

Interim Technical Report #3

Titanium Matrix Composite Processing:
Tapecast Preforms

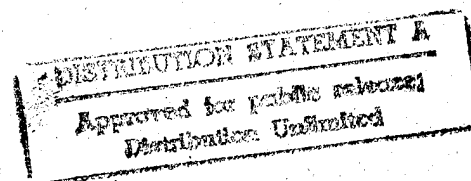
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Principal Investigator: Dr. John V. Busch

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Summary

Titanium matrix composites (TMC's) would enable significant advances in commercial and military aviation product design, yet at the present there has been little implementation into promising engine applications. In general, economical processing technologies and reinforcing fibers are not yet available. This report focuses on evaluating the economic potential of one promising technology to produce TMC preforms. This process, known as tapecasting, has been developed at Textron Specialty Materials (Lowell, MA). The endproduct of this process is a long, thin tape of titanium metal and silicon carbide fibers which is further processed to produce bar stock TMC product.

This analysis identifies the conditions under which this process becomes economically feasible on a commercial scale, and evaluates specific options for potential cost reduction. The conclusions drawn from this indicate the dominance of fiber price on total cost, which is independent of the manufacturing process. Process variables such as wind speed, yield, scrap, and labor rate all have a marginal effect on total cost, leaving low potential for cost reduction in these areas. The analysis demonstrates that a commercially viable TMC tape preform can be realized as long as the fiber cost drops accordingly.

The economic analysis presented in this document was performed using Technical Cost Modeling (TCM), a technology costing approach developed by IBIS Associates. Further information about this approach is available through the Principle Investigator.

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About The Process

Textron Specialty Materials has developed a proprietary tapecasting technology for producing titanium matrix composites. The process is a two step process in which a titanium-laden powder in a powder-tape form is combined with SCS-6 silicon carbide fiber to produce a uniform composite tape. This tape is considered a "mill product" which would require subsequent processing to fabricate final components.

Powder and binder film fabrication occurs on a film coating machine which casts a powder slurry onto a paper substrate. The slurry consists of titanium powder, binder, and cyclohexane solvent. During film coating, the slurry is applied to the paper substrate via a doctor blade onto a heated roll. Afterwards, the solvent is removed as the tape passes through a vented heater before final take-up on a roll. This step occurs at a rate of 7 feet per minute.

The second step of the tapecasting process consists of combining the powder tape with silicon carbide SCS-6 fibers through hot roll bonding. Fibers are pulled from 600 creels and are aligned through a collimator. Just beyond the collimator, the powder tape is fed around heated nip rollers and is pressed by an opposing roller onto the incoming fibers. The resulting composite structure is then passed over a chill plate before the paper substrate is removed and the powder/fiber tape reaches the take-up roll.

Process Assumptions

The Technical Cost Modeling methodology employed in this analysis is not reviewed in this document, as it has been addressed in other reports related to this contract. Further information regarding this methodology will be supplied by IBIS Associates upon request.

This analysis is based on a scaled-up production environment and has assumed certain technical and processing goals would be achieved. Processing assumptions were obtained from Textron personnel and other technical sources, and are shown in Figure 1.

| <u>Process Assumptions</u> | |
|-----------------------------------|--------------|
| Volume Fraction Fiber | 35% |
| Fiber Cost | \$1200/lb |
| Tape Casting Rate | 1 ft/min |
| Direct Laborers - Film Coat | 1/station |
| Direct Laborers - Hot Roll | 2/station |
| Direct Wages | \$15/hour |
| Direct:Indirect Labor Ratio | 4 to 1 |
| Production Volume | 15,000 kg/yr |
| Tape Rejection Rate | 2% |
| Average Downtime | 10% |
| Cost of Powder Winder | \$30,000 |
| Cost of Bonding Unit | \$250,000 |

Figure 1

TMC Tape Cast Cost Analysis

Figure 2 presents a cost breakdown for short and long term production scenarios. The dominant cost element is fiber cost, accounting for 65.5% of the tape cost in the short run and 76.1% of the tape cost in the long run at constant fiber prices. Other material costs remain unaffected by increases in production volume, and as a result, fiber cost becomes an even greater cost driver as other elements of cost are reduced with increasing production volume. The other variable costs, direct labor and energy, are independent of production volumes as well. Effects of production volume on cost are visible with fixed costs only, such as equipment and building costs, as these expenses can be amortized over a higher volume of product. The other category consists of overhead labor, cost of capital, maintenance, tooling, and building expenses. For this analysis, the fiber cost was assumed to be \$1200 per pound. This fiber cost must become a reality in order to achieve a \$400 to \$500 per pound TMC tape manufacturing cost. For the long term scenario, TMC tape cost is shown to be \$450 per pound for the given processing assumptions.

