaks.
(All of the above samples were obtained and shipped from Portland, Oregon.)				
Red Alder	2"x2"x18"	Lockheed	--	Very good impregnation.
Luan (Philippine Mahogany)	2"x2"x46"	Lockheed	--	Poor impregnation, nonuniform.
Western Ash	2"x2"x40"	Lockheed	--	Porous but probably satisfactory.
Western Maple	2"x2"x40"	Lockheed	--	Very good impregnation.
(Except for the Red Alder from Portland, the above group was obtained in Seattle.)				
White Fir - A	2"x4"x30" from small tree	Lockheed	130	Nonuniform treatment, but probably could be improved.
White Fir - B	2"x4"x30" from small tree	Lockheed	50	Has some heartwood at one end. Heartwood treated better than sapwood. Results rather inconclusive.

Review of Results on Various Wood Species in the Form of Irradiated Wood-Plastic Combination (Cont'd)

<u>Wood Species</u>	<u>Dimensions</u>	<u>Processed By</u>	<u>Weight Gain %</u>	<u>Comments and Observations</u>
Larch	2"x4"x30"	Lockheed	0	Very dense wood. Almost completely resistant to impregnation - no monomer pick-up! Concluded that this species is totally unsuitable for present process.
Idaho White Pine, A, B, and C	2"x4"x30"	Lockheed	104-125	Wood was noticeably distorted. Saturation of sapwood favored over heartwood but not totally. Like other western pines, has a grainy appearance indicating numerous small areas with decidedly differing concentrations of polymer.
Ponderosa Pine A and B	2"x4"x30"	Lockheed	130-142	From tree of fast uniform growth. Generally satisfactory but with uniform grainy appearance. Good Pickup of monomer.
Ponderosa Pine C	2"x4"x30"	Lockheed	90-100	Very dense old growth. Generally quite good, sapwood definitely favored in impregnability. Some whitish streaks in heartwood but not grainy.
Cedar	2"x4"x30"	Lockheed	77-82	Unsatisfactory. Heartwood essentially completely unimpregnated.
Hemlock	2"x5"x30"	Lockheed	102-103	Generally very good. One section of one piece showed splitting and at the same area less satisfactory impregnation.

Review of Results on Various Wood Species in the Form of Irradiated Wood-Plastic Combinations (Cont'd)

<u>Wood Species</u>	<u>Dimensions</u>	<u>Processed By</u>	<u>Weight Gain %</u>	<u>Comments and Observations</u>
Douglas Fir A, B, & C	2"x4"x30"	Lockheed	67-89	Dense old growth high density wood. Generally good. Very slight difference between inner and outer wood.
Western Maple	3-1/2"x3-1/2"x 12"	Lockheed	67	Highly complex wavy grain pattern. Generally good except for severe depletion at surfaces.
Lodgepole Pine	2"x4" & 2"x6" unfinished	Lockheed	0-31	Unsatisfactory - almost exactly like cedar. Essentially no penetration in heartwood. Good penetration in sapwood.
Lodgepole Pine	2"x4" finished	Lockheed	10	Strikingly different from other pines.

2. Questionable wood species:

Redwood (many fine lines of nonimpregnation throughout)
Sitka Spruce (difficult to impregnate, nonuniform)
Luan (Philippine mahogany) (difficult to impregnate, nonuniform)
Western Ash (porous, not fully loaded)
White Fir (the best of this group. Further study may show it to be suitable, may merely need more time for impregnation)
Idaho White Pine (fair, somewhat less impregnation of heartwood, and with some noticeable distortion. Grainy appearance)

3. Satisfactory wood species:

Douglas Fir (good to very good on all samples)
Western Hemlock (poor to very good)
Engelman Spruce (very good)
Ponderosa Pine (good, sapwood favored by impregnation)
Sugar Pine (good, between Ponderosa and White Pine in appearance and quality of impregnation)
Incense Cedar (good)
Red Alder (the major western hardwood - very good)
Western (Big Leaf) Maple (the next most prominent western hardwood, very good)

General Observations and Comments

In external appearance the best specimens of the wood as submitted and as returned after satisfactory treatment are essentially unchanged in color, texture, or dimensions. (See Figure 1) To obtain a specimen typical of that of treated wood the surface must be planed off to a significant depth below the deepest surface gouge. This is probably due to the volatility of the methyl methacrylate monomer and results in more or less depletion of the monomer at the surface of the wood during the prolonged exposure in the radiation step of the process. The problem is aggravated by the usual but modest temperature increases prevailing during the radiation step. This increased temperature results from both the heat of reaction released by the chemical process of polymerization and the usual heat imparted to bodies in which intense radiant energy is being

FIGURE 1. Appearance Comparison of Treated and Untreated Wood. Douglas Fir -- Sample at left is the original wood as purchased (2" x 4"). Sample at center is a piece of the same board treated. There is no distinctive difference in color or surface texture. The only apparent difference is a major increase in density, noticeable only by lifting the board. Sample at right is treated wood from same board which has been trimmed, planed, sanded and buffed. Picture does not show smooth glossy texture of surface.

absorbed. The practical result of this is that a thin layer of the entire outer surface of the wood being treated is essentially devoid of polymer and must be subsequently planed off to yield a product of acceptable appearance and uniformity. In addition and for many applications the loss at the end grain of the wood is much more of a problem. In all samples (which were mostly "two by four's") the depletion phenomena extended generally about a half-an-inch back from all ends (See Figure 4). Similar depletion occurred at points where the grain structure was marred or crushed. See Figures 4, 5, 6 and 7. However, except for the ends, the amount of surface which needs to be removed may generally be less than one-sixteenth of an inch for carefully selected, graded lumber.

For large scale uses where the wood is applied in flat, rectangular dimensions these planing and cut-off requirements are not serious from a use or cost-of-waste standpoint. For this report the cost estimates allow a 10 per cent yield loss to accommodate this sort of unavoidable waste. However, for wood that is pre-shaped for treatment in forms which expose much more end grain as in curved sections, scroll work, or carved areas of any kind, the process as now developed has obvious limitations. Veneer applications also would have to be completely discounted. Although a large market exists for "flat" work such as flooring, trimming and molding of simple cross sections, the cost of the process impairs the use of the product for applications where something of more complex shape is cut from bulk wood-plastic stock with appreciable nonrecoverable waste, such as curved parts for furniture, legs, arm rests, backs, rockers, etc.

