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Topic No: 6b **Subject Area:** Advanced Composites **Code:** 5544

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The primary objective of Phase I was to develop the approach and basic data upon which a full technology assessment of advanced composite materials could be built. The emphasis in this project has been on future use of composites for purposes other than transportation applications, such as construction and mining equipment and other structural items. However, the approach developed is applicable to the complete range of applications, and related issues. The approach combined two features related to methods and data: 1) taking appropriate portions of methodologies of analagous assessments already performed and adapting them to the advanced composite situation; and 2) performing the necessary analyses and projections starting from the available, extensive, and collected source data. How this will be applied in the case of advanced composites is explained in a step-by-step description of the basic data, relationships, projections, and identification of impacts that will comprise the substantive assessment of Phase II of this program. At the completion of Phase I, it appears that the probable future range and amount of composites application is much more extensive than generally recognized, and hence the potential impacts and issues involved are extensive. In particular, issues of national productivity, safety, and subsidies for product development are raised. It is concluded that the future role of advanced composites in applications of a structural nature warrants full-scale study.

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PROJECT SUMMARY

The primary objective of this project was to develop the approach and basic data upon which a full technology assessment of advanced composite materials could subsequently be built.

Because of substantial amount of effort in government and industry has been and is being focused on transportation applications for composites the emphasis in this project has been on future use of composites for other purposes, such as construction and mining equipment and other structural items. However, the approach developed is applicable to the complete range of applications, and related issues.

The approach developed for performing the desired technology assessment was a combination of two features related to methods and data:

1. Taking appropriate portions of methodologies of analagous assessments already performed and adapting them to the advanced composite situation, and
2. Performing the necessary analyses and projections starting from the available, extensive, and collected source data.

How this will be applied in the case of advanced composites is explained in a step-by-step description of the basic data, relationships, projections, and identification of impacts that will comprise the substantive assessment of Phase II of this program.

At the completion of this project (Phase I of a proposed two-phased program), it appears that the probable future range and amount of composites application is much more extensive than generally recognized, and hence the potential impacts and issues involved are extensive. In particular, issues of national productivity, safety, and subsidies for product development are raised. Therefore, it is concluded that the future role of advanced composites in applications of a structural nature warrants full-scale study.

SECTION 1
INTRODUCTION

1.1 PROJECT BACKGROUND

This report describes the research conducted, conclusions reached, and recommendations made in developing an approach and methods for conducting a comprehensive technology assessment of advanced composite materials. The project was sponsored and funded by the National Science Foundation as part of the Research Applied to National Needs (RANN) program.

The conclusions and recommendations extensively reflect data and ideas developed and published by many organizations involved in some aspect of advanced composites. The project, therefore, reflects a multidisciplinary information base. However, the emphasis, interpretation, and presentation context of the information in this report is entirely the product of Applied Engineering Resources, Inc. (AER).

1.2 PROJECT OVERALL OBJECTIVES

The project reported in this document is Phase I of a two-phase technology assessment effort:

> Phase I Objective: Develop a feasible and definitive study approach, including supporting data and illustrative procedures, that will form the basis for performing a comprehensive technology assessment of advanced composites under Phase II.
>
> Phase II Objective: Conduct a comprehensive and substantive technology assessment of advanced composites, including an information transfer and utilization plan.

In addition, the NSF objective of acquiring a venture - capital commitment for follow-on R&D effort, as an incentive test of the RANN program, is included in Phase I.

The role of venture capital in carrying on the results of a technology assessment of advanced composites is not, at this time, clear. There appears to be a contradiction in the objectives of each. Technology assessment is a means of providing information for decisionmaking regarding future use of technology. The results of its analyses and projections of impacts, both favorable and harmful, are intended for the use and guidance of decisionmakers and others concerned with broad public needs and issues. On the other hand venture capital is usually an investment in a new enterprise, made primarily in expectation of future profit.

Additionally, NSF RANN support is stated as being directed toward "industry and national problems", rather than "product, process, or market development". These technology assessment tasks are contrasted with venture-capital incentives, which generally are directed toward "company problems". It is recognized that capital might be committed by a company to develop the ability to utilize an industry- or nationally-oriented technology assessment. This likelihood seems greater, however, if the PhaseI/PhaseII technology assessment work develops and formats information, and has a plan to transfer information, in a form useful to individual companies as well as to government planners and policy makers.

Therefore, even though advanced composite technology has a multi-institution involvement, the assessment methods developed should take into consideration their likely use in product- and industry-oriented research. Figure 1-1 suggests the overlap that exists among product-oriented research, technology assessment tasks, and venture-capital incentives.

1.3 PROJECT OBJECTIVES RELATED TO ADVANCED COMPOSITES

Almost any arbitrary boundary around or taxonomic system of description of advanced composite technology will illustrate the central but less than dominant position of specific characteristics of any particular material in the total information that must be considered in a technology assessment. For example, Figure 1-2 is a simple schematic of some of the economic, physical, and institutional interfaces to be found in one possible description

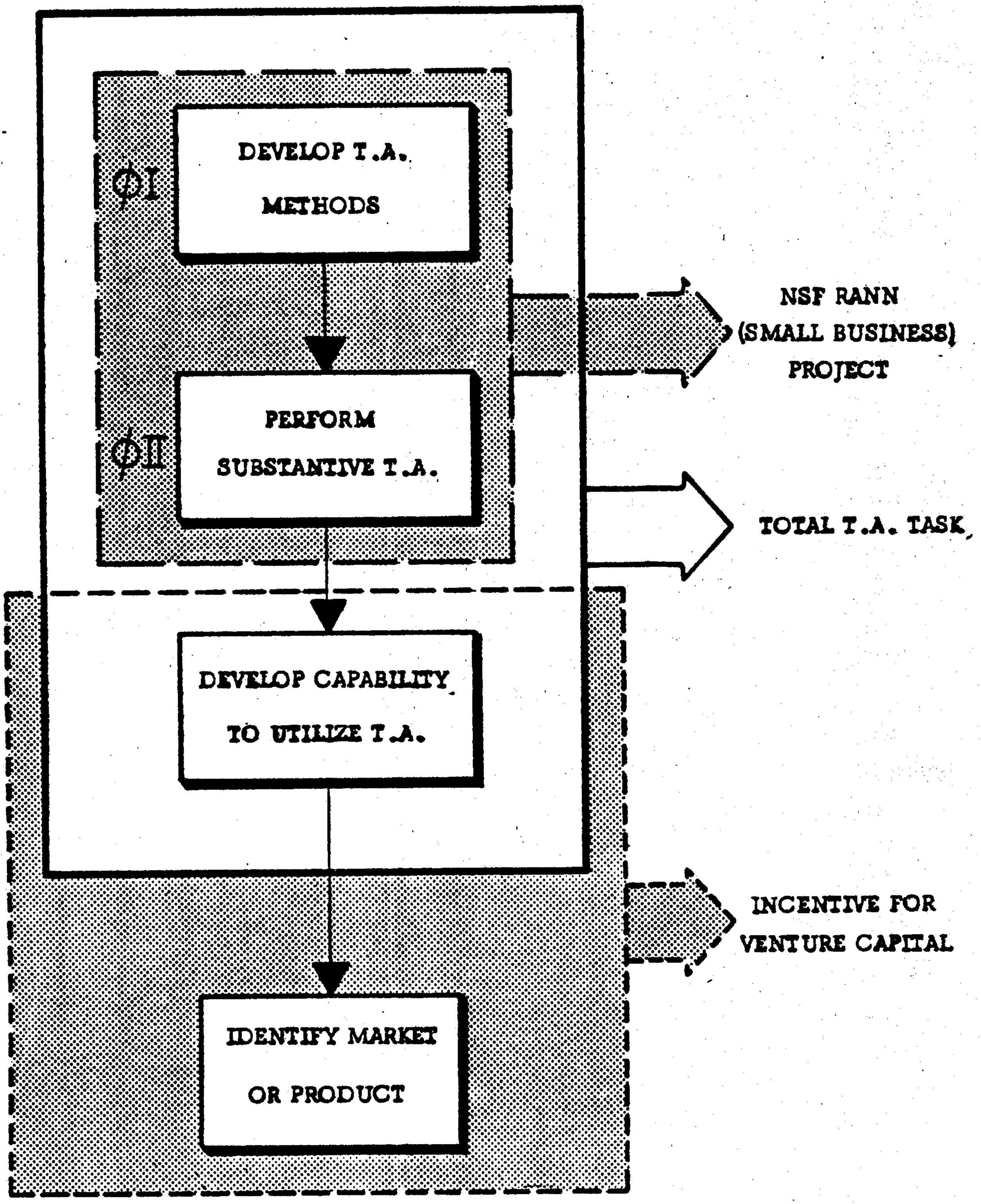


Figure 1-1. Project Objectives Related to Venture Capital Incentive

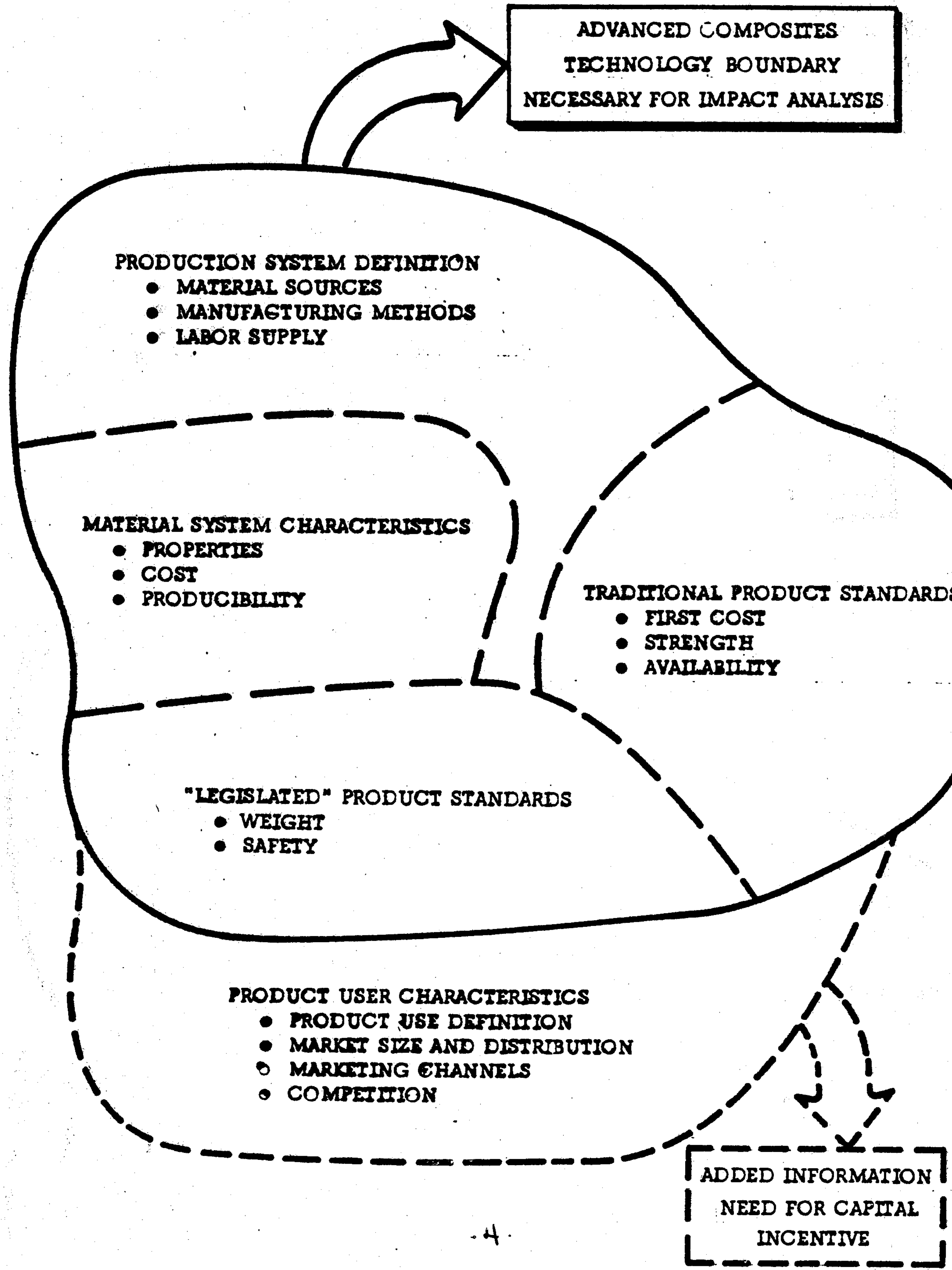


Figure 1-2. Technology Boundaries Related to Venture Capital Incentive

of advanced composites technology. From this it is evident that much more than the physical properties of the material are involved. Also to be noted from this diagram is the separation of product users from product producers and composites producers, effected by the barriers of two types of standards.