The sensitivity of fiber cost to overall TMC tape product cost can be shown in Figure 3. The effect of fiber cost on total tape cost is once again demonstrated as each decrease in fiber cost by \$600 per pound lowers the overall tape cost by \$173 per pound. Economies of scale for the process are reached as early as 2000 kilograms of tape per year.

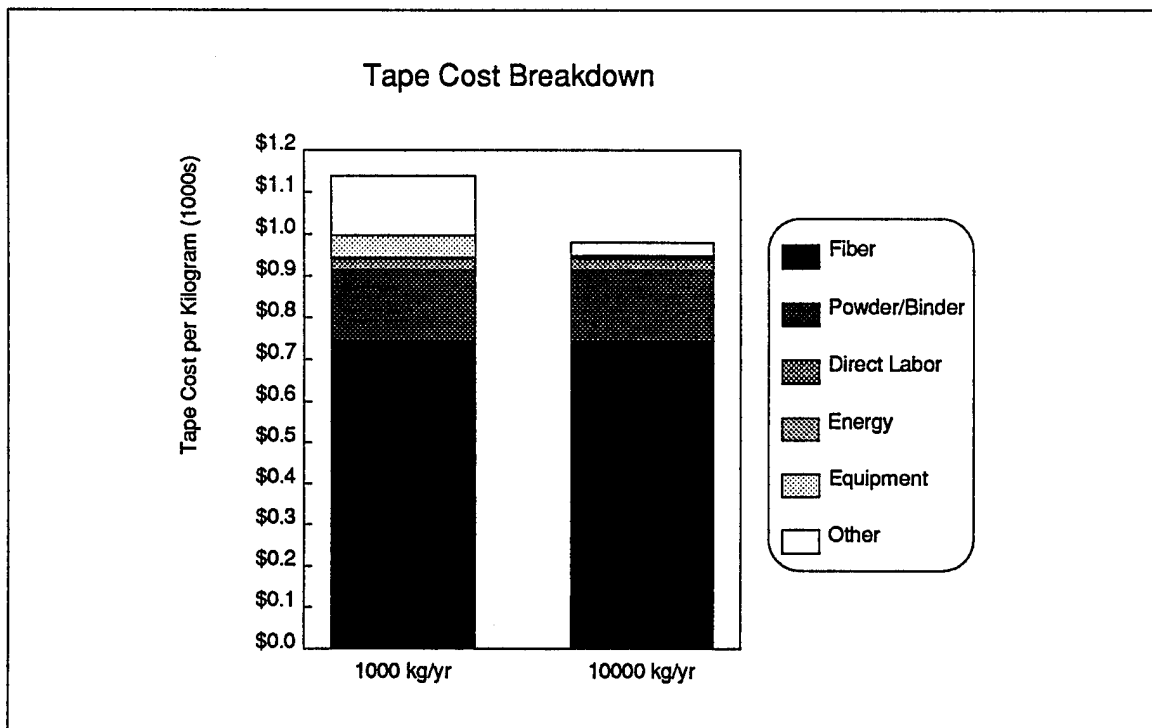


Figure 2

The effect of increasing the production rate with the production volume for three different processing rates is shown in Figures 4 and 5. In Figure 4, the large jumps in each curve reflect the necessity to add additional TMC tape processing lines to meet the increasing yearly demand. At higher volumes, a strong argument can be made to increase processing rates rather than increase capital expenditures. However, as shown in Figure 5, rate increases greater than 2 feet per minute will experience diminishing returns on cost improvement. Unlike the high potential for cost reduction with reducing fiber cost, improving process rates has a noticeably lesser effect.

The following graphs reveal the marginal effect of improving certain process variables commonly evaluated as potential cost reducers. Figure 6 reveals the effect of direct labor wages on total cost with increasing production volumes. This effect is small; a \$5.00 increase in direct wages will result in \$10.00 per kilogram increase in total cost. The effects of powder scrap rates and process yield are shown in Figures 7 and 8. In Figure 7, each 10% increment in powder scrap rates results in roughly \$25 per kilogram of increased tape cost. It should be noted that for this analysis, none of the powder scrap is being recycled. From this analysis it can be seen that a reduction in powder scrap rates has minor effects on cost and should not be assigned a high degree of priority. In Figure 8, increases in the process yield by 2% result in corresponding reductions of \$20 per kilogram in tape cost. Since the process yield is already known to be high, further efforts to increase yield will not have significant positive effects on total tape cost.