In view of this surface depletion problem it is quite obvious that highly selected wood will be required by the process. Desirable and highly figured woods with irregular grain or with large areas of grain intersecting the flat surfaces other than at the ends, will provide more opportunities for surface diffusion and loss of monomer which would be costly and probably intolerable. Wood damaged by cracks, gouges, mars and indentations would also require excessive planing to produce satisfactory wood-plastic material (See Figures 5 and 7).

Apart from the surface depletion phenomenon there are other problems. A prominent one relates to the natural submicroscopic heterogeneity of wood which shows up rather strikingly in the nonuniformity of saturation of the wood with

FIGURE 2. Treated and Untreated Wood Species. Sample on left is a finished specimen of treated western hemlock; it is considered an excellent irradiated wood-plastic material. The next sample is untreated hemlock. The next sample is a piece of finished treated big leaf maple; it is considered excellent. The sample at the right is a piece of finished treated red alder, also regarded as excellent.

FIGURE 3. Wood Species That Do Not Respond Satisfactorily to Treatment. Samples at left are of western red cedar. Samples at right are lodgepole pine. Upper left and lower right have been trimmed, planed and sanded on all sides. Lower right red cedar sample has not been trimmed or planed. It shows quite well the surface depletion effect. The upper right lodgepole pine has been only partially trimmed and shows surface depletion at the untrimmed left edge. Both of these species seem to be completely resistant to impregnation in the heartwood, but almost complete impregnation in the sapwood.

FIGURE 4. Surface Depletion at the End Grain. This photograph shows the characteristic loss of monomer at the end grain for four wood species. The hemlock piece has been cut at an angle to show the extension of the depleted area in depth. The depletion around the surface defect in the Douglas Fir specimen should be noted; also an enlargement of this section in Figure No. 5.

FIGURE 5. Surface Depletion at a Damaged Area. This is an enlargement of the area on the Douglas Fir specimen shown in Figure 4. The surface has been marred or dented. The cell structure around the damaged area has been sufficiently disrupted to allow rapid release of the monomer before much polymerization has taken place.

FIGURE 6. Distortion in Idaho White Pine. Samples at left are all treated material with only the top section of the specimen at the lower left planed off. The samples at the right are sections of adjacent areas of the original boards (2" x 4"). Light colored areas identify areas of low polymer content. Surface depletion is noticeable but not severe; however, the crack or split in the upper left corner of the middle specimen of treated wood shows the extent of the surface depletion effect throughout the surface of the crack. An enlarged view of this same defect is shown in Figure 7.

FIGURE 7. Depletion of Monomer Around the Surfaces of a Crack. This is an enlargement of the crack identified in Photograph No. 6. It shows the depletion of the monomer from the surface of the crack. Such loss obviously occurred before significant polymerization had been induced. Such cracks probably develop during the vacuum drying stage just before impregnation begins.

monomer. A specimen which after treatment shows an excellent pick-up of monomer as observed by weight change may show areas, even near the surface, of very low loading with the wood showing essentially no increase in the expected and desirable improvements such as hardness or abrasion resistance. These areas may be large or small and as in untreated soft woods can be easily scratched or dented with a fingernail. Some of this type of nonhomogeneity is observable as light colored areas in Figures 6 and 7. Even those wood species regarded as most suitable for the process may show this characteristic in some regions.

Some consideration has been given to the concept that perhaps wood need not be completely saturated to yield a suitable product. These observations of wide differences in attainable saturation levels indicate that partial saturation will still show objectionable nonuniformity. It is concluded that such differences will also show up as undesirable variations in the properties of the products. Therefore, the concept of uniform fractional impregnation does not appear to be attainable without some process modification yet to be developed.

Although much has been done to define the nature and composition of wood, it still must be regarded as a rather heterogeneous material with wide differences in mechanical properties and in the biochemical and physical chemical nature of the material particularly as these relate to lignin and other complex constituents such as gums, resins, and sugars. Furthermore no practical methods appear to exist which permit selection of bulk wood or lumber pieces which will impregnate uniformly (except possibly by species).

It is emphasized that these limitations apply to our understanding of the process and the quality observed on the wood-plastic specimens which we have received. We also believe that the process can be modified by modest and economical means to minimize the problem of methyl methacrylate vapor depletion at surfaces. This monomer is fairly volatile; furthermore, we understand that the irradiation process is conducted at fairly warm temperatures. Such temperatures may arise from both the irradiation environment and from the heat released by the polymerization reaction. A process modification to provide cooling during irradiation and/or the use of a less volatile monomer may be all that is required to assure the application of the process to pre-shaped complex forms

and veneers.* A cost estimate was therefore developed for veneers and assumed the use of less volatile isobutyl methacrylate (boiling point = 155 C as compared to 100 C for methyl methacrylate). (See Appendix.)

Operating Costs and Selling Prices

In the appraisal of the marketability of any product the need for reasonable estimates of total manufacturing costs and selling prices is recognized at an early stage. In fact such estimates may be the beginning steps in many inquiries to establish whether or not research and development should even be initiated on a new process or product. In the present case such estimation is essential to determine the potential class of uses for which the product may be considered. At an early period in the study it was quite clear that the cost and quantity of monomer required to give the product the desirable properties would exclude the product from conventional structural uses where a thicker and cheaper quantity of ordinary wood or alternate material could accomplish the needed results. Then the conclusion was developed that the product would find its most likely market in those uses where the in-depth beauty of fine wood was retained or accentuated, and where the improvements in strength, hardness, toughness, abrasion resistance and dimensional stability would be of major benefit. But for consideration of any uses, cost or prices are essential for a reasonable appraisal of the market potential. Thus, by utilizing the data in references [10] & [13] for guidance and applying the usual experience and judgement, total manufacturing costs and estimated selling prices were developed. These figures included all anticipated usual costs and expenses as well as taxes, working capital costs, distribution, warehousing, selling expense, and return

*In a single small scale test at Battelle-Northwest veneers were processed in the simplest manner using isobutyl methacrylate to produce irradiated specimens of fully impregnated 1/24" veneers with essentially no surface or endgrain depletion. In view of this single "once tried" test it is apparent that the process can produce satisfactory veneer samples and therefore, with further research and development, the process should therefore be regarded as eventually applicable to veneers as well as complex pre-shaped forms. It should, however, be realized that this conclusion is based on a single laboratory test on a small scale and that anyone contemplating such applications needs the support of development work to assure the practical feasibility and economics of the process. Therefore, for the purpose of this study the process as now practiced can not be claimed as suitable for the treatment of veneers.

on investment. Adjustments were made in total investment on the assumption that the plant would be a part of a large wood products or chemical manufacturing operation. Significant factors were assumed for scrap in selecting, grading and preparing wood for treatment as well as yield losses in production of the finished products. Figures were also developed for cases where the wood treatment process is provided as a service to customers who submit their own preshaped wood and veneers for treatment (See Appendix). Many of the figures are based on data from the indicated references with suitable adjustment where necessary. Details of the calculations are shown in the Appendix. Although different investigators may use other estimates and judgements in arriving at total costs and estimated selling prices, it is felt that these present estimates are reasonable and realistic and are not subject to major changes by alternate methods of estimating or calculating.