As a simplified example of this separation, consider the small painting contractor who decides to buy several new ladders or scaffolds. He is very little involved in the total process that configured his new lightweight composite ladders, since:

1. He does not recognize that a ladder made of advanced composite, though costing more initially, will be cheaper in the long run because its light weight will increase his painters' productivity.
2. He is not involved in establishing product safety standards that include restraints on material usage.
3. The design process by which the material used in his ladder was selected as a compromise choice because of some optimum set of properties, not just strength or stiffness, or weight, or cost, is of little interest to him.
4. And finally, the painter is not aware that the price of his ladder is dependent on a production system and raw material producer that has been developed to some degree with his own tax money.

On the other hand, the capitalist involved with composites is more interested in the painter than in the other elements involved in advanced composites technology.

Considering the above, Figure 1-2 also illustrates the somewhat diverse interests of national labor, and industrial policymakers, and the individual company. Again, the degree to which the technology-assessment task considers the product-orientation bias of the capitalist (at least in the case of composites), is also a measure of the incentive for risking capital investment in the technology assessment.

1.4 ORGANIZATION OF REPORT

The body of this report follows the general proposal format, including identification of the problem, descriptive approaches considered, detailed presentation of approach developed, conclusions, recommendations, and a plan for utilization of results in Phase II.

SECTION 2
PROBLEM DEFINITION

2.1 OVERALL PROBLEM DEFINITION

The total technology assessment task, or "major objectives" (Reference 2), includes:

1. Methodological development
2. Substantive assessment
3. Utilization enhancement and promotion.

Phase I objectives are essentially the equivalent of the methodological development subtask. (See Figure 1-1). Accordingly, an extensive body of literature related to technology assessment was reviewed, to assist in structuring the work on advanced composites. Types of data examined can generally be categorized as:

a. Methodological studies related to technology assessment (References 3 through 37).
b. Partial technology assessments, technology forecasts, and a limited number of technology - driven impact or cost benefit studies (References 38 through 119).

Item b above was considered as a possible source of future - oriented ideas that may actually represent a form of ad hoc technology assessment.

A common pattern was noted in comparing data from partial assessments, with that from methodological studies. The structure and approaches used in the partial assessments are very much state-of-technology-peculiar, and can only indirectly be related to the formalized or generalized approaches in the methodological studies. In fact, Reference 3 suggests that this situation will probably apply to most technology assessments.

Therefore, the overall problem considered in this project was to structure an assessment method that uses the available technology assessment general methods and approaches, and that also reflects the realities and boundaries of advanced composites technology. Figure 2-1 visualizes the problem being so addressed as a combination of (1) defining the advanced composites state-of-technology and (2) adapting technology assessment general methods, based on the state-of-technology.

2.2 STATE-OF-TECHNOLOGY IMPACT ON TECHNOLOGY ASSESSMENT

The particular approach that was developed considered three basic state-of-technology factors:

1. Overall definition of what technical and institutional factors are involved in advanced composites technology; i.e., defining a boundary around the technology to be assessed.
2. The technical state-of-the-art of advanced composites, and its rate of change.
3. The relative importance of the physical aspects of technology compared to institutional factors.

A slowly-advancing technology in a very structured and slow-changing institutional environment might well result in only minor, future consequences in the social, economic, and environmental areas. Even a rapid, dramatic change in some technology might still have few and minor impacts overall, if it comprised a very small part of a total technological institution.

For example, it would be hard to underestimate the actual and future societal impact of plumbing technology advancements in the last 30 years. Relative to many other technologies, during this time, advancements have been slow, and the few dramatic advancements (i.e., plastic parts and pipe) have had almost no societal impacts because of the inertia and resistance of material producers, manufacturers, contractors, unions, plumbers, and building codes.

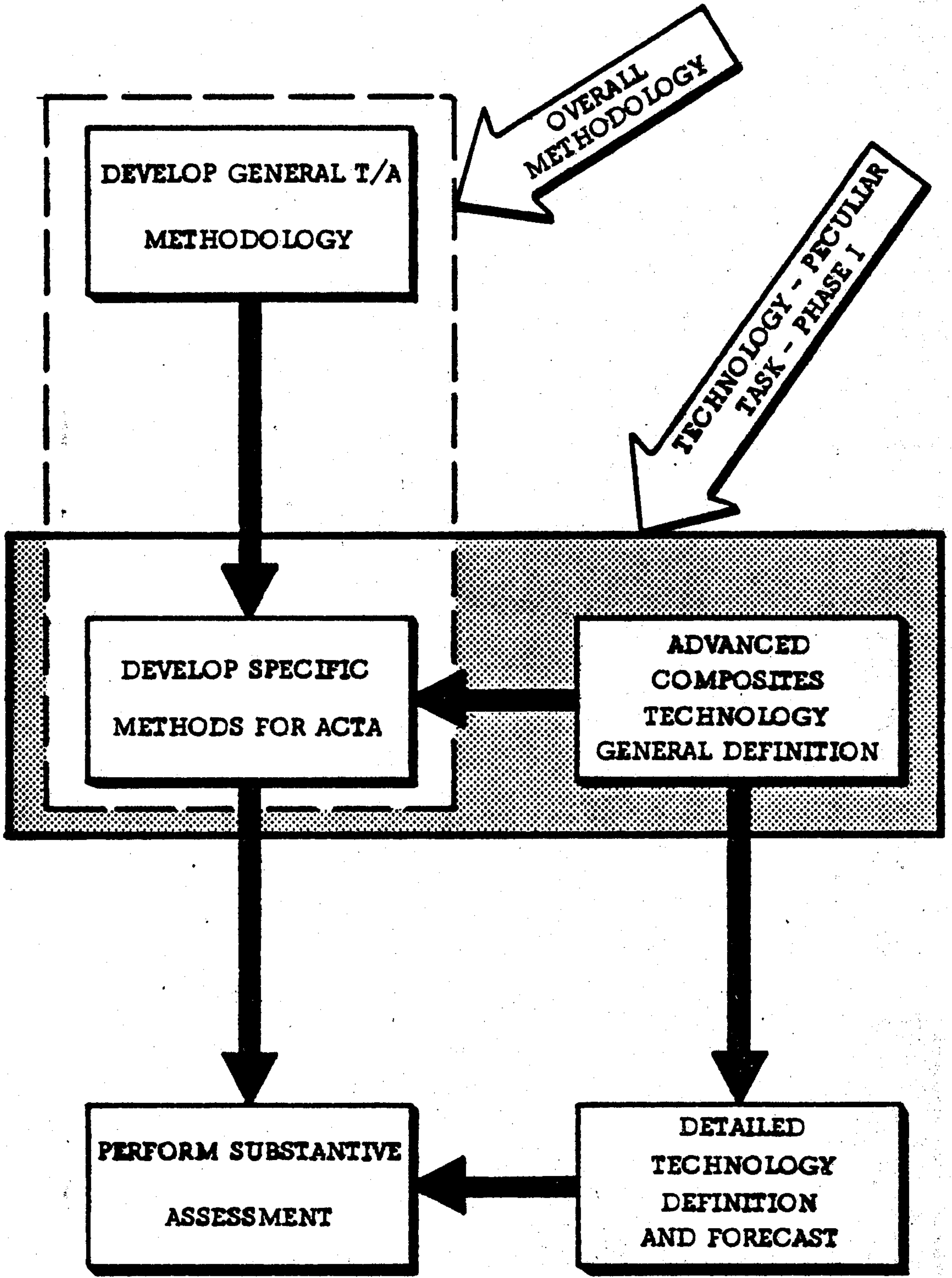


Figure 2-1. Overall Problem of Advanced Composites Technology Assessment

On the other hand, a boundary drawn incompletely around a technology or an assessment that neglected user involvements, may overlook some unusual, major impacts of what might seem minor technological advancements. For example, imagine the cost and other impacts to society, and the issues raised, of a rapid addition (say over 5 years) of 200,000 patients, 10,000 surgery cases, 1000 orthepedic surgeons, and the related lost time, resulting from the appearance of a new medical problem. Yet, this has been one result Reference 119) of somewhat-minor advances in the manufacturing technology of urethane and ultra-high-molecular-weight polyethylene. This advance, used in skateboard running gear, almost everywhere, has allowed skateboards to be ridden by almost everybody almost anywhere, with a resultant new surgical industry based on skateboard accidents. One recalls that when skateboards first appeared in the early 1950's their hard-mounted metal wheels required an expert to ride them, and they consequently never became generally popular.

Therefore, the technical and institutional boundaries of advanced composites and their state of advancement must be the basic driver in the formulation of a technology assessment project, equal in importance to selecting and following a more traditional approach to technology assesssment.

Approach and methods are discussed in Section 3. The following material presents initial definitions of the boundaries and rate of advancement of composites technology and of related institutions.

2.3 TECHNOLOGY BOUNDARIES

Both of the previous examples of the effects of change involved materials. They served to illustrate the ideas of "importance" of a technology and rate of change of technologies and institutions. They also show that an advanced materials impact, whether rapid or slow, major or minor, is most directly related to a product impact. Materials not being end-items of themselves, it is hard to make an obvious case that a material technology has been a driver in a first order societal change; instead, impacts have been the fallouts of de-facto problem - driven technology developments, having appeared as an optional solution to a perceived problem.

Instead, it is the second and higher order impacts that should be identified (as in the case of skateboard injuries). Further, as suggested by both the plumbing example and the skateboard example, the material, as defined by its properties, is only a small part of the complex set of input-output relationships that result in a societal impact from a material advancement.

Figure 1-2 suggested an overall technology boundary definition, consisting of the following elements:

1. Material System Characteristics
2. Production System Characteristics
3. Traditional Product Standards
4. Legislated Standards

2.3.1 Material System Characteristics

Characteristics include strength, stiffness, density, toughness, and the many other physical properties normally used by designers, plus costs and producibility (as defined by any of many "complexity factors" in common use). Many of References 38 through 118 present current and forecast characteristics. A further ordering of these characteristics is part of the technology assessment approach described in Section 4. Review of the noted references illustrates that a boundary definition for composites technology must also consider the proliferation of types of composite material systems that result from the growing number of useful system elements (reinforcement matrices and reinforcement form). Figure 2-2 illustrates this idea. The possibilities available for hybrid systems of materials are still growing. This growth not only confronts the designer with a set of design-cost tradeoffs of an order of magnitude greater than existed just 5 years ago, but also suggests the possibility that societal impacts might also be growing apace.