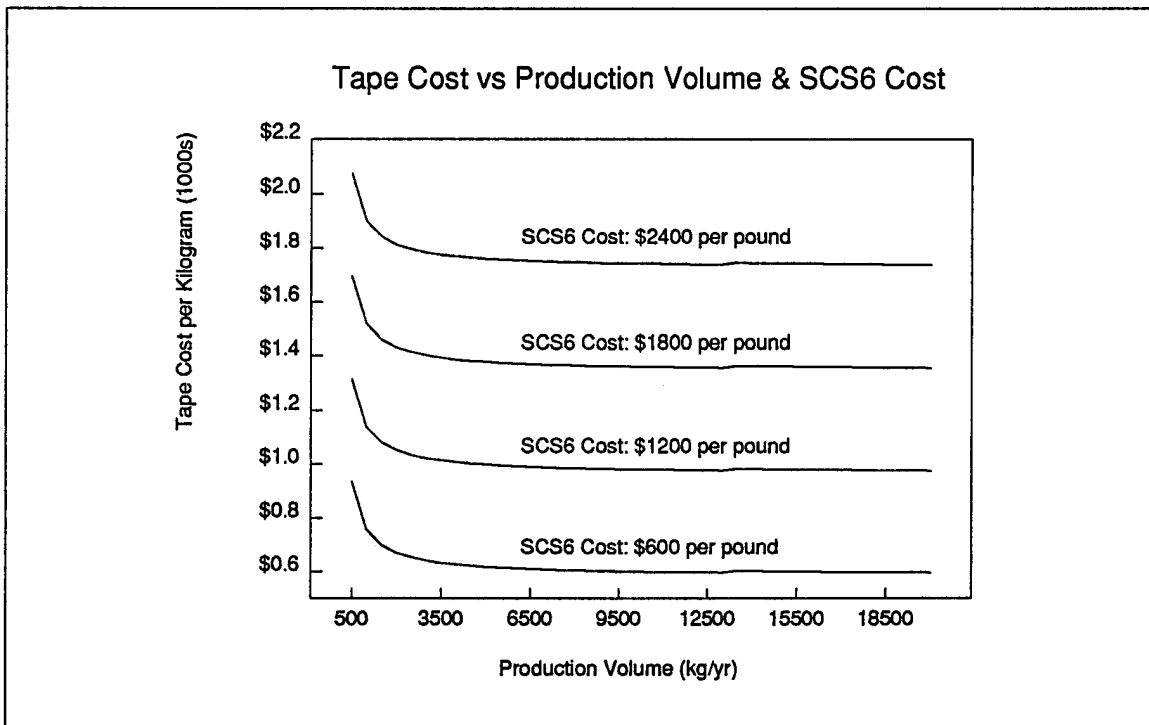


Figure 3

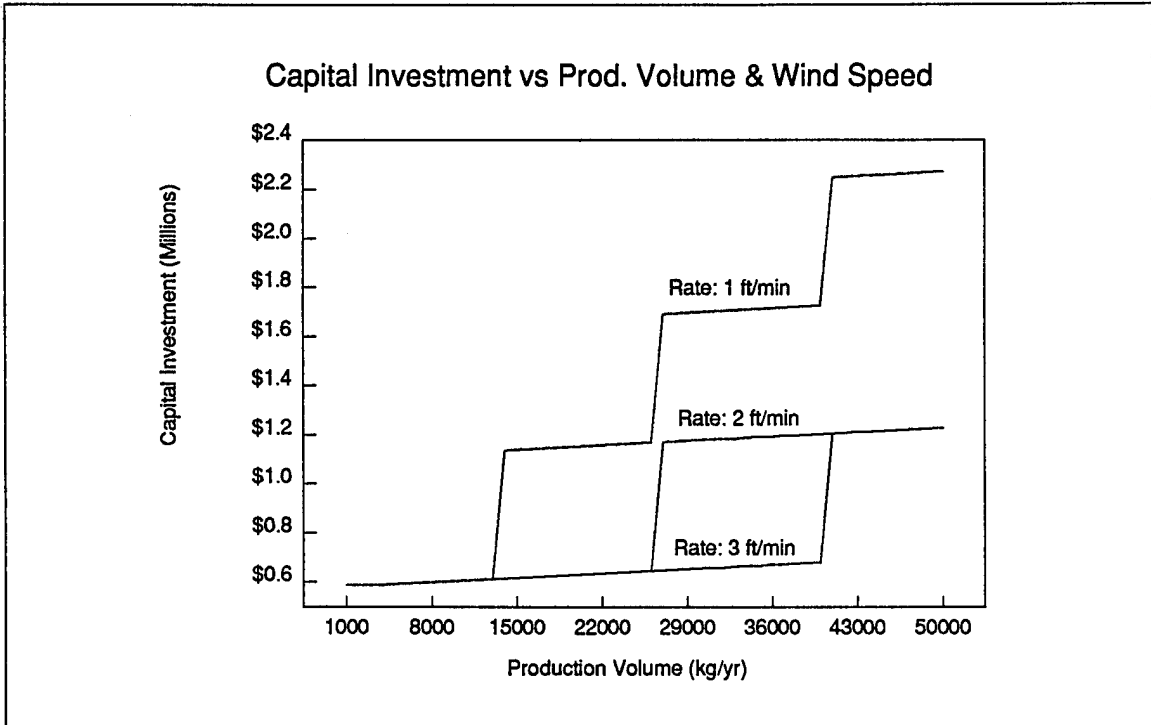