The estimated prices for bulk products apply to a situation where a producer is marketing to large scale users who convert the wood-plastic product to the ultimate application on an industrial scale. The price estimate thus does not assume marketing through the usual lumber yard or retail hardware dealer. If the usual mark-up under retail conditions were applied, the estimated prices would increase by at least 40 percent or to about \$2.80 to \$3.60 per board foot for soft and hardwood plastic combinations, respectively. These prices then would apply for purchases from retail stores by small scale users who may wish the material for their own home craft work - flooring, cabinetry, furniture, framing, etc. These distinctly different and realistic pricing levels and bases should be clearly understood by the reader who may be considering the ultimate use of plastic-wood combinations.

Although larger scale production could be expected to lower the ultimate costs and prices, the anticipated reductions can not be spectacular because of the large fraction of cost which is in the raw materials, selected wood and particularly the monomer. Methyl methacrylate, the preferred monomer, has enjoyed a succession of lowered prices in recent years. Further major drops are not expected.

The most attractive means of gaining the advantages of the wood-plastic combinations at lower cost appears to be in assuring a uniform but fairly deep surface treatment. This would be considered a "finish in depth" and would feature an easily restored permanent finish. This may be provided by the use of fully treated veneers of suitable thickness. Thickness which approaches that of existing printed overlay type surfaces on plywood would not provide the needed and desired advantages. Thickness must be sufficient to permit simple surface repair of scratches or mars by sanding and buffing. It is believed that veneers of about one twenty-fourth of an inch thickness would be satisfactory. As has been discussed, such veneers probably can not be assured by strict adherence to the process as presently developed. The cost of producing treated veneers (assuming simple process modifications which would make the process applicable) appears to be reasonable and tolerable for the advantages to be gained. Furthermore, the estimate is based on a very large production of treated veneer - about ninety million square feet per year. The estimate as shown in the Appendix thus probably represents near minimum costs for the particular monomer used in this example.

Steps Necessary for Commercialization

The following factors required for commercialization of essentially any manufactured product are:

1. A product must be produced that has properties suitable for the market and consistent from batch to batch and day after day.
2. The price of the product must be acceptable to the market.
3. The market must be large enough to support a profitable production facility.
4. A manufacturer must be sufficiently convinced of 1, 2, and 3, above, to risk the venture into the production and marketing of the product.

In the wood-plastic area it appears that a product with desirable properties can be produced. Consistency of quality, however, may be sharply dependent on species and selection of wood under new specifications and evaluation techniques yet to be developed. Although the price will be high, it appears that there are applications for the wood-plastic products. Also, the market appears large enough to support at least one multipurpose production facility, probably with emphasis

on the manufacture of flooring. Obviously, venture capital has not yet been advanced for a specific full scale manufacturing plant. It is hoped that the data presented in this report, along with the test treatment program now underway for a variety of industrial products under a companion AEC Division of Isotope Development program, may encourage favorable action along this line.

Consideration of Alternate Monomers

In the course of the research and development conducted by a number of investigators, a variety of monomers has been studied for application to the field of irradiated wood-plastic materials. In view of the heavy loadings required to yield the most desirable properties in the products (in excess of about 100 percent for softwoods based on the weight of the original dry wood), the trend has been naturally toward the development which assures the use of the cheapest monomer, which the simplest process can most readily utilize. Most of the work therefore has involved low cost liquid monomers, specifically methyl methacrylate (21¢/lb in tank car shipments). Work is continuing on cheaper liquid monomers such as styrene and acrylonitrile. Future development may result in the use of these cheaper materials in some variant of the process, or for some specific products.^[14] For this present study, however, consideration has been limited to the methyl methacrylate monomer or other very closely related acrylates, for which the present process is known to be directly applicable.

Although a variety of monomers could be considered for wood treatment the choice of methyl methacrylate is a logical one. Its polymers are noted for hardness, toughness and durability among all commercial plastics. Its durability under exterior weather and sunlight conditions has been substantiated by over fifteen years of use in the outdoor sign industry.^[15]

Although there are many monomers which are cheaper than methyl methacrylate, it has distinct advantages in this process; it is readily polymerized and produces products with outstanding properties. Until other monomers are shown to impart properties as good as or better than methyl methacrylate there does not appear to be any great expectations for the use of alternate materials and particularly if these are more costly. Methyl methacrylate has recently enjoyed a substantially lower price; however, it is still a relatively expensive material. In view of the

present manufacturing processes and the competition in the field this price level may be stable for some time with little prospect for further major price reductions. It can be regarded as a "mature" chemical product which is being sold at prices less than one-half of what they were twenty-five years ago and at production levels exceeding a quarter of a billion pounds per year.

Contacts with producers of high quality furniture who use large quantities of costly veneers volunteered that if the color, hardness and generally improved durability properties characteristic of the irradiated wood-plastic material could be assured throughout the veneer sheet an increase in cost in the range of ten to twenty-cents per square foot could be tolerated. This leads to the possibility that isobutyl methacrylate which has a much lower vapor pressure than methyl methacrylate very likely would be highly suitable for veneers although more expensive (38¢/lb), thus avoiding the intolerable surface depletion problem. This conclusion was subsequently demonstrated in a single exploratory experiment (See footnote page 13). The cost estimate for treating veneers (see Appendix) was therefore based on the use of the more costly isobutyl methacrylate. The selling price of such material, produced on a large scale in one-twenty-fourth inch thickness, with liberal cost allowance for lower yields of the more difficult to handle product and higher labor cost was calculated to be 12 cents per square foot, exclusive of the cost of the original veneer. This price then provides a veneer which after assembly as plywood needs only a sanding and buffing operation to achieve the final surface finish. No costly and multiple liquid coating, drying, sanding and other treatment appears to be needed. However, other finishes such as lacquers, varnishes, and waxes could be applied to achieve additional surface gloss or texture. Also, it is very likely that such finishes could be applied more economically to the wood-plastic material than to normal wood.