While Figure 2-2 is a simplified classification system, it does illustrate the complex technical choices available today. Not shown are secondary composite characteristics possible as subdivisions of the basic types, such as:

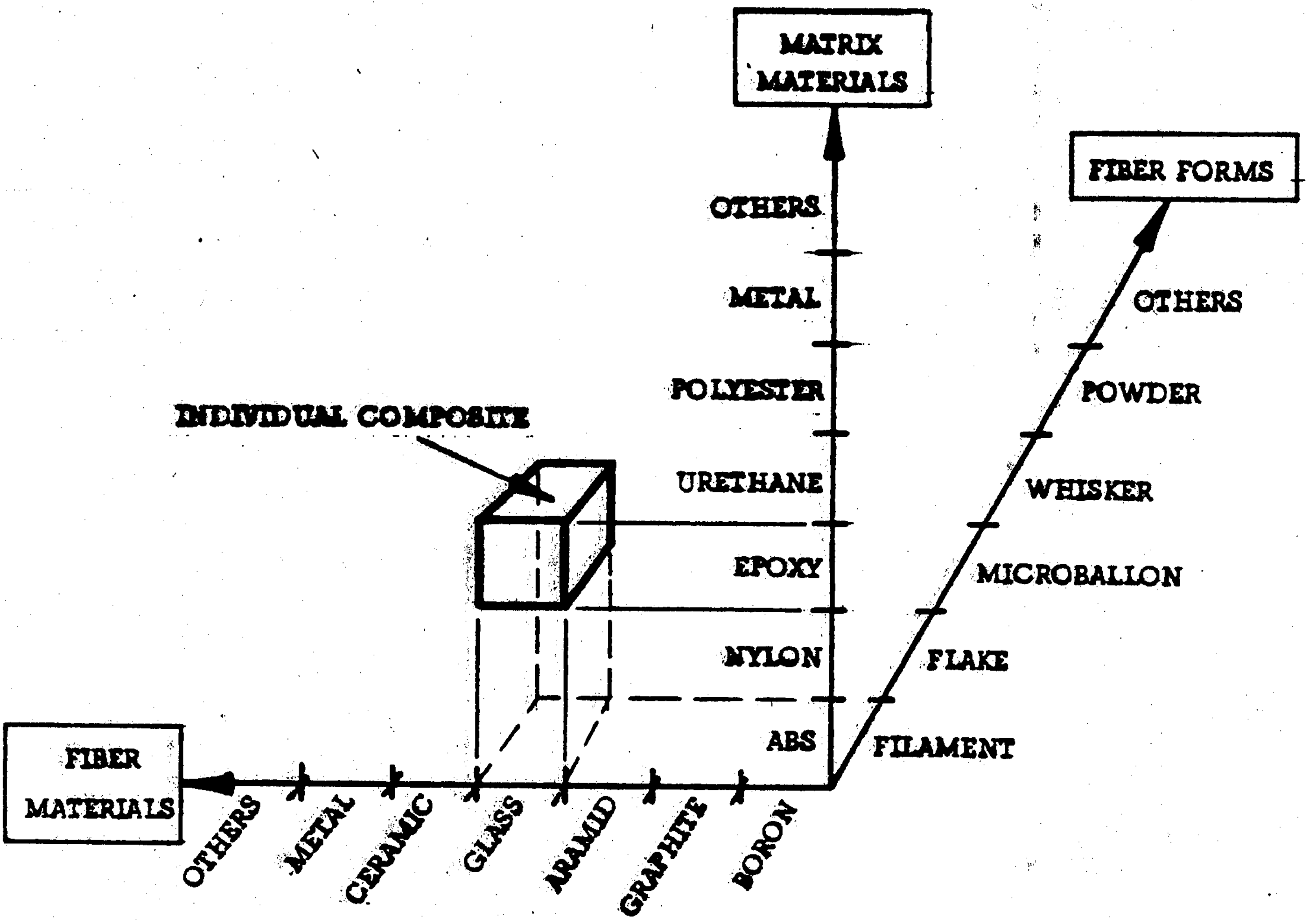


Figure 2-2. Components of Composite Types

1. Customized or standard ply design, and fiber/matrix volume fraction.
2. Additives:
    - a. Anti oxidants
    - b. Release agents
    - c. Activators, accelerators
    - d. Smoke, fire inhibitors
    - e. Plasticizers
    - f. Ultra-violet light absorbers
    - g. Foaming agents
3. Adhesives
4. Finishes
5. Hybrids, with two or more different fiber materials/forms

A product designer must then select from roughly 10 generic matrix types, 10 basic fiber types, 10 fiber forms, and 4 basic secondary characteristics, for a total of about 4000 primary candidates, before he even begins his structural optimization process. Even assuming that the typical designer is efficient in his approach, can he really optimize his design facing all these choices? Therefore, can societal benefits be optimized? Can policy makers be ready for all the possible impacts hidden in these choices?

2.3.2 Advanced Vs. Non-Advanced Composites

Another aspect of materials charaterization is suggested by the term "advanced composites". There has been an arbitrary and not fully justified distinction between "advanced" composites, and those "non-advanced" composites having similar performance characteristics in some aspect. Advances in application engineering, and appreciation of possible impacts from the use of composites as a generic type (including all the variants of Figure 2-2), have tended to caused the broad middle ground of fiber and particle-filled plastics to be ignored. Instead design has concentrated on the high-stiffness, lightweight, and expensive epoxy-matrix, boron, graphite, or aramid - reinforced composites. Therefore, a technology assessment problem that must be addressed is a definition of "advanced" that will include all composites in which technology advancements may cause a significant impact. Cost, strength and stiffness-to-weight ratio are not the only parameters to consider in measuring advances in materials, again as illustrated by the skateboard example.

A material advancement creates impacts and issues because of more extensive use in existing applications or by use in new ways. In terms of the technology assessment problem, the impacts and issues are possible from two directions:

1. Use of more material, independent of its application
2. The creation of new products, or different use of existing products because the product has some different or new characteristic related to the use of the advanced material.

In the first case, the impacts and issues are centered within the technology boundary of the industry, or material-production institutions (see Paragraph 2.3.3 for a discussion of material-production institution).

In the second instance, each product area involved has its own technology boundary and institutions that may be impacted by a material substitution or more extensive material application.

Figure 2-3 is a schematic showing the two directions that a technology assessment of a material advancement may take. A simple example is the current problem caused by the electrical conductivity of graphite fibers, which results in electrical short circuits during the material system manufacturing process, accidents with products (i.e., airplane crashes; automobile fires, etc.), and product disposal. The problem must certainly be considered by the material producers, as it involves safety and added costs within the companies involved, affects the labor force, and may be the subject of some form of regulation. Similarly, these same areas, and product design, are impacted in the aircraft production and user institution. However, it is not obvious that issues arise from this problem in the sporting-goods user institution, for example.

In total, the fiber form, fiber type, matrix type, and secondary characteristics discussed in Paragraph 2.3.1 represent the components of the material

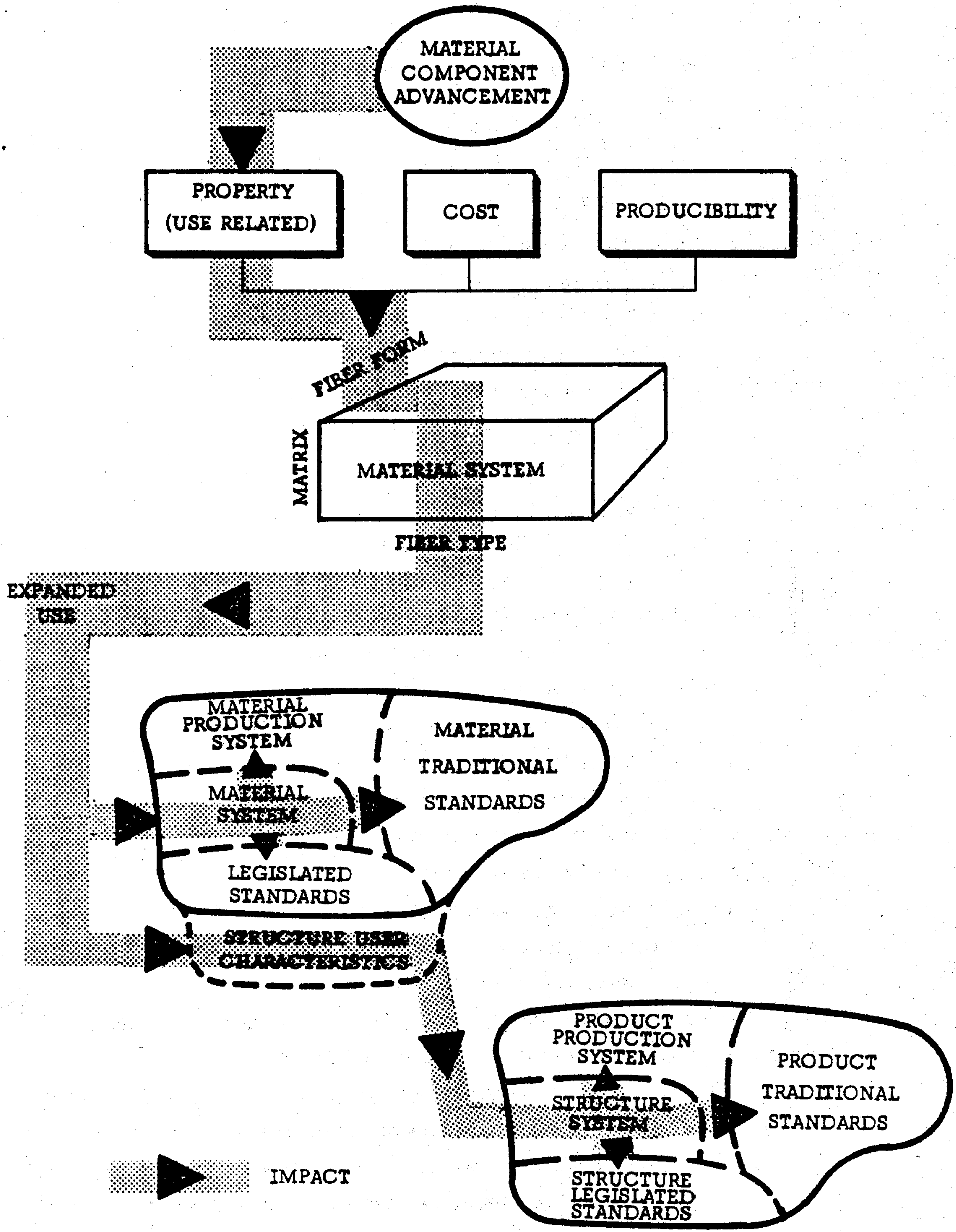


Figure 2-3. Technology Assessment Directions Based on Material Advancements

system element of the technology definition.

2.3.3 Production System Characteristics

The overall system that describes how products are made from advanced composites is shown in Figure 2-4. The major phases of this system are broken down to show component elements, each of which is a candidate area for technological advancement. This figure also represents an outline of a so-called "relevance tree" (Reference 4), permitting a morphological analysis. Each component of the major phases is then in turn further broken down, as shown in Figure 2-5 for manufacturing methods of the structure production system. A similar analysis of material sources for fibers and matrixes is illustrated in Figure 2-6. Figure 2-7 presents analysis of labor sources and Figure 2-8 the break-out for technology developers.

Figures 2-4 through 2-8 indicate how to develop a relevance tree of the items and factors making up an overall production system based on advanced composite technology. The presentation suggests that there exists a high degree of dispersion in this production system. This disaggregation can be observed today in the composites field, especially if one includes the entire reinforced plastics industry. There is found little vertical integration, either organizationally or from an information - flow standpoint. Fiber producers, matrix producers, fiber/matrix producers, and structure producers are generally numerous and separate, intermediaries in the raw-material to structure chain. This contrasts sharply with the aluminum and steel production systems, where single companies extract ore, convert the raw material, and fabricate a large array of standard shapes, such as I-beams, and other finished products, such as forgings, cable, and large structures.

From an information-flow standpoint,this disaggregation also exists. The composites production system information flow can be typified as follows:

1. The material developer and producer concentrates on property improvements in a laboratory environment. In the universities and plastic and fiber company laboratories which generally are not part of the structure-producer institution, there is very