Figure 4

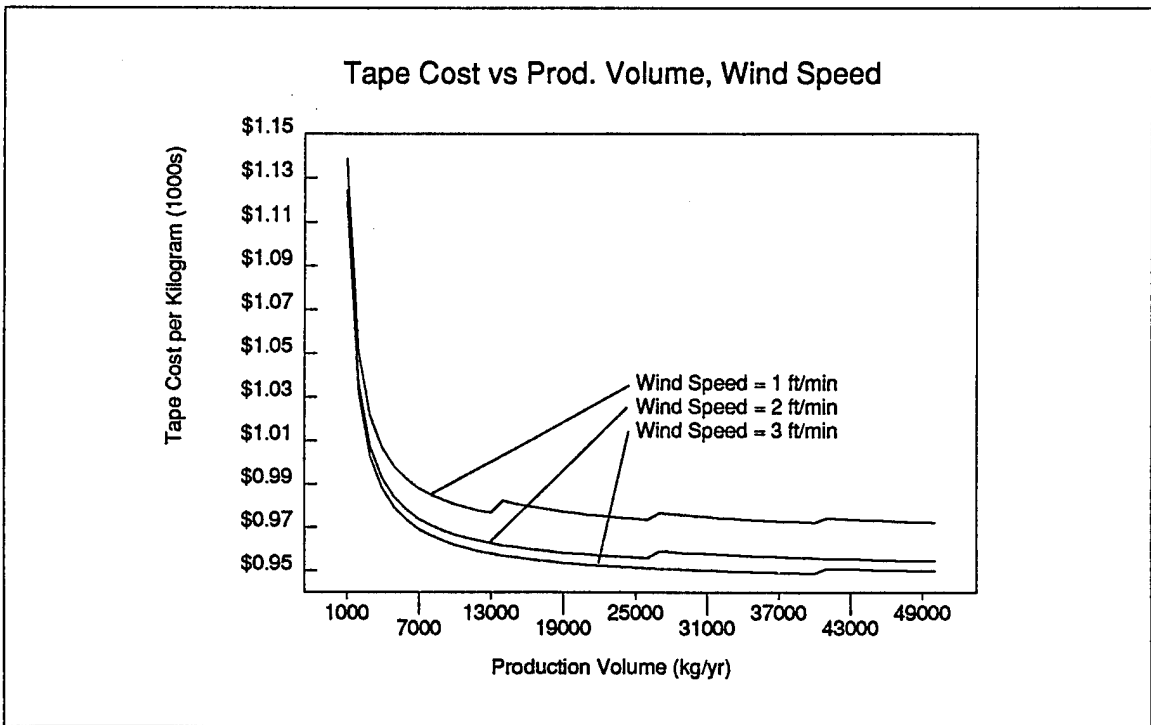


Figure 5

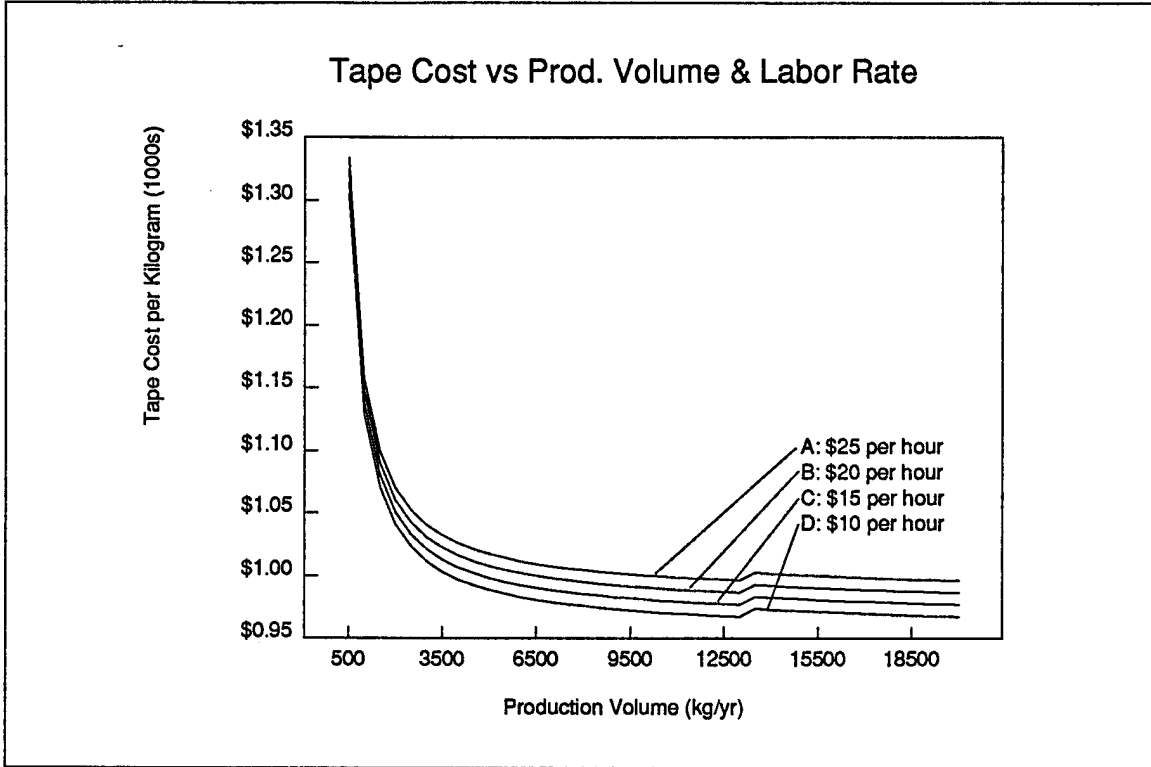