Although a conservative view has been taken of the applicability of the process to veneers by the selection of the more costly and less volatile monomer (See Appendix), it is of interest to note the cost penalty involved. This penalty indicates the justification for research and development needed to assure the development of practical techniques which assure the use of a cheaper monomer.

Assuming monomer costs alone with retention of all other costs and factors, a 21¢/lb monomer would result in a 3.75 cents decrease per square foot in selling price for softwood-plastic veneer, and 3.1 cents decrease for hardwood-plastic veneer in comparison with a case using the more costly isobutyl methacrylate. This poses an impressive justification for work on low cost monomers. Basically it doesn't appear logical for the isobutyl monomer to cost so much more than the methyl in view of published prices for the corresponding alcohol raw materials. The prices may instead reflect the rather great differences in production volume. Thus, the entrance of a large scale use for the isobutyl monomer may in reality assure a lower price - perhaps even competitive with the methyl monomer. There is therefore a hazard in basing future programs of research and development on existing published prices of ultimate raw materials without a more thorough knowledge of the monomer manufacturing business.

The estimated selling prices for typical wood-plastic material as shown in the table (pages 25-26) shows a figure in the range of 52 to 64¢/sq ft for wood which is one-quarter of an inch thick. If advantage can be taken of the real improvements obtained in the durability characteristic (hardness, toughness, abrasion resistance, etc.) it is conceivable that even thinner sections may be entirely acceptable for flooring applications. Even though the price as estimated here fairly clearly indicates economic justification for large scale flooring applications, any advantage that can thus be taken in view of the improved properties to accept thinner sections further support a firm conclusion that commercialization in the flooring area is attractive.

Summary Statement on the Process, the Product and the Economics

It appears that the process as practiced today on a variety of woods of simplest forms - essentially flat, rectangular boards of high quality lumber - could be operated profitably at the prices estimated in this report. A major technical problem with many woods is in the non-uniformity of impregnation in localized areas. However, with modest improvements to correct the surface depletion problem, which appear feasible via further research and development, the process may be extended to veneers and pre-shaped forms for a variety of uses.

COST ESTIMATE FOR IRRADIATED WOOD-PLASTIC MATERIAL

Production: 21,600,000 pounds (hardwood or softwood*) treated material per year (72,000 pounds per day).

300 days per year (24 hours per day, six days per week), 90% yield on wood and monomer.

Plant Investment: \$1,330,000 plus \$20,000 share of allocated common facilities -- TOTAL \$1,350,000

	Annual Cost	
	Softwood	Hardwood
Wood:		
Softwood -- 10,920,000 lbs @ 15¢/bf (6¢/lb)**	\$ 655,000	
Hardwood -- 14,120,000 lbs @ 54¢/bf (15.4¢/lb)***		\$2,175,000
Monomer: (methylemethacrylate @ 21¢ lb)		
13,080,000 lbs for softwood	2,747,000	
9,880,000 lbs for hardwood		2,075,000
TOTAL COST OF RAW MATERIALS	\$3,402,000	\$4,250,000
Utilities: (Vitro basis) ^[10]	13,500	13,500
Labor: (152 manhours/day @ 3.50/hr., including also shift supervision, maintenance, laboratory, shipping and plant clerk).	160,000	160,000
General Overhead: (80% of labor)	128,000	128,000
Maintenance and Repairs: (Equipment and materials including tools)	50,000	50,000
Depreciation: (10% of total investment)	135,000	135,000
Engineering and Administration:	100,000	100,000
Patent Rights: (@ 1/4¢ per pound of product)	54,000	54,000
Office and Miscellaneous Expenses:	40,000	40,000
Share of Start-Up Expenses: (15% of \$100,000 for interest, labor and materials)	15,000	15,000
Source Rental: (¹³⁷ Cs)	75,000	75,000
Third Party Liability Insurance: (Vitro's figure)	75,000	75,000
Plant and Equipment Replacement: (0.4% of investment)	5,400	5,400
Property Taxes and Insurance: (1.5% of investment)	20,000	20,000
Other Local Taxes: (1% of investment)	13,500	13,500
ANNUAL MANUFACTURING COST	\$4,286,400	\$5,134,400

* Softwood is initially 2.5 pounds per board foot. Treatment results in a loading of 1.2 pounds of monomer per initial pound of softwood and yields a product weighing 5.5 pounds per board foot.

Hardwood is initially 3.5 pounds per board foot. Treatment results in a loading of 0.7 pounds of monomer per initial pound of hardwood and yields a product weighing 5.95 pounds per board foot.

** 15¢/bf for cheapest softwoods @ double the published prices to allow for ripping, trimming and inspection losses. (Flooring grade Douglas Fir 1×4, flat grain, is \$165.00/Mbf.) Hemlock, white fir and larch are the cheapest softwoods.

*** 54¢/bf is the average cost of White Oak, Birch, and Hard Maple @ double the published average prices to allow for ripping, trimming and inspection losses. Red Alder and Western (Big Leaf) Maple would be cheaper hardwoods for a western

	<u>Softwood</u>	<u>Hardwood</u>
Plant Investment + Allocated Facilities:	\$1,350,000	\$1,350,000
Working Capital:		
Cash -- 10% of annual manufacturing cost	429,000	513,000
Accts. Rec. -- 10% of 1 year annual manufacturing cost	429,000	513,000
Inventory of Finished Product -- 10% of annual manufacturing cost	429,000	513,000
Inventory of Raw Material -- 10% of wood + monomer	340,000	425,000
	<hr/>	<hr/>
TOTAL WORKING CAPITAL	\$1,627,000	\$1,964,000
TOTAL INVESTMENT + WORKING CAPITAL	\$2,977,000	\$3,314,000

Annual Manufacturing Cost:	\$4,286,400	\$5,134,400
Gross Return Required: (30% of investment + working capital)	893,000	994,000
Federal Taxes: (50% of gross return)	446,500	497,000
Net Return: (15% of investment + working capital)	446,500	497,000
	<hr/>	<hr/>
Distribution and Warehousing: (@ \$10/cwt of product)	2,160,000	2,160,000
Sales Expense: (20% of annual manufacturing cost)	858,000	1,027,000
	<hr/>	<hr/>
TOTAL ANNUAL SALES VALUE	\$8,197,400	\$9,315,400
(mfg. cost + gross return, + distribution + sales expense)		

Selling Price: (at warehouse)		
\$/board foot	2.09	2.56
\$/lb	0.38	0.43
\$/sq.ft. @ 1/4" thickness	0.52	0.64

* These two figures comprise the breakdown of Gross Return and are thus neither added nor included in the total Annual Sales Value figures. The Gross Return figure is, of course, included in the Total.