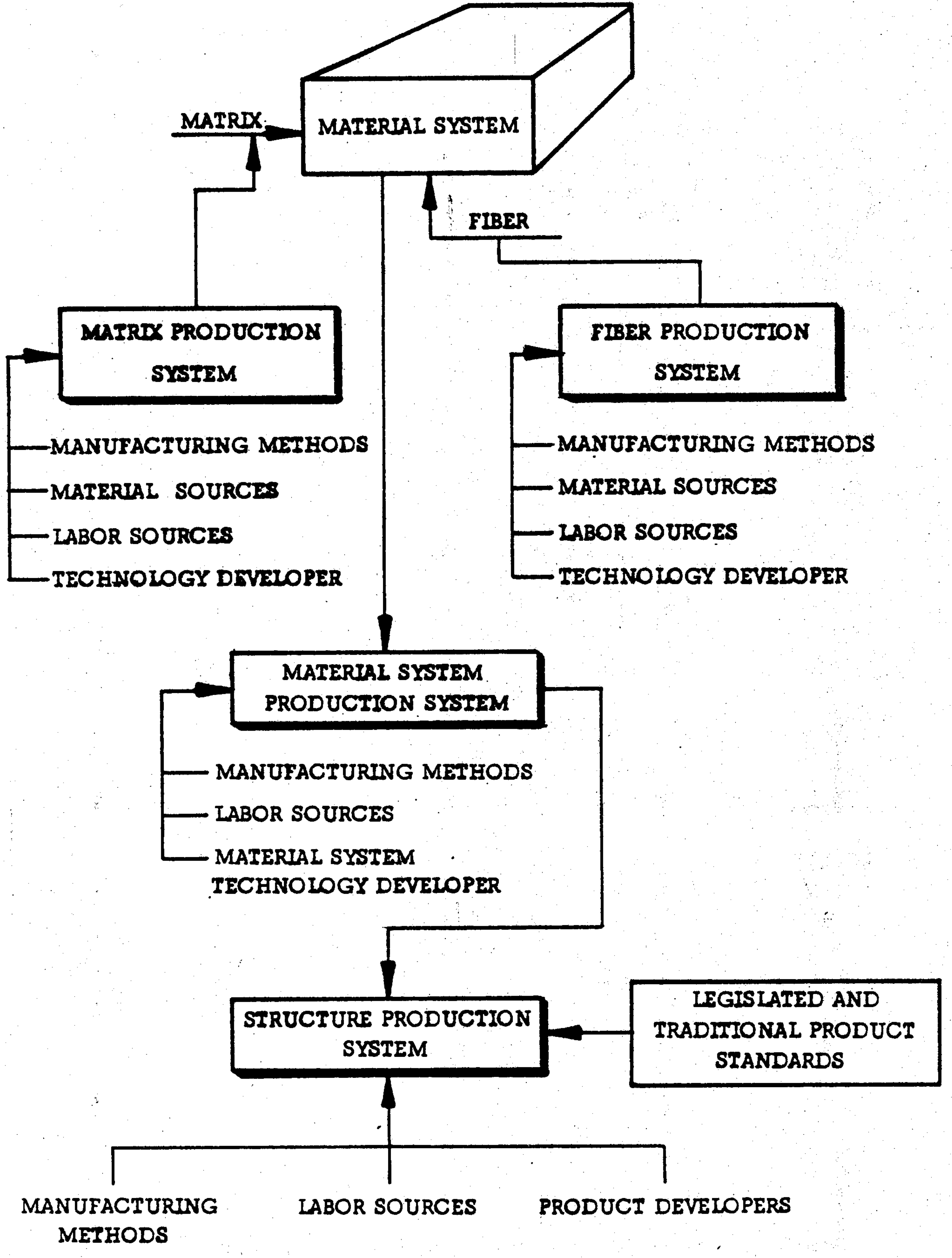


Figure 2-4. Components of Advanced Composites Production System

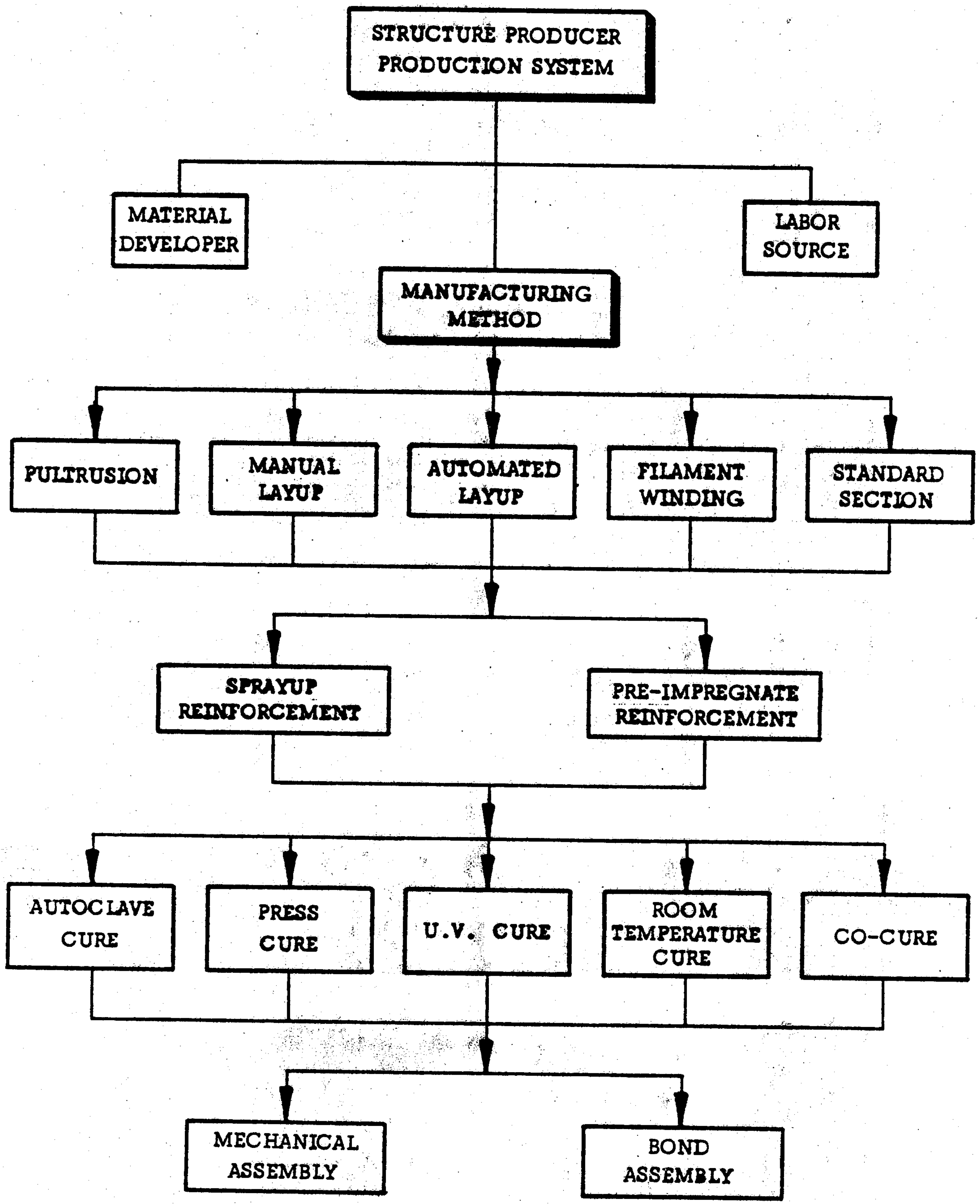


Figure 2-5. Manufacturing Method Component of Advanced Composites Production System