Figure 6

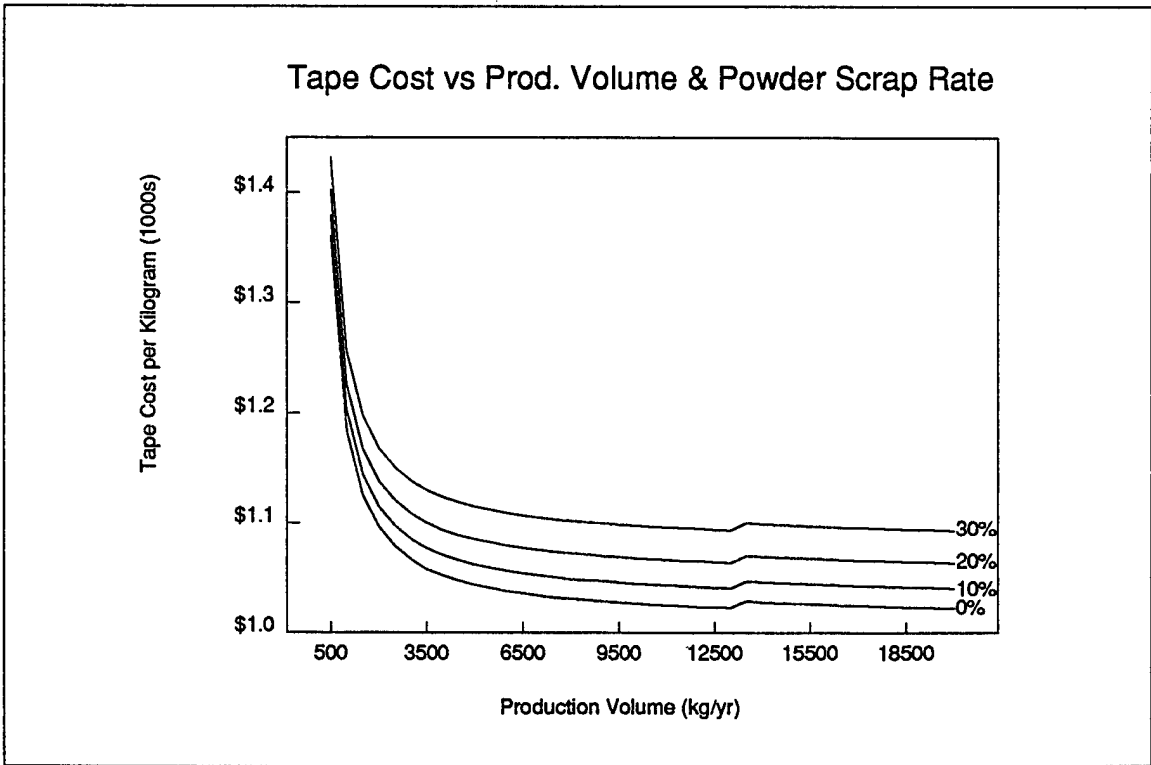


Figure 7