At the present time, without additional development, flooring products could be produced. Also, for those products, which could afford the cost, the same stock used for flooring could be cut to the shapes needed. What specific products these might be have not been determined but would probably be in the nature of novelties, specialties and souvenirs. However, the output of these would not be expected to be large - alone, not enough to support a plant.

If the prices as estimated are accepted as realistic, wood-plastic flooring would be competitive for sure if advantages can be taken of the improved properties so that the thickness required can be reduced. It does not seem logical to assume that wood-plastic at \$2.10 to \$2.60 per board foot can compete with oak flooring at about \$0.60 per square foot installed and finished. However, a wood-plastic material about one-quarter inch thick (or perhaps thicker) would probably be competitive with conventional oak flooring, particularly in view of its improved durability and no need to refinish it other than by sanding and buffing after future periods of wear.

With the extension of the process via further research and development to treat veneers a very large market appears probable even at the additional cost of \$0.12/square foot. Decorative uses are first visualized - fine woods converted to prestige paneling and furniture. This may not, however, be the principal use for treated veneers. An extremely durable plywood made with treated veneer surfaces perhaps with treated thickness as great as 3/32" may be justified for such rough usage as concrete forms. The exterior type plywood now used for this purpose is of premium quality and high cost, it is reused several times. A similar plywood made with a veneer surface of wood-plastic may have exceptional durability properties that could readily justify the added cost.

This commercialization study did not include experimental work at Battelle-Northwest. An adequate supply of treated wood was, however, provided by both West Virginia University and the Lockheed-Georgia Company through arrangements with the Division of Isotopes Development. Under this arrangement representative wood species generally in the form of "two by fours" were obtained from retail

suppliers locally, shipped to West Virginia and Georgia, treated and returned to Battelle-Northwest for examination. These treatments were done in the period of May through October, 1965, and were assumed to be representative of the process as developed up to those dates. Other elements of technology used in this study depended on developments as reported up to about August, 1965. This report with all its conclusions and opinions is based on the results of the process as exhibited in the wood species treated in this time period and on the technology as reported to about August, 1965. As late as September 15, 1965, when details were presented at the Chicago information meeting there appeared to be no significant departures from the basic process as outlined in the Arthur D. Little report^[4] of a year earlier.

Plant Location

This study emphasizes only one potential irradiated wood-plastic product; flooring, which appears most reasonable for rapid and large scale commercial development. In view of manufacturing costs as developed in this study we can visualize no strong economic bases for precise locations of plants. This is concluded because of the large fraction of cost in raw materials alone, especially since the shipping charges for large loads of raw wood and chemicals are not excessive. The shipping costs of these are therefore not a great fraction of the production cost. More significant are factors such as the motivation of a wood or monomer producer to expand his business or to diversify his line of products. These plants would probably be integrated with either an existing manufacturer of flooring or other wood products, or a producer of monomers, plastics, or other chemicals. The advantage in marketing "know-how" for this business to be a part of a flooring manufacturer's line of products seems to be especially favorable. The integration with major consumers of monomers also suggests integration with a chemical producer. A somewhat different situation would exist, however, in the case where the irradiated wood-plastic plant was primarily built to provide custom treating service for a variety of suppliers of wood products - such as furniture parts, including table legs, cabinet edges, and specialty items such as tool handles,

sporting goods and wood novelties. For such a plant, nearness to the customer would probably be a significant factor in location. The processing of highly selected veneers for furniture also would benefit from such a location; however, the advantage of also being a part of an existing wood products supplier or a chemical company would still be significant.

In consideration of the geographical limits of this study a flooring plant utilizing western hardwoods such as red alder or big leaf maple or softwoods such as Douglas fir or hemlock, would appear to be logical for either the lower Columbia River or Puget Sound areas near a large supply of these wood species which are already being marketed from these areas. A similar situation is visualized for a native hardwood flooring plant in the Great Lakes Area. In this area, however, the opportunity appears greater for the same plant also to service-process a variety of wood articles for use by the furniture industry, most likely by a company already in the business of producing flooring or furniture parts. A central Michigan location is thus indicated. A chemical company integration also appears very attractive in the same area.

INDUSTRIAL AND RESEARCH CONTACTS

With a fair understanding of the process, its potential costs, and the nature of the resulting products a number of companies and institutions were interviewed to explore their interest and response to the potential applications for the product. In general a careful review was made of companies to select those for contacts which had a known and strong background in wood technology and wood applications research. This selection alone provided a screening process which assisted greatly in getting a firm understanding and dependable response.

In general, the response was extremely variable even among the giants of the business. Some of these showed very little interest and stated that because of the apparently small specialized nature of the irradiated wood-plastic material business, it was of insufficient size to justify their consideration of it. Other equally large concerns expressed great interest as a potential area for profitable diversification of their line of wood products.

Some wished to be kept advised of developments, particularly if research and development progress involving pooled resources with others were being contemplated for further study of the process and applications. Some tied such expression of interest to qualifications which would assure their proprietary interests. From this standpoint some were apprehensive of such arrangements, if government support were involved.

Although there was no assurance that the present process would be satisfactorily applied to the treatment of veneers, the interest in veneers was almost universal. Many felt that in view of the probable cost of the treatment process that veneers would comprise the only logical large scale application of the process.

Flooring applications also appeared to have favorable response in a number of contacts. These included flooring for sporting areas where durability and dimensional stability are very important.

Chemical (monomer) producers also showed interest in the developments.

In many of these contacts questions on real durability and weatherability could not be satisfactorily answered because data were still being developed.