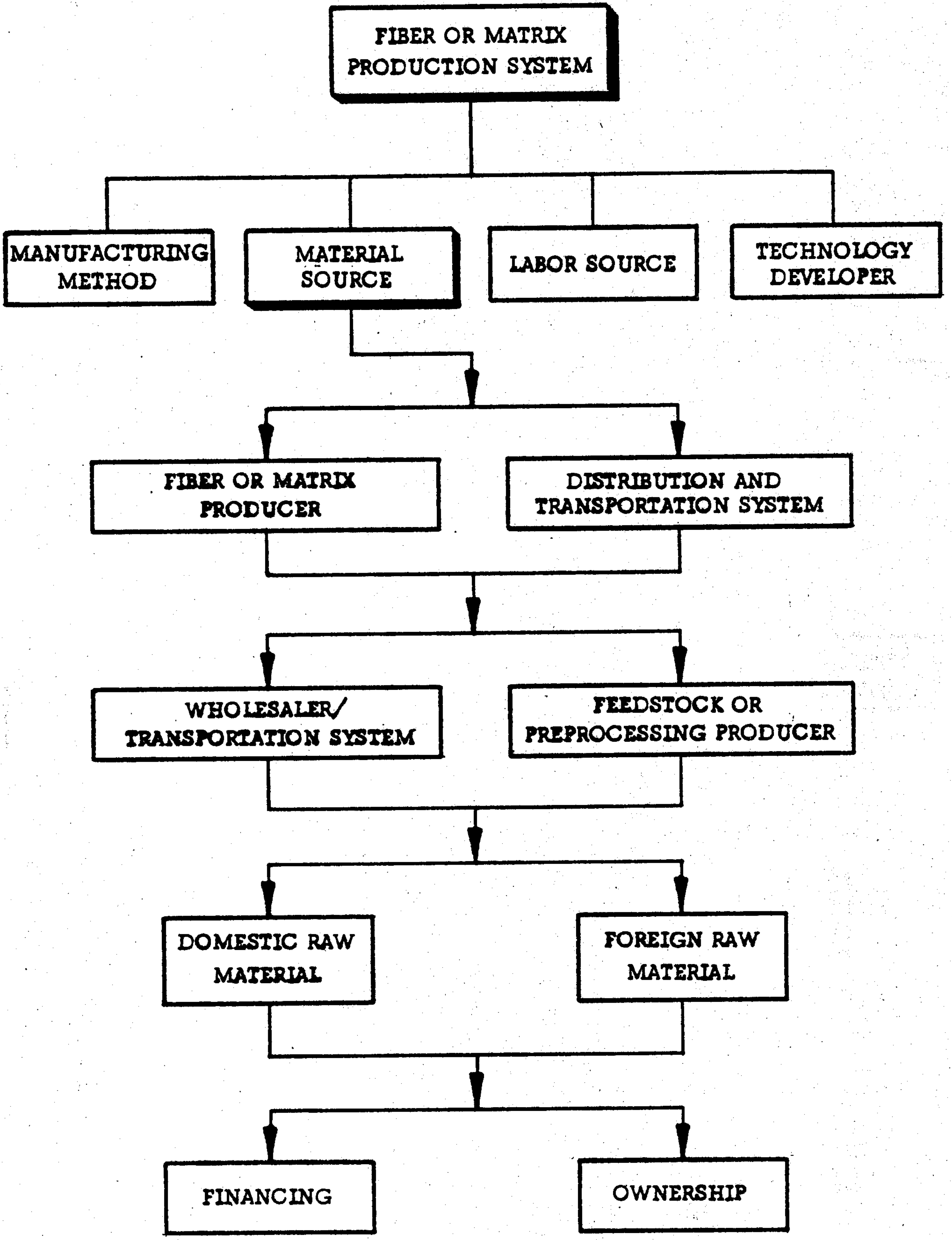


Figure 2-6. Material Sources Component of Advanced Composites Production System

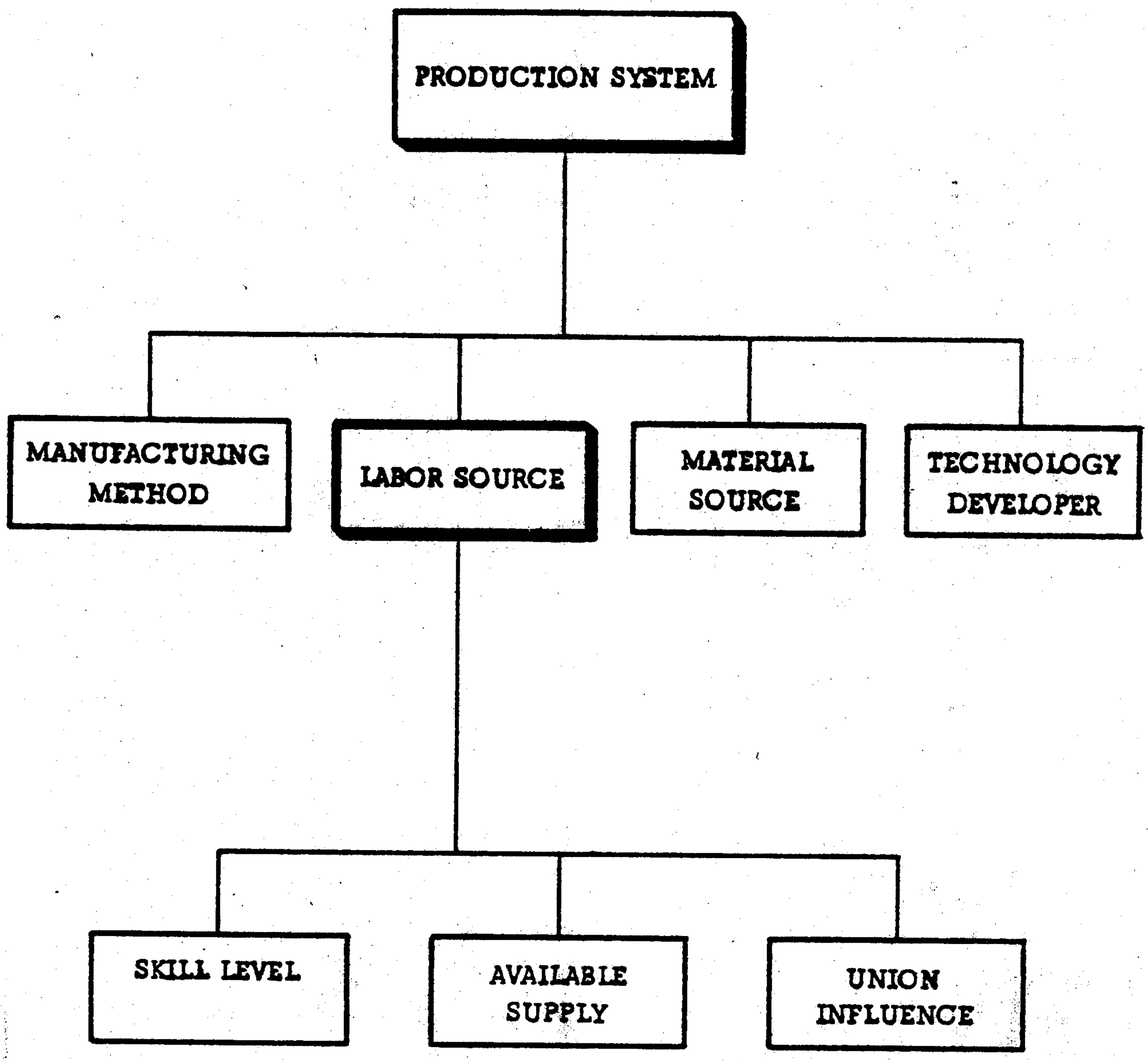


Figure 2-7. Labor Supply Component of Advanced Composites Production System

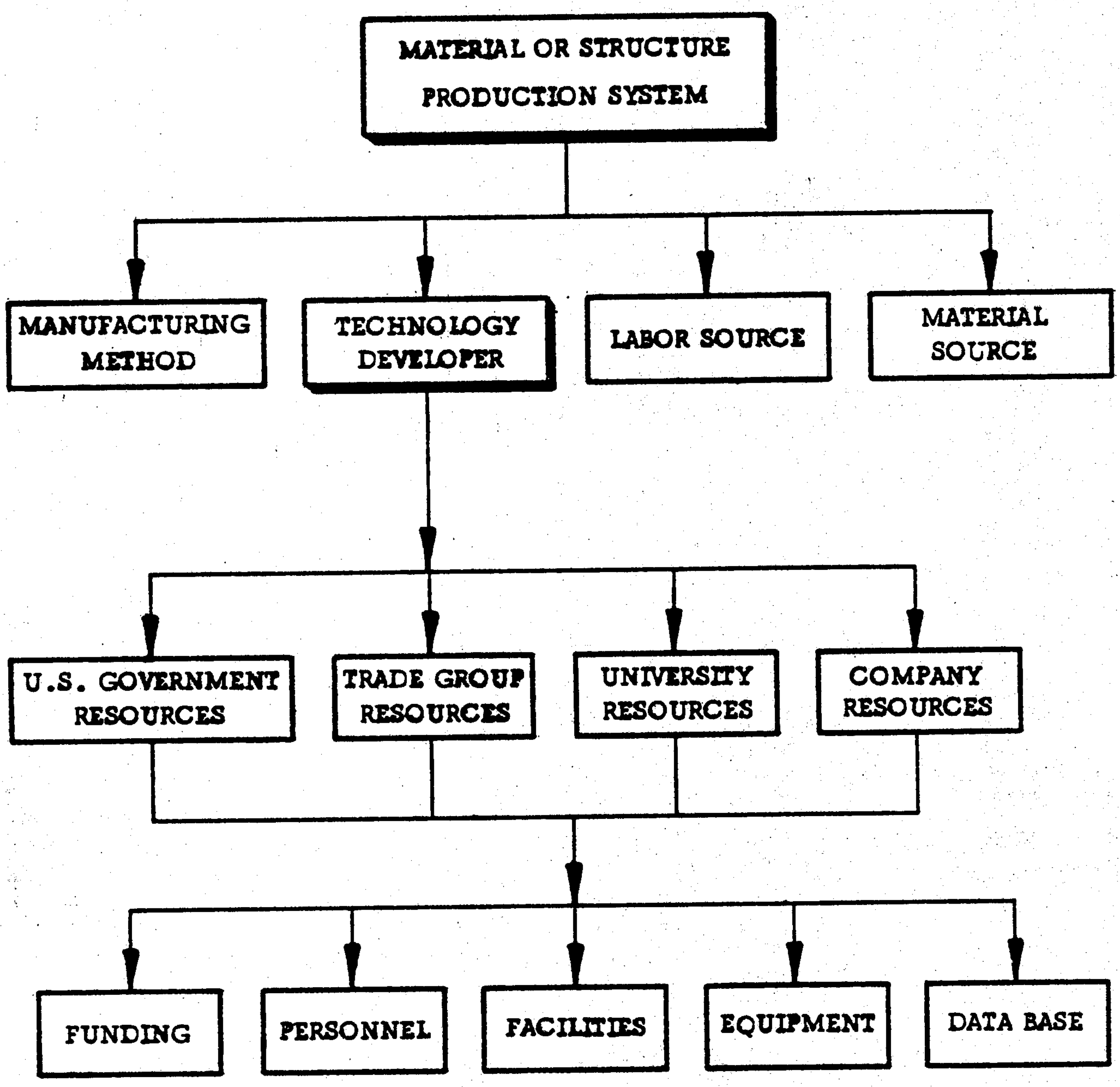


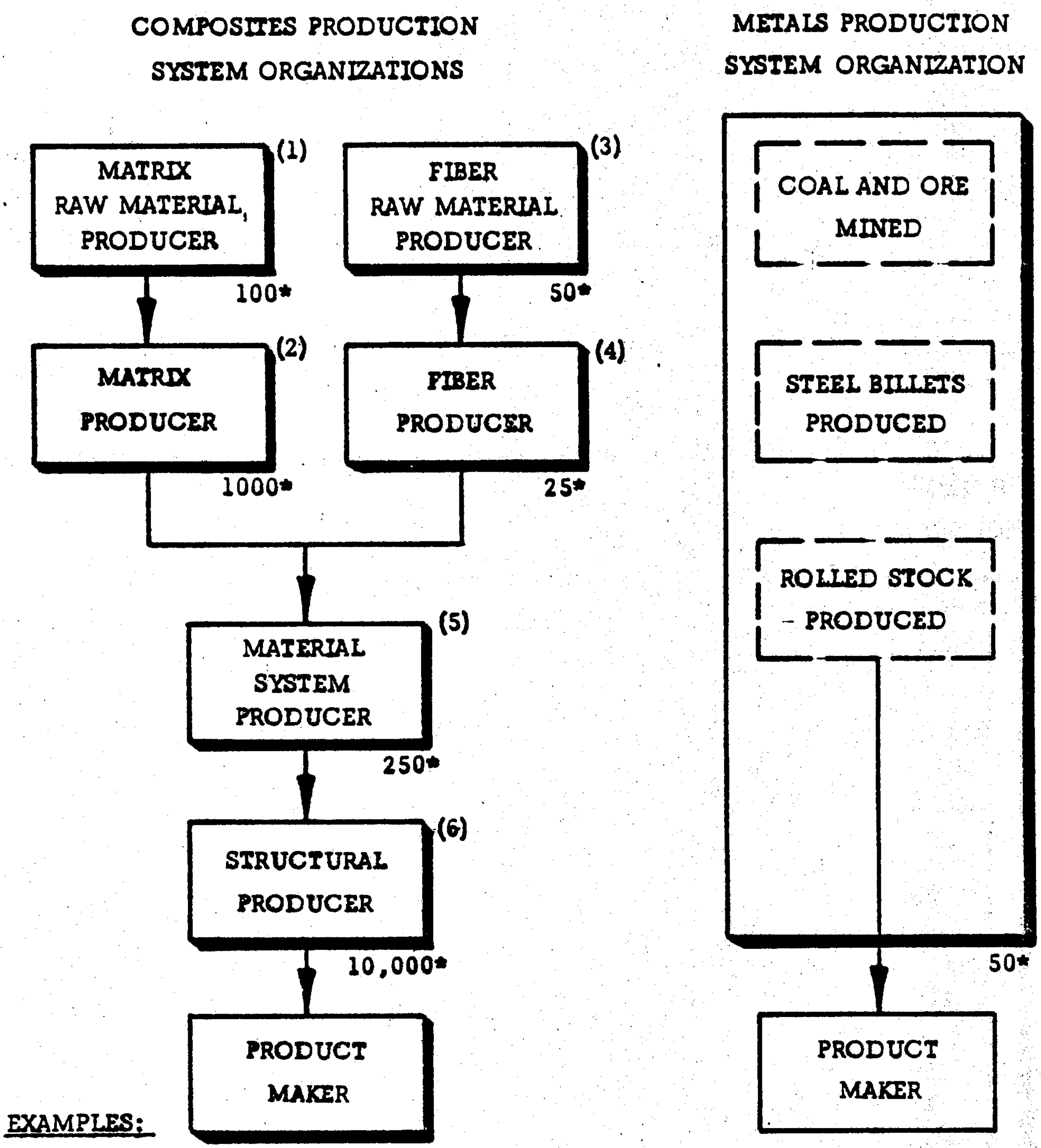
Figure 2-8. Technology Developer Component of Advanced Composites Production System

limited involvement in full scale development and demonstrations of structures and products, especially regarding design, productivity, and product economics. Data developed is property-oriented, not application oriented.

2. The material system producer (the so-called "pre-pregger" in industry jargon) combines materials into an array of standard forms, such as tape, pre-impregnated fiber,mat, etc. While material system producers are somewhat equivalent to an ALCOA or U.S. Steel, they do not however, have a corresponding set of product standards that apply to the industry. In fact, the material system producer generally does not characterize his product at all, except in some very basic variables such as fiber/matrix volume ratio. This is left to the structure producer. The material institution is still basically a customized operation, farther removed from the structure user than in the metallics production system.
3. Likewise the structure producer, in introducing himself into a composites production system, is more remote from the material-producer data base than in the metallics field. The structure producer is in a high-risk situation in that he must search and/or conceive opportunities for product improvements possible from materials (i.e., composites) of a completely divergent nature and source than perhaps traditional in his product area. An analogy to the metallics structure production system is the perception of structure producers as product producers; i.e., there are can-makers, pipe makers, etc.; not"metal-product makers".

Figure 2-9 is a schematic of the disaggregation in the composites production as compared to the metallics production system, with number of organizations indicated.

The above characterization of the production system element suggests several things about the technology assessment problem:



EXAMPLES:

(1) OIL COMPANY PRODUCES FEEDSTOCK
(2) CHEMICAL COMPANY PRODUCES MATRIX
(3) MINING COMPANY PRODUCES REFINED MINERALS
(4) PROCESSOR PRODUCES BORON FIBER
(5) PREPREGGER PRODUCES IMPREGNATED MAT
(6) PULTRUDER PRODUCES BAR STOCK

* APPROXIMATE NUMBER OF ORGANIZATIONS IN U.S. (REFS 39,43,46,120)

Figure 2-9. Disaggregation of Institutions in the Composites Production System

1. Using the terminology on Page 30 of Reference 3, the preference stated for "comprehensiveness" in technology assessment, to be achieved by considering only a restricted set of technologies, would tend to exclude many related materials and production technologies. An approach to this would be to deliberately exclude some types of composites. For example, fiber reinforced metallics could be excluded. Another approach(that of the NSF solicitation, Reference 1) would be to "differentiate" (Reference 3, Page 30) by considering only technologies that were involved in producing high strength and stiffness-to-weight structures, and ignoring the producibility aspects of composites.
2. It is possible that no single technology change in the wide array of technology components will have a significant impact on the national or industry policy level, nor will any combination. For example, in the labor area, supply and demand, and similar basic skill requirement between metals and nonmetallic production, will facilitate the shift of jobs and people from area to area or from company to company on a national level. Machinists will become layup technicians, the shops will acquire process and bonding equipment and expand into the non-metallics area, and management will also make the transition.

Therefore, the technology assessment problem related to the production system element of advanced composites technology is the justification of the comprehensiveness of the effort and the explicit differentiation of impacts considered and not considered.

2.3.4 Traditional and Legislated Material and Product Standards

In order to define what characterizes a material technology, Paragraphs 2.3.1, 2.3.2 and 2.3.3 have presented a hierarchy of objects, characteristics, and institutions that basically describe what a material is, and how it is produced. Figure 1-2 presented two other elements that are useful in a technology assessment to help visualize impacts from a material or production system change, namely:

1. Traditional product or material standards of acceptance.
2. Legislated product or material standards of acceptance.

A simple, materials-oriented example of traditional material standards would be the selection of a material based on its static strength. If experience or research showed that product failures were consistently resulting from metal fatigue, the user, or producer, or trade association, or engineering society, or educational system, or the government, might then require that the product be designed using a fatigue life criterion.

The application of traditional and legislated standards in a materials technology definition and assessment is that, basically:

1. Traditional standards applied to a changing technology may inhibit the technology development or application, thereby representing a boundary around the technology (i.e., identifying or creating problems and issues related to variance from such standards).
2. Legislated standards may likewise create problems and issues related to variance from standards, and also may drive the technology creating other problems and issues, such as:
    a. Who pays?
    b. When will technology be available?
    c. Can traditional standards be ignored?