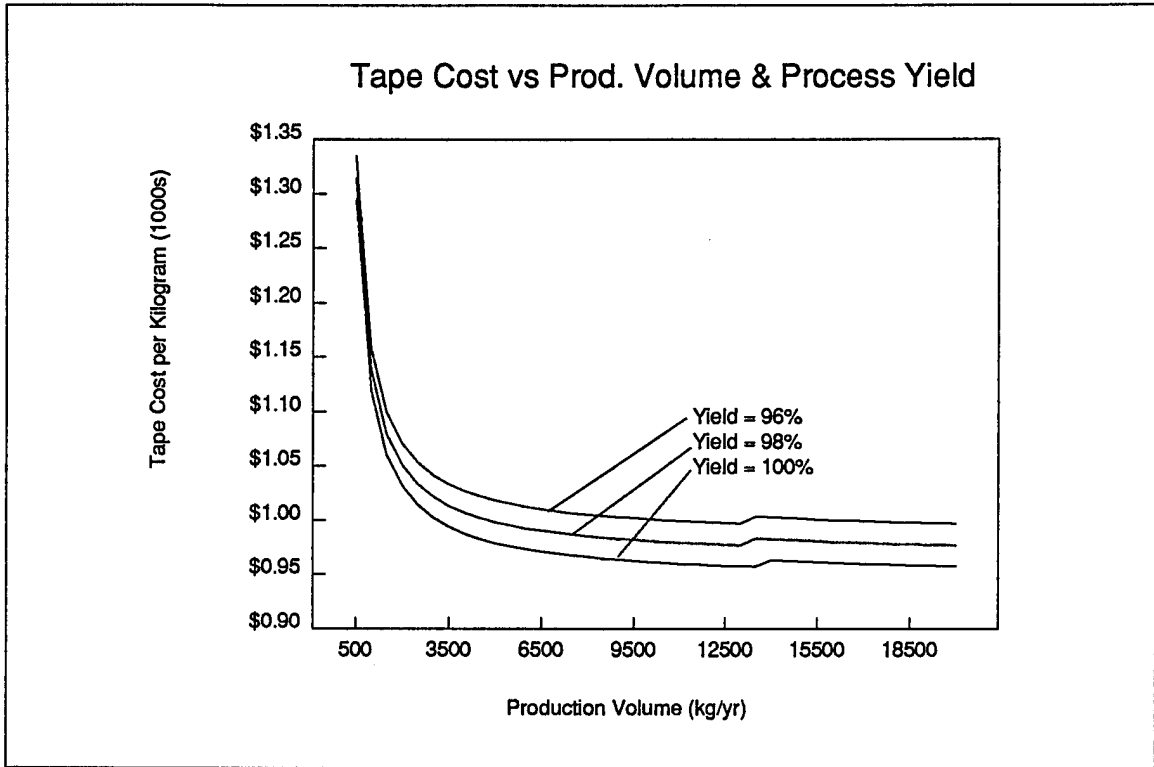


Figure 8



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