The possible effects on manufacturing processes or the users processes were discussed in view of the probability that the problem of wood waste would require treatment of pre-shaped pieces. At the present time the surface depletion problem discourages any practical consideration of the process for such material especially if extensive carving, curved sections and scroll work are involved in the pre-shaped pieces.

The potential and desirable extension of the process to include cross linking or grafting of the polymer to the wood cellulose and also the use of treating agents which would concurrently impart fire retardency to weatherable structures were suggested in the course of many of these contacts.

An example of the situation which illustrates the concept of the economic unfeasibility of cutting wood parts from bulk treated lumber involved the consideration of the curved rockers for chairs. For this rather simple structure, inexpensive but high quality (straight grain) hardwood is used. About four board feet of such wood is used to produce a pair of rockers. This involves a waste loss of about seventy-five percent, but with a total cost of wood of only about

forty cents. Such a situation does not support a decision to cut rockers from irradiated wood-plastic material. The cost of such a technique would obviously be prohibitive. Furthermore, the present IWPM process can not be depended upon to produce a satisfactory pre-shaped piece because of the end grain exposure in curved structures, specifically shapes such as rockers. If we accept this view of inadequacy of the present process, similar situations in many applications will exist particularly in the furniture industry where a large number of turned wood shapes and irregular forms are used. This situation further supports a present decision to limit the commercial promotion of the process today to flat regular forms of wood, specifically flooring or other forms on which there would be a minimum of waste in going from treated wood to the finished product.

Uses of flooring, however, cover a wide range of applications, such as for homes, sporting areas, boat and box car decking, institutional and industrial. The annual volume of business among these is enormous. One billion, two-hundred million board feet of hardwood flooring were produced in 1954. This comprised eighty percent of all flooring produced from both soft and hardwood. Ninety-two percent of the hardwood flooring is oak. Bases used in our estimate for a plant would use only a very small fraction of this total to justify a plant (about 4,000,000 board feet of hardwood per year). It would seem that a vigorous selling effort for the superior but high priced product that the process can produce would certainly result in a marketing volume equivalent to at least this small fraction of the total business.

CONCLUSIONS

We conclude that in the area of flooring there are possibilities for near future commercialization. The product quality is outstanding for certain wood species in both soft and hardwoods. The cost is high but in certain thicknesses could be competitive with the more common and less desirable flooring materials, including some of the synthetics.

The process is not sufficiently developed at the present time to assure its application to pre-shaped wood other than in flat rectangular form or in forms which would yield a minimum of waste in converting to the finished article after treatment. The process is not suitable for veneers because of the problem of depletion of monomers at surfaces before polymerization is sufficiently advanced.

The cost is too high to hope for much of a business in cutting shapes from treated bulk wood unless waste losses were low, a situation which does not appear to exist in many of the wood-using industries which consume wood mainly because it is inexpensive in situations where waste levels may be large but tolerable in cost.

The wood to be treated will necessarily be of high quality because of the waste losses associated with lower grade wood which may be characterized by a large portion of knots, checks, cracks, or splits, irregular grain, mars, damaged areas and surface imperfections. All these defects aggravate the surface depletion problem and yield non-uniformly treated wood. This conclusion may be at variance with some earlier reports on the process and with the general belief that plastic impregnation involves a syrupy or viscous liquid that will fill voids, bridge over cracks or pits and in general cement together a rather discontinuous woody material. In reality the extreme fluidity or low viscosity of the monomers generally used greatly minimize any tendency toward the filling of cracks, voids, or surface imperfections; in fact monomer impregnated wood should be held in a horizontal position with respect to the grain to minimize the migration of the monomer by gravity within the wood from top to bottom during the polymerization step! (See reference 10, page IV-6)

The high cost of the products does not provide a strong basis for optimum siting. Very likely siting will be most strongly determined by the investment and marketing preference of the producer who most probably would be presently engaged in wood processing to produce an integrated range of products including economical utilization of all wood waste.

The likely wood species which could be processed in the Pacific Northwest based on the appearance of treated material obtained in the course of this study include both of the major local hardwoods, red alder and big leaf maple, and softwoods as follows: western hemlock, Douglas fir and ponderosa pine. Those species which appear to be definitely unsuitable include western red cedar, western larch and lodgepole pine. Maple and birch used by the furniture industry in the Great Lakes area also treated satisfactorily.

The conclusions reached in the course of this study have been developed from our own observations which we concede have been influenced to a great extent by comments, advice and counsel obtained through discussion with the many specialists in the wood process technology field.

SUGGESTED FUTURE DEVELOPMENTS

Although we believe the present process has been developed to the stage where a few suitable products and process economics can be reasonably specified to establish the desirability of near future commercialization, there are major unresolved problems that prevent a more widespread application of the process. The solution of these problems or process advancements would go a long way toward assuring the practical realization of the process for a more diverse line of important and improved wood products.

The first among these advances would be to develop techniques which will assure the application of the process to a wide variety of veneers both for decorative as well as industrial uses.

Although the weatherability properties of IWPM have not yet been adequately reported we believe improvement will be necessary to achieve the properties necessary for the stringent requirements encountered in marine applications, for example. Again, although data have not been made available, we believe grafting or cross-linking between polymer and the cellulose of the wood will be necessary in order to assure outstanding exterior weatherability. A process modification to assure a large fraction of crosslinking between cellulose and polymer appears to be a logical and necessary extension of the process.

A concurrent development which would assure long-term (life time) flame or fire retardancy to irradiated wood-plastic products for exterior use also seems to be a needed extension of the process. This possibility was brought up many times in the course of our industrial contacts.

A development which could assure high loadings of monomer to controlled and predetermined depths from the wood surfaces has hopes of contributing greatly to the reduction of the cost of the treated wood products.

The whole area of the physical chemistry of wood as it relates to impregnation with monomers, preservatives and fire retardants appears to need more extensive study. The heartwood versus sapwood chemistry appears to be undefined and unexplained. Treatments which greatly improve the impregnability of wood need development.

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APPENDIX

COST ESTIMATE BASES

Process Time Cycles

<u>Operation</u>	<u>Estimated Time (hr)</u>
Evacuation of wood	1/2
Addition of nitrogen to impregnator	1/2
Re-evacuation of wood	1/2
Addition of monomer	1/2
Immersion at atmospheric pressure	1 to 4

For irradiation an average dose rate of about 30 rads per second (10^5 R/hr) would require about fifteen hours of exposure to polymerize methyl methacrylate (see Reference 4, Table XII, page 49).