In both cases, standards cover not only material properties, but other measures of worth or methods of measurement such as costs, procedures, and anything that encourages, specifies, or disallows the use of a material system.

In examining the concept of "standards" as a part of a materials technology definition, it should be noted that an applicable standard does not have to directly concern a material. For example, current and forecast legal standards for automobile gasoline mileage have encouraged weight reduction efforts in automobile design, and in response to this perceived weight problem, have enhanced the use of advanced composites. This example of a legislated standard is typical of a class of new standards that will soon be generated from "outside" the materials technology boundary. Other such standards that will create issues and problems with the expanded use of advanced composites in end-products are:

1. Product safety
2. Product reliability and durability
3. Product life-cycle cost
4. Product producibility.

Note that these are product-oriented a whole set of added or new material standards can fall out of added or new product standards. Figure 2-10 is a sample of hierarchy of standards, many interrelated, that originate from outside the materials industry. Many involve weight; i.e., if a tool is lighter, it is, safer, more productive, and presumably cheaper.

One traditional material and product standard shown in Figure 2-10 that will create major issues in a future scenario that includes productivity and cost-to-society standards set by the government, is the measurement of product cost. For example, it is recognized that dams are planned and built based on an analysis that considers cost versus societal benefits. Nevertheless, in the case of composites, a mine owner who must buy, say, an expensive composite roof support beam because the cost to society for accidents will be less, has a problem. While mine productivity will not be higher, because unions require him to keep his crew size the same (even though one miner can now install a support), the owner will still be as unhappy as the farmer who has his fields flooded to make row boaters happy.

2.4 SIGNIFICANCE OF TECHNOLOGY ASSESSMENT PROBLEM

The possibility of both opportunities and problems attendant on the more widespread use of composites is suggested by Figure 2-11, which repeats Figure 2-10, but with those standards circled which could favor the use of composites, due to their physical and producibility characteristics. Note that composites are equal or have particular advantages over metallic structure

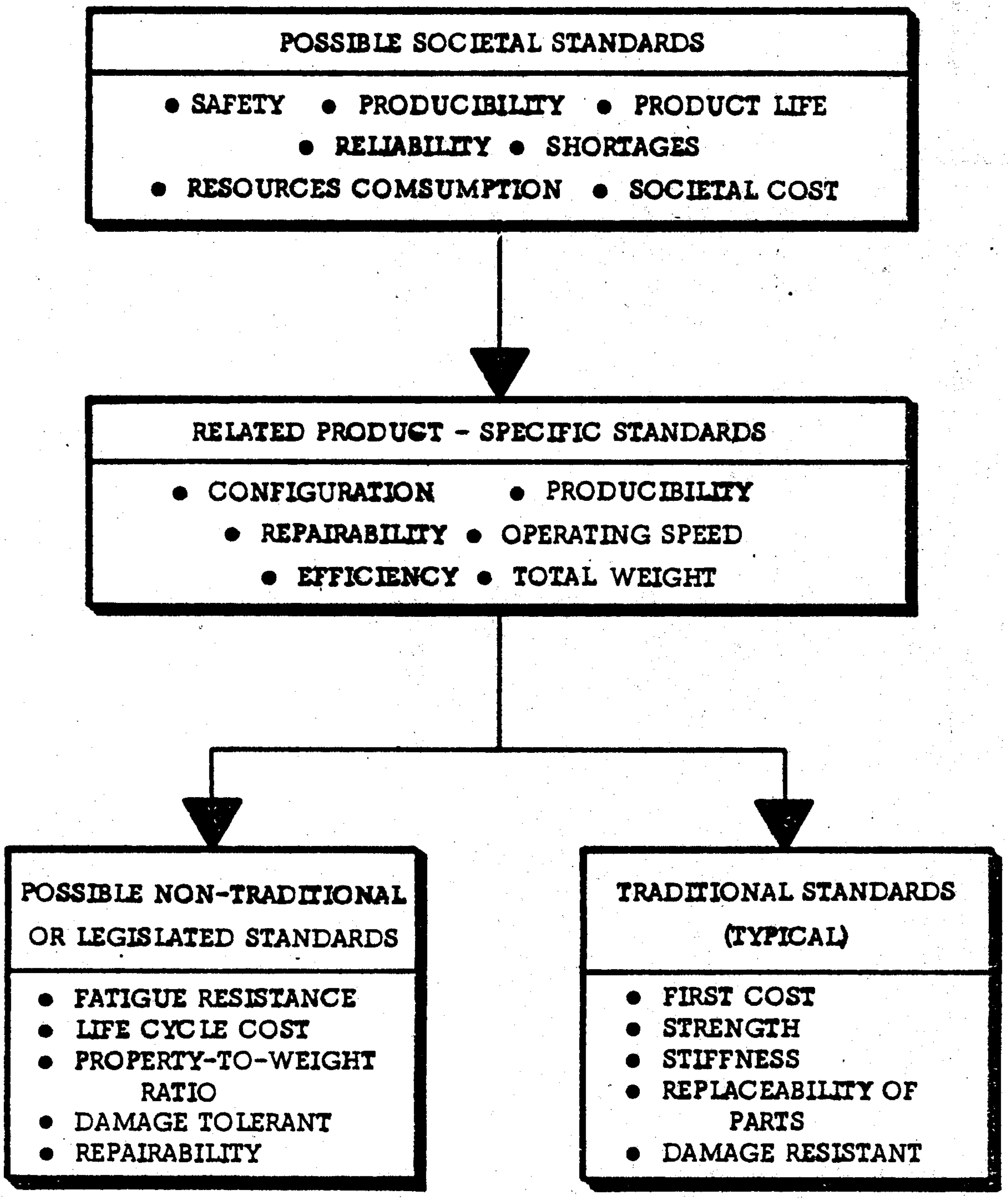


Figure 2-10. Legislated and Traditional Product and Material Standards

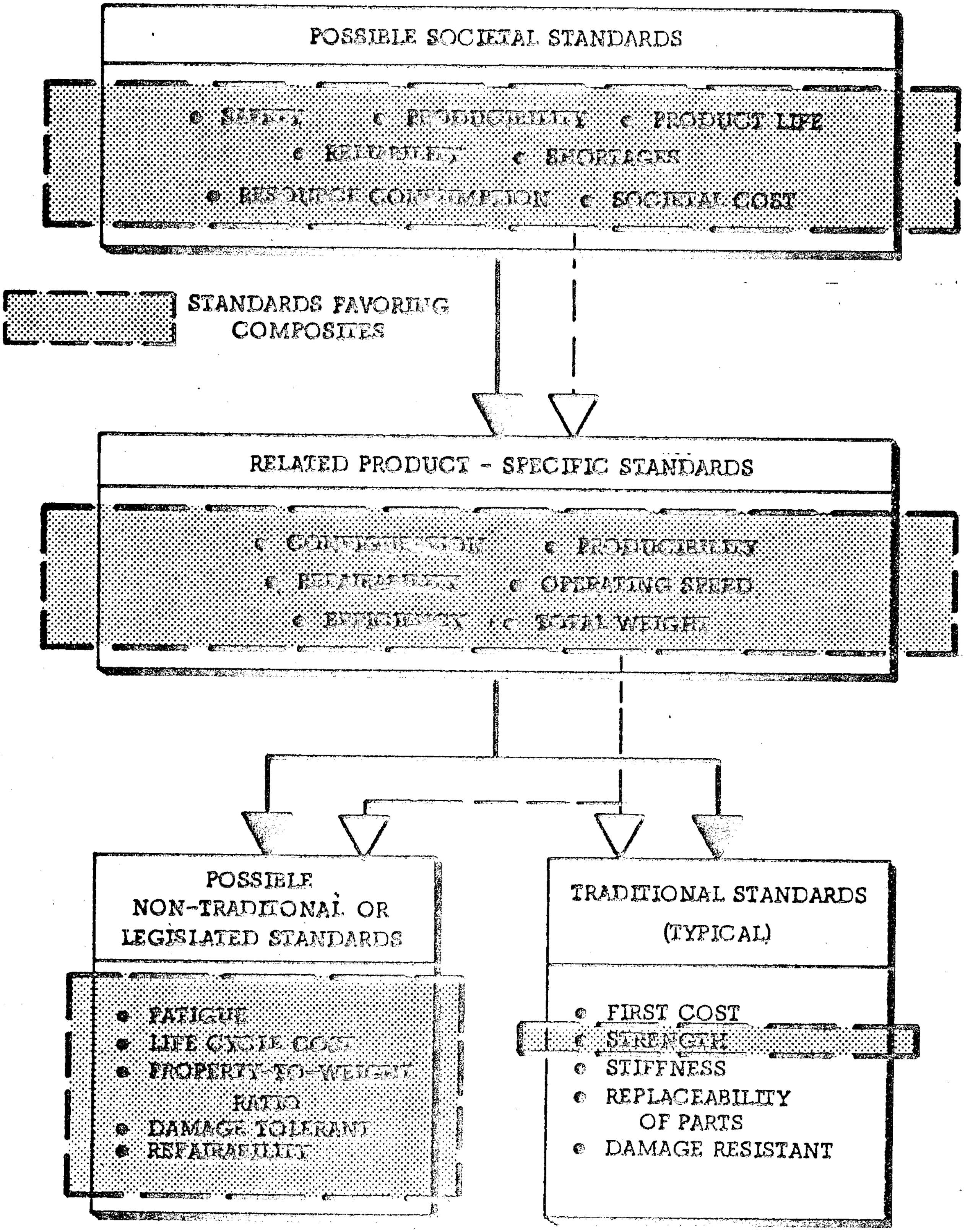


Figure 2-11. Legislated and Traditional Product and Material Standards Favoring Composites

in many traditional standards, and with a scenario of legislated standards, become more attractive in spite of higher cost. It is emphasized again that the term "legislated" is intended to encompass those standards that become conventional wisdom by virtue of an educational process, not just standards by law.

Currently, the growing uses of composites have been in products such as cargo containers, aircraft structure, automobiles, anywhere that weight reduction in moving vehicles has a primary payoff. Only minor utilization has occurred in static structural applications that currently are the province of metallics and low-performance composites. Nevertheless, weight reduction, fatigue resistance, damage tolerance, etc. might have more attraction if a scenario of legislated standards were postulated.

In addition, most composites application has taken the form of "direct material substitution", in which the advanced material directly replaces the original material without any change in structural configuration to take full advantage of the potential of advanced composites, not only in the high strength and stiffness to weight ratio, but also its other property-to-weight ratios, and its producibility.

Therefore the total potential usage is much broader than in just transportation - related products, and with such extended usage, more impacts are probable. The significance of this situation, in terms of technology assessment is seen to be as follows:

1. Information Transfer: Broad applicability and disaggregated industry represents a problem in the sense that cross-country and user-producer information transfer regarding "advanced" composites is somewhat lacking. This is in spite of some notable successes in government and aerospace-sponsored product development programs.

2. Lack of Innovation: There is not only a reluctance to undertake development programs for application of advanced composites in non-transportation/aerospace, but even a hesitance in considering substituting superior materials. In other words, not only is there a lack of commitment to product improvement, but lack of innovation. Specifically, except in aerospace/

transportation, the introduction of reinforced, tailored material systems has been limited to a slow evolutionary introduction of fiberglass-reinforced plastics into industries producing equipment for coal mining, oil production, construction, and food production. This pace has fallen behind even that of improved fiberglass material systems, and even further behind the pace of introduction of superior and cost-competitive "advanced" composite systems. This situation has prevailed in parallel with a decade of rising prices and decreasing availability for basic, conventional structure materials.

3. Lower Productivity: In a national sense, the problem significance is multi-faceted:

- a. Increased productivity and safety in mining, construction, and food production that might result from use of composites in equipment for those industries, has not been examined sufficiently.
- b. Productivity in structure manufacture has not benefited to the degree that would be possible by more-widespread introduction of advanced composites, which are basically more producible.
- c. In general, market potential for advanced composites has not been defined in the breadth probably possible. This, in turn, limits visibility of overall impacts possible on labor environment, safety, health, and alternate material sources.

4. National Policies: Finally while basic development of advanced composites has been extensively underwritten by the U.S. government, primarily for aerospace, the ultimate national payback must come from other industries. Therefore, multi-industry guidance, regulations, and illustration/demonstration of opportunites seems necessary, to overcome the instituional factors noted in Paragraph 2.3.