For estimating purposes a twenty-four hour cycle for the whole treatment process appears reasonable in view of the above reported time estimates.

With data as referred to above, plant economics as discussed in the interim Vitro report^[10] and other reference material^[13], a production cost and selling price estimate was made for three processing situations.

1. A plant which purchases wood, treats it and markets it. (Results were shown earlier in the text of this report.)
2. A plant that serves other wood processors by accepting their wood, treating it and returning the treated forms back to the processor.
3. A plant that custom treats veneers. Again in this case, no charge has been included for the cost of the veneer. However, a substantial cost has been assumed for handling losses in processing the fragile veneer sheets.

Plant Investment

Adjustment of Vitro's figures^[10] were made on the assumption that the plant is located on the property of and the operation is integrated with a large wood products or chemical plant.

Site, yard-work and extension of services	\$ 40,000
Process building and equipment	750,000
Irradiation facility (exclusive of source*)	365,000
	<hr/>
	\$1,555,000
Engineering for construction, 15% of above costs	173,000
Allocated cost for share in common service facilities**	22,000
	<hr/>
TOTAL INVESTMENT	\$1,350,000

* Rental of the source is assumed, and this cost element is included in the Annual Manufacturing Cost.

** Steam plant, waste disposal, first aid, patrol and fire protection, etc.

Estimate for Manpower

Receiving, stacking and yardwork	1
Inspection, selection and preparation of wood for processing	1
Discharging, inspection, selection and preparation of product shipments.	2
Chemical make-up, impregnation and irradiation	3
Shift supervision	3
Process control and laboratory service	2
Maintenance	3
Clerk	1
	<hr/>
	16
Sixth day operation	3
	<hr/>
TOTAL MANPOWER	19

Total Manpower	19
Hours per day per man	8
Total MANHOURS per day	152
Average rate per hour	\$3.50
Manpower cost per day	\$532
Operating days per year	300
	\$159,600
Total annual manpower cost (rounded)	\$160,000
Manpower overhead @ 80%	\$128,000

Start-Up Expenses

Interest during construction plus training, equipment testing, and preliminary production.

Construction cost = \$1,330,000 over a period of one year

Interest on construction costs = 8% of an average of one

half of the construction cost = \$ 53,200

Labor and materials 46,800

Total Start-Up Expense \$100,000

It is assumed that the above expense is recovered as a part of the manufacturing cost at a rate of 15 per cent per year (\$15,000).

Source Rental

Recent developments in the production and pricing of radiation source isotopes, namely Co^{60} and Cs^{137} , encourage the consideration of the latter isotope source and as a rental rather than investment basis. Recent pricing announcements on these two isotopes make them essentially equal on a "cost of energy" basis; in other words, the cost per curie for Cs^{137} is now low enough so that even with the lower photon yield and lower energy per photon for Cs^{137} , it is equivalent in cost to Co^{60} as a radiation source. This coupled with much longer half-life of the Cs^{137} (lower annual radioisotopic

depletion) favors the use of this material. The high initial investment in these sources which are constantly decreasing (but at greatly differing rates) in radiant energy output suggests a rental basis rather than an investment basis for their use. This is particularly appropriate for the Cs^{137} which has a 30 year half-life (instead of Co^{60} with its 5.3 year half-life). The Vitro report (Ref.10) proposes a Co^{60} source of 1,280,000 curies. An equivalent Cs^{137} source would be about 5,120,000 curies.

Source Cost Comparison

	<u>Cs^{137}</u>	<u>Co^{60}</u>
Cost of encapsulated source material, cents per curie	12.5	65
Total curies required	5,120,000	1,280,000
Total value of source	\$ 640,000	\$ 832,000
Annual decay (depletion) rate* (first year basis)	2.3%	13%
Cost of depletion (first year basis)	\$ 14,720	\$ 108,150
Annual Rental Rate @ 9.5% of total initial value	60,800	79,000
ESTIMATED ANNUAL RENTAL CHARGE.....	<u>\$ 75,520</u>	<u>\$187,150</u>

*See HW-57670, page 6, "Consideration of the Present and Future Market for Cesium-137", by L.E. Brownell, Aug. 29, 1958.

The above comparison on a rental basis clearly supports a decision to use Cs^{137} .

COST ESTIMATE FOR IRRADIATED WOOD-PLASTIC MATERIAL
WITH COST OF THE WOOD EXCLUDED

(Assumes a customer is paying only for having his preshaped wood treated.)

	<u>Softwood</u>	<u>Hardwood</u>
<u>Subtractions and Items to Change:</u>		
Annual Manufacturing Cost (see estimate for IWPM with wood included)	\$4,286,400	\$5,134,400
Cost of wood (subtracted)	655,000	2,175,000
ANNUAL MANUFACTURING COST	<u>\$3,631,400</u>	<u>\$2,959,400</u>
<u>Total Investment:</u> (same as IWPM with wood included)	1,350,000	1,350,000
<u>Working Capital:</u>		
Cash: (10% Annual Manufacturing Cost)	1,092,000	888,000
Accounts Receivable: (10% Annual Manf. Cost)		
Inventory Finished Product: (10% Annual Manf. Cost)		
Inventory Raw Material: (10% of Monomer only)	275,000	208,000
Total Working Capital	<u>\$1,367,000</u>	<u>\$1,096,000</u>
TOTAL INVESTMENT + WORKING CAPITAL	\$2,717,000	\$2,446,000
<u>Gross Return:</u> (30% of Investment + Working Capital)	815,000	734,000
<u>Distribution and Warehousing:</u>	--	--
<u>Sales Expenses:</u> (20% of Annual Manufacturing Cost)	726,000	592,000
TOTAL ANNUAL SALES VALUE	<u>\$5,172,400</u>	<u>\$4,285,400</u>
<u>Price:</u> (FOB Factory)		
\$/board foot	1.32	1.18
\$/lb	0.24	0.20
\$/sq ft 1/4" thickness	0.33	0.30

COMMENT AND ESTIMATE FOR COST FOR TREATING VENEERS:

(Cost of wood veneer not included)

Although it might be assumed that the cost of veneer treatment would be quite similar to that arrived at by dividing the board foot price by the number of veneer thicknesses in a board foot, this is not a realistic conclusion because of expected higher monomer and scrap losses in processing the rather fragile veneer sheets. For example, on a straight thickness basis (like the "square foot of 1/4" thick" calculation in the earlier cost estimate) 1/24" veneer treatment would appear to cost 5.5¢ per sq ft for softwoods and 4.9¢ per sq ft for hardwoods (exclusive of the cost of the wood veneer). However, these figures do not allow for: (1) the higher losses of monomer, (2) lower overall yield on the acceptable treated veneer, and (3) the lower overall plant throughput or higher labor cost in processing such materials.