Regarding Item 3c typical major impacts of widespread use of composites could result from such factors as: (a) a significant substitution of composites for aluminum resulting in a significant reduction in the large electricity consumption for primary aluminum production, with consequent changes in environmental effects; (b) the considerable difference in equipment and skill requirements between producing basic aluminum (and other metals), and producing resins, fibers, composite tapes, cloth, etc. would therefore impact labor markets; (c) extended in-service experience with composites (aging, durability, and longer-term safety and health-related structural performance of composites) has not been demonstrated to the same extent as for metals. (d) similarly, the potential hazards (toxicity, combustion products, handling problems, etc.) of composites during production and use, while recognized, are not generally "managed" uniformly from a regulatory standpoint.

SECTION 3
SELECTION OF APPROACH

3.1 BASIC APPROACH

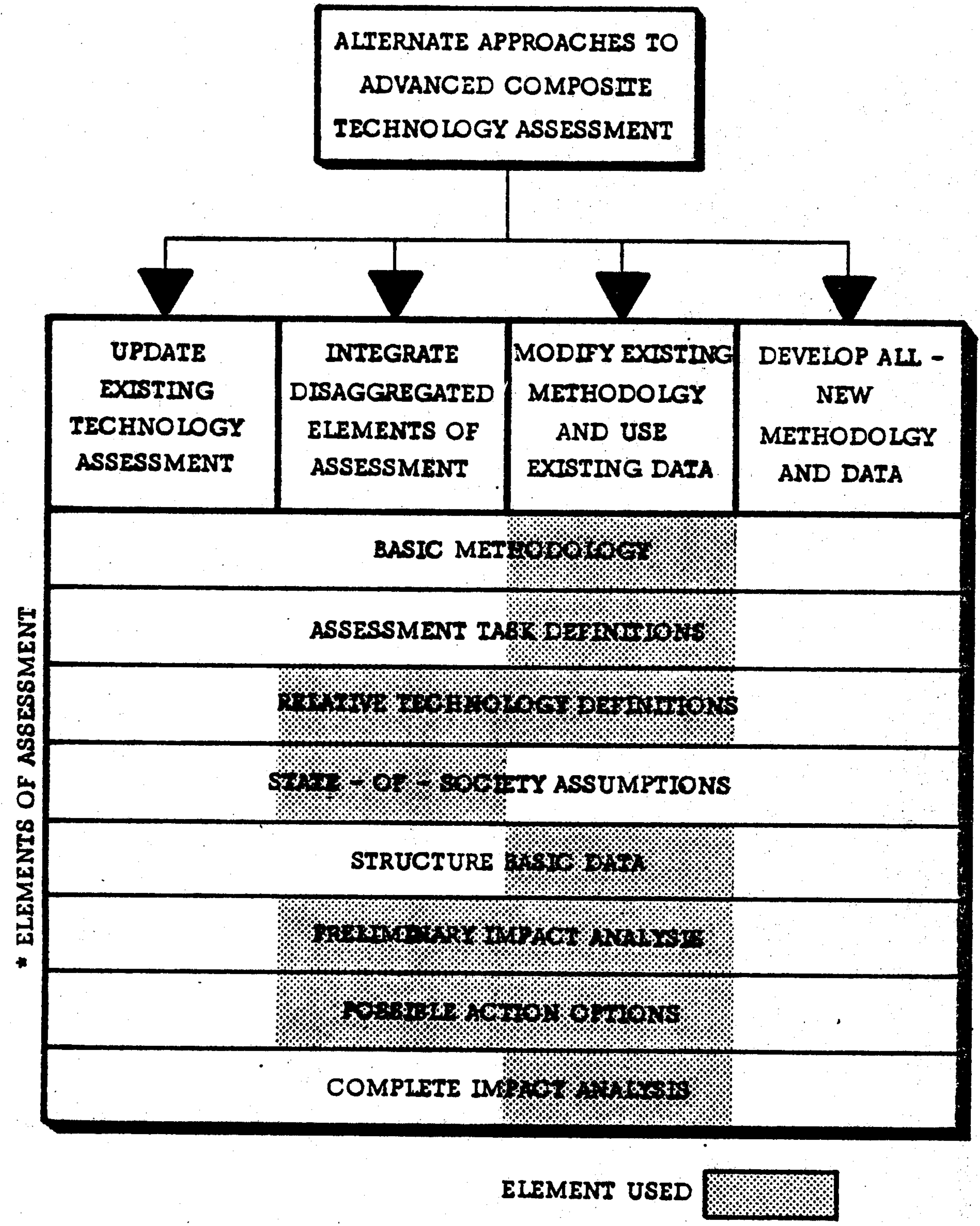
Four different approaches for assessing the technological impacts of advanced composites that suggest themselves are:

1. Locate an existing comprehensive technology assessment, perhaps labeled under a different name, and update and expand it.
2. Collect existing but disparate elements of a technology assessment, integrate and update them.
3. Use an existing technology assessment methodology (as required) to develop a basic analysis from existing source data.
4. Develop a new assessment methodology and acquire or develop fresh basic data.

Figure 3-1 summarizes these alternate approaches and schematically indicates that a combination of parts of approaches 2 and 3 is the preferred direction. Such a combined approach has the advantage of using an existing data base and available basic methods, but accommodating the methodology modifications necessary to produce a user-oriented technology assessment (i.e., product-oriented, in the case of advanced composites).

Referring to Figure 3-1, the basic methodology to be used is described generally in Reference 3, and will also incorporate the concepts presented in References 4 through 36. Specific additions and modifications to the basic methodology are described in Section 4 of this report.

Assessment task definitions and other terminology used are also described in Reference 3. The relative technology definitions are summarized in Section 2 of this report, detailed definitions or descriptive characteristics of technology



* GENERALLY AFTER REFERENCE 3

Figure 3-1.

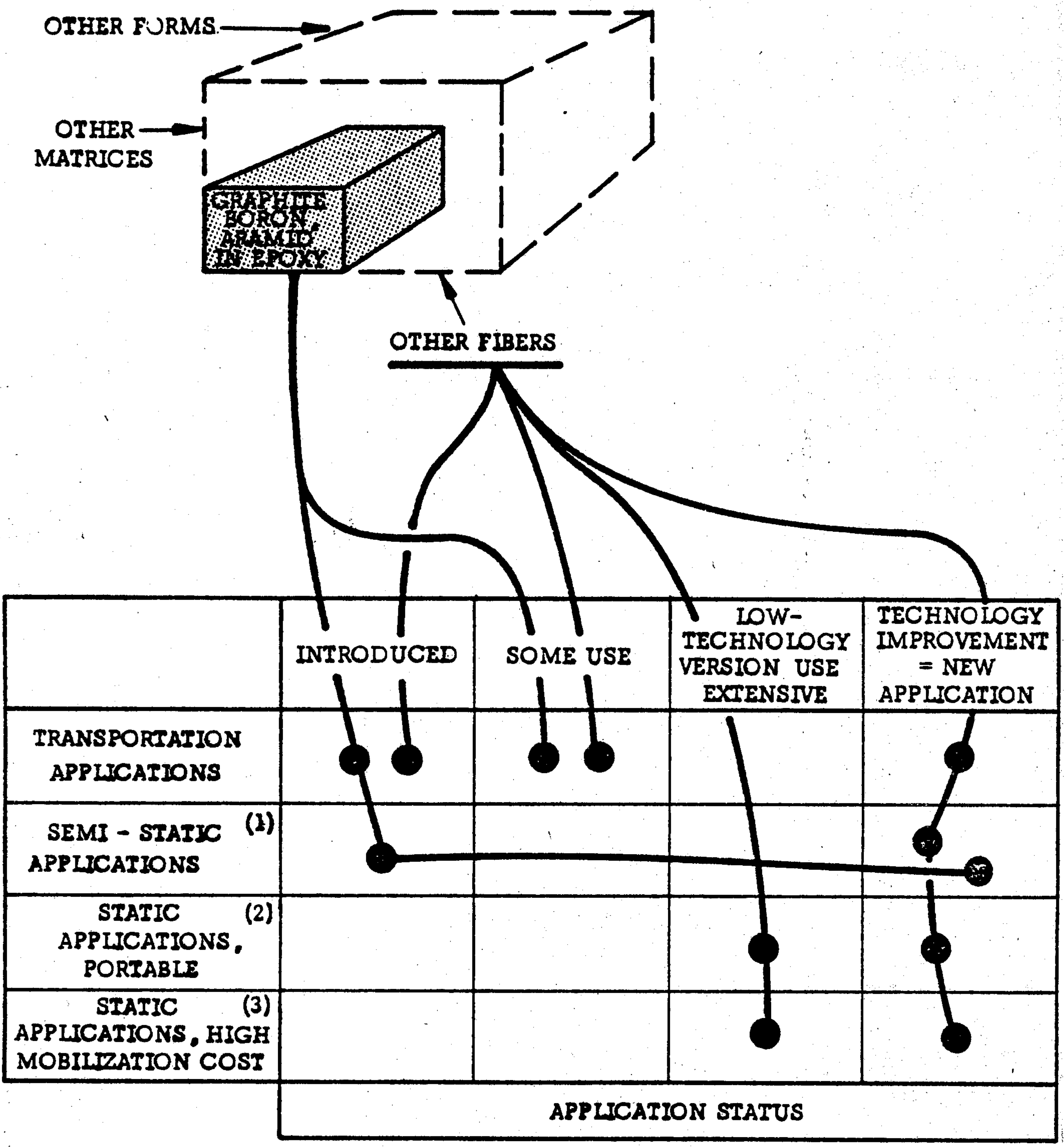
elements are in accord with current general usage, as described in References 38 through 118. Justification for state of society assumptions will be extracted from existing studies. Generally the direct and fallout assumptions will be centerd around the concept of a society changing, with increasing use of "legislated standards" for products, as discussed in Section 2. Basic data structure will be prepared in a form tailored to the requirements of an advanced composites technology assessment.

Preliminary impact analysis will draw heavily on existing studies of possible problems with composites, and marketing-oriented studies that suggest new applications. Possible problems as well as applications should lead to conceivable issues and options. In addition, the technology definition, production systems definition, and inventory of traditional and legislated standards presented in Section 2 will also be used to identify other issues and possible action options.

3.2 BASIC ASSUMPTIONS AND LIMITS

Reference 1 summarized the objective of a technology assessment as being " a systematic definition,exploration, and evaluation of the full range of economic, social, environmental, institutional, and other consequences of the introduction of a new technology or the expansion of an extant technology more extensively, intensively, or in new ways". Figure 3-2 is a simplified presentation of an approximation or definition of the paths that advanced composites have followed for introduction and expanded use. As noted previously many "non advanced" composites might also be improved sufficiently to make them possibly competitive with high-performance, expensive composites. Similarly, cost reductions in advanced composites may accrue from increased usage in transportation and sporting goods applications. Therefore a possibility exists for introduction and expanded use of "non-advanced composites" into transportation, and of "advanced composites" into the domain of lower cost metallic and non-advanced composites applications.

AER is aware of the extensive assessment work related to the use of advanced composites in transportation (including military applications).



EXAMPLES:

(1) DRILL PIPE; MOVING ELEMENTS OF MACHINES, ETC.
(2) PORTABLE BUILDINGS
(3) PIPELINES

Figure 3-2. Paths for Introduction and Use of Advanced Composites

Therefore the technology assessment will proceed assuming that:

1. Many significant, near term and longer range, problems, impacts, issues, and options related to composites will be generated from the non-transportation-related use of composites.
2. Impacts, issues, and options resulting from transportation-related use being assessed by others will not necessarily identify non-transportation national issues.
3. A transportation-related technology assessment of advanced composites falls into the category of a "problem-driven" assessment (i.e., longer range, more mileage, etc.)
4. A non-transportation related technology assessment, at this point in time, is a "technology-driven" assessment, and is currently being addressed.
5. Becuase of the total greater composites usage possiblity including non-transportation and transportation, a total assessment is not only worthwhile, but possibly more necessary than a transportation-only assessment.

Therefore, the technology assessment will proceed with the assumption and ground rule that a complete assessment will be conducted that includes both transportation and non-transportation areas, even though there are several current transportation-related assessments underway.