The following estimate attempts to factor into the cost these less favorable elements in the treatment of veneers.

Bases: \$100,000 higher investment in equipment to process the more bulky veneer assemblies.

Use more costly, low vapor pressure monomer, isobutyl methacrylate.

70% yield on monomer.

25% increase in labor requirements.

1/24" veneer thickness.

An arbitrary wood waste charge of 1¢/sq ft for softwood and 2¢/sq ft for hardwood.

1/24" treated veneer, softwood = 0.229 lbs/sq ft.

1/24" treated veneer, hardwood = 0.247 lbs/sq ft.

21,600,000 lbs = 94,300,000 sq ft of softwood veneer
= 87,100,000 sq ft of hardwood veneer

Scrap loss for softwood @ 1¢/sq ft = \$ 943,000/yr

Scrap loss for hardwood @ 2¢/sq ft = \$1,742,000/yr

Cost of "spacers" @ \$1.00 each and used ten times before discard = 10¢/320 sq ft veneer (call it \$30000/yr for softwood or hardwood, including "bundle binding" material such as wire, metal strap, or fiber).

	<u>Softwood</u>	<u>Hardwood</u>
Waste Wood Expense:	\$ 943,000	\$1,742,000
Monomer: (Isobutyl methacrylate @ 38¢/lb, 70% yield)	6,400,000	4,830,000
	<u>\$7,343,000</u>	<u>\$6,572,000</u>
COST OF RAW MATERIALS		
Utilities:	14,000	14,000
Labor:	200,000	200,000
General Overhead:	160,000	160,000
Maintenance and Repair:	60,000	60,000
Depreciation:	145,000	145,000
Engineering and Administration:	100,000	100,000
Patent Rights:	54,000	54,000
Office and Miscellaneous:	40,000	40,000
Share of Start-Up Expense:	20,000	20,000
Source Rental:	75,000	75,000
Third Party Liability:	75,000	75,000
Plant and Equipment Replacement:	6,000	6,000
Property Taxes and Insurance:	22,000	22,000
Other Local Taxes:	14,500	14,500
	<u>\$8,328,500</u>	<u>\$7,557,500</u>
ANNUAL MANUFACTURING COST		
Plant Investment:	1,450,000	1,450,000
Working Capital:		
Cash:		
Accounts Receivable:	2,500,000	2,267,000
Inventory, Finished Product: } 30% Annual Manf. Cost		
Inventory Raw Material: (10% monomer only)	640,000	483,000
	<u>\$4,590,000</u>	<u>\$4,200,000</u>
TOTAL INVESTMENT + WORKING CAPITAL		
Gross Return (required): (30% of WC + Investment)	1,377,000	1,260,000
Distribution and Warehousing:	--	--
Sales Expense: (20% of Annual Manufacturing Cost)	1,666,000	1,512,000
	<u>\$11,371,500</u>	<u>\$10,329,500</u>

Price: (FOB Factory)

\$/lb

0.527

0.12

\$/sq ft

0.478

0.12

Densities of Woods* (oven dry basis)

Birch (Yellow)	41.70 #/cu ft
Birch (Sweet)	44.58
Maple (Sugar)	42.2
Walnut	35.09
Oak (White)	44.33
Beech	40.89
Hemlock (Western)	26.97
Pine (Ponderosa)	28
Douglas Fir	31 [27.84 mountain type, 31.96 coast type]
Engelman Spruce	23.2

For representative hardwoods assume: 42 lb/cu ft
3.5 lb/b ft

For representative softwoods assume: 30 lb/cu ft
2.5 lb/b ft

*From "Handbook of Chemistry and Physics" 42nd Ed. Page 1567-1570.

COMPANIES CONTACTED DURING COURSE OF STUDY*

A. D. Little Company, Boston, Massachusetts
American Novawood Corporation, Lynchburg, Virginia
American Plywood Association, Tacoma, Washington
American Seating Company, Grand Rapids, Michigan
Biles-Coleman Lumber Co., Omak, Washington
Bohemia Lumber Co., Inc., Culp Creek, Oregon
Boise Cascade Corporation, Boise, Idaho
Brunswick, Balke, Callender Company, Muskegon, Michigan
Conway Corporation, Grand Rapids, Michigan
Dow Chemical Company, Midland, Michigan
Eaton-Young Lumber Company, Eugene, Oregon
Fine Hardwoods Association, Chicago, Illinois
Heritage, Mr. Clark C., Consulting Engineer, Tacoma, Washington
Herman-Miller Company, Zeeland, Michigan
High Voltage Engineering, Burlington, Massachusetts
B. J. Johns' Furniture Corp., Portland, Oregon
Koppers Company, Pittsburgh, Pennsylvania
Lockheed Georgia Corporation, Dawsonville, Georgia
McGuane, Mr. H. H., C.P.I. Veneers, Seattle, Wash.
Michel Lumber Co., Lake Oswego, Oregon
North Carolina State University, Raleigh, North Carolina
Northwest Veneer, Inc., Grande Ronde, Oregon
Olympic Manufacturing Co., Portland, Oregon
Plywood Research Foundation, Tacoma, Washington
Potlatch Forests, Incorporated, Lewiston, Idaho
Research Triangle, Raleigh, North Carolina
Rohm and Haas Company, Philadelphia, Pennsylvania
St. Regis Paper Company, Tacoma, Washington
Simpson Timber Company, Seattle, Washington
Southern Interstate Nuclear Board, Atlanta, Georgia
National Forest Products Association, Washington, D.C.

* Including those from which inquiries were obtained or from which samples were required.

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Tacoma Boat Building Company, Tacoma, Washington
U.S. Forest Products Laboratory, Madison, Wisconsin
U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.
U.S. Plywood Corp., Seattle, Wash.
United Shoe Machinery Company, Beverly, Massachusetts
Vitro Engineering Co., New York, New York
West Virginia University, Morgantown, West Virginia
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