Figure 3-4 presents a summarization of composites usage by general product category. In the chart shown, which is a compilation of information from References 120,121, 39, 115 and 46, "composites" include both conventional and advanced. The data shown tends to support the concept that composites usage, both current and potential, has the greatest growth potential in non-transportation fields, if advancements or changes are postulated in the "technology" areas defined in Figure 1-2, namely:

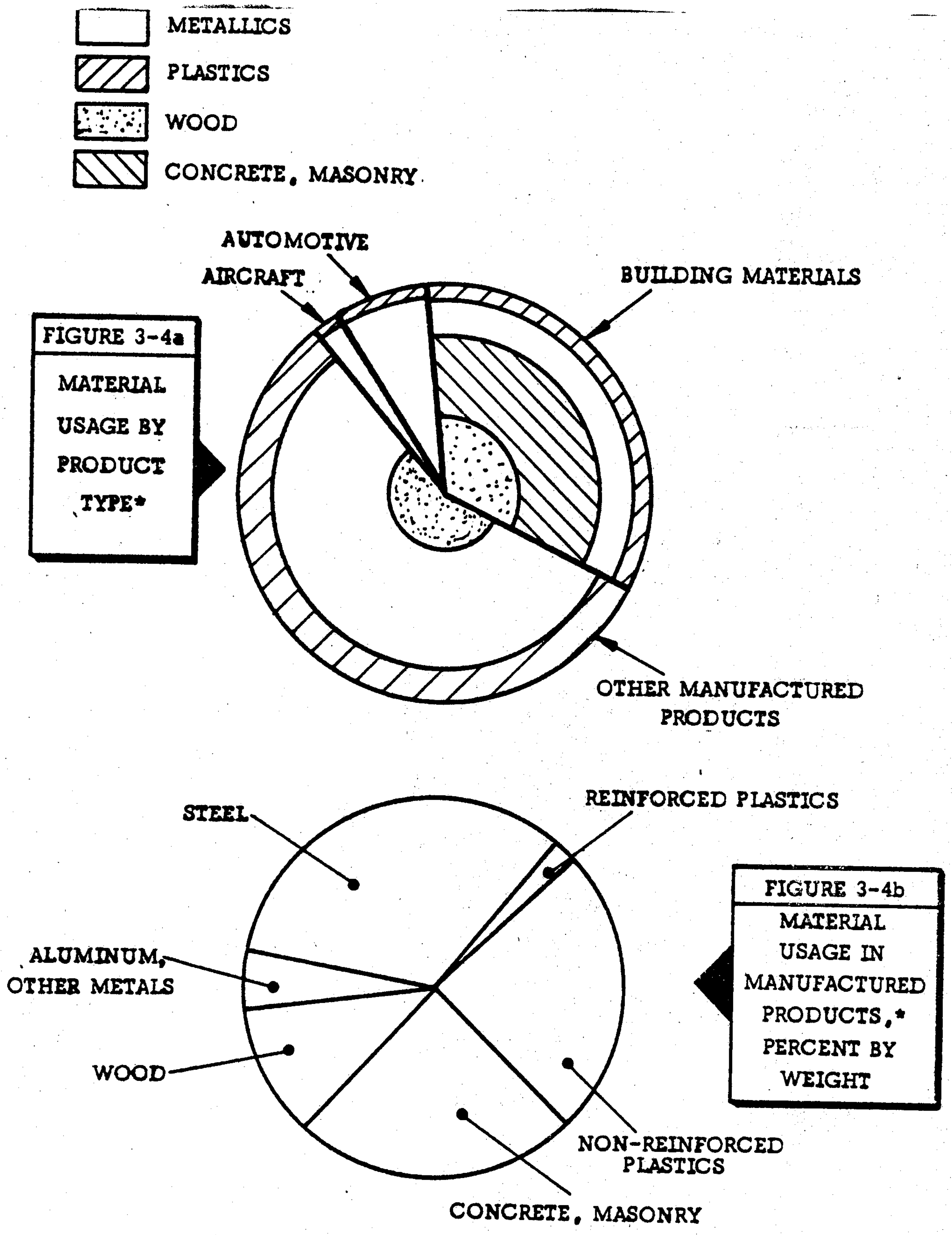


FIGURE 3-4a

MATERIAL USAGE BY PRODUCT TYPE*

FIGURE 3-4b

MATERIAL USAGE IN MANUFACTURED PRODUCTS,* PERCENT BY WEIGHT

* NOT INCLUDING CLOTHING, PACKAGING PRODUCTS, ROADWAYS, DAMS (REFS: 39,46,115,120,121)

Figure 3-4. Composites Usage Summary

1. Material characteristics
2. Production system definition
3. Legislated standards
4. Traditional standards

The rationale for growth potential is that since the use of non-metallics is well established in each area of manufactured products (see Figure 3-4a), there exists basic acceptance. Further, total usage (see Figure 3-4b) is sizable enough so that the basic infrastructure necessary to advance materials technology is in place and of sufficient size to compete with metallics. Finally, high potential exists for composites to at least displace non-composites so that even a minor penetration into a large market could produce significant impacts.

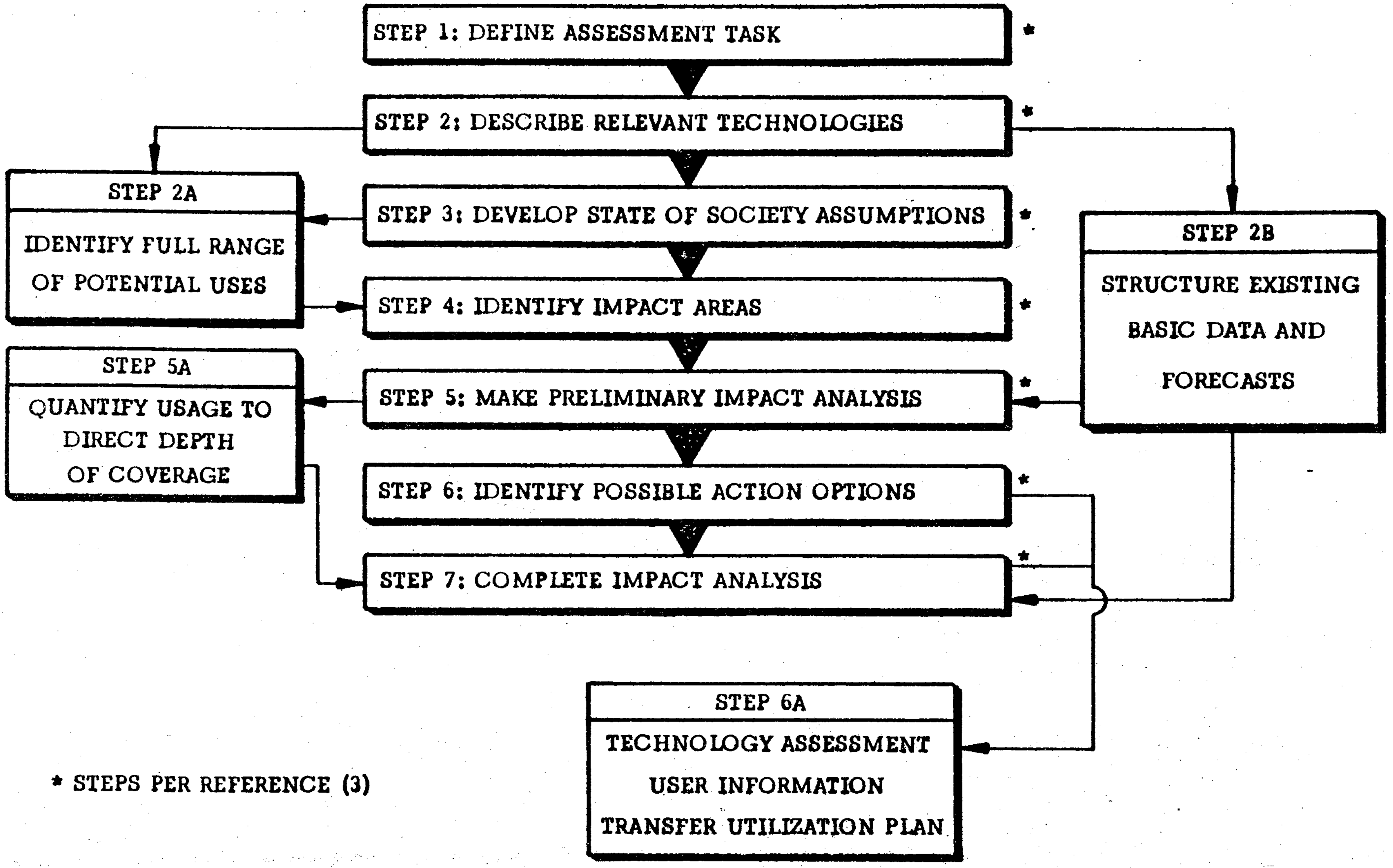
3.3 BASIC METHODOLOGY

The concepts of a structured technology assessment, the "checklists" and examples, and the formats and definitions, contained in Reference 3, "A Technology Assessment Methodology - Some Basic Propositions", seem a very useful starting point to develop an advanced composites technology assessment. The technology definitions of Section 2 were developed using the suggested methodologies in that reference. Generally, the "seven steps" for making a technology assessment presented there, (see Figure 3-5, adapted from the Reference), applied to advanced composites, would immediately identify the impacts on society, qualitatively. (This assumes a satisfactory technology definition). It is suspected, however, that in the case of composites, impacts will be numerous, widespread, but individually minor.

A comprehensive technology assessment must therefore really assess the quantitative level of the impacts in order to test the 'major-minor" hypotheses in each impact. To accomplish the quantitative impact assessment, basic methodology must be expanded, which is really the core of the project Phase I activity. Figure 3-6 repeats Figure 3-5, with the addition of the major specific additions or interpretations of the "seven steps" to be pursued.

STEP 1	DEFINE THE ASSESSMENT TASK DISCUSS RELEVANT ISSUES AND ANY MAJOR PROBLEMS. ESTABLISH SCOPE (BREADTH AND DEPTH) OF INQUIRY DEVELOP PROJECT GROUND RULES
STEP 2	DESCRIBE RELEVANT TECHNOLOGIES DESCRIBE MAJOR TECHNOLOGY BEING ASSESSED. DESCRIBE OTHER TECHNOLOGIES SUPPORTING THE MAJOR TECHNOLOGY. DESCRIBE TECHNOLOGIES COMPETITIVE TO THE MAJOR AND SUPPORTING TECHNOLOGIES
STEP 3	DEVELOP STATE-OF-SOCIETY ASSUMPTIONS IDENTIFY AND DESCRIBE MAJOR NONTECHNOLOGICAL FACTORS INFLUENCING THE APPLICATION OF THE RELEVANT TECHNOLOGIES.
STEP 4	IDENTIFY IMPACT AREAS ASCERTAIN THOSE SOCIETAL CHARACTERISTICS THAT WILL BE MOST INFLUENCED BY THE APPLICATION OF THE ASSESSED TECHNOLOGY
STEP 5	MAKE PRELIMINARY IMPACT ANALYSIS TRACE AND INTEGRATE THE PROCESS BY WHICH THE ASSESSED TECHNOLOGY MAKES ITS SOCIETAL INFLUENCE FELT.
STEP 6	IDENTIFY POSSIBLE ACTION OPTIONS DEVELOP AND ANALYZE VARIOUS PROGRAMS FOR OBTAINING MAXIMUN PUBLIC ADVANTAGE FROM THE ASSESSED TECHNOLOGIES.
STEP 7	COMPLETE IMPACT ANALYSIS ANALYZE THE DEGREE TO WHICH EACH OPTION WOULD ALTER THE SPECIFIC SOCIETAL IMPACTS OF THE ASSESSED TECHNOLOGY DISCUSSED IN STEP 5.

Figure 3-5. Seven Major Steps in Making Technology Assessment



* STEPS PER REFERENCE (3)

Figure 3-6. Additions and Interpretations of Basic Technology Assessment Methodology

3.4 COMPREHENSIVENESS AND DIFFERENTIATION

To Figure 3-4, the following assessment tasks have been added:

Step 2A: Identify Full Range of Potential Uses
Step 5A: Quantify Usage to Direct Depth of Coverage
Step 2B: Structure Existing Basic Data and Forecasts

These provide for (a) comprehensiveness and (b) differentiation. The two terms, as used in Reference (3) suggest that the technology assessment be approached as follows:

1. Differentiation: "considerations....omitted because they were regarded as of little or no importance....(or) because of time/data limitations.
2. Comprehensiveness: "narrowing the area of technology covered....(to allow consideration of as comprehensive an array of impacts as possible).

The example cited of this approach was a problem driven technology assessment, rather than a technology driven assessment. The added steps are a formal process to study and differentiate between considerations of little importance. They identify the most comprehensive array of impacts, considering that advanced composites may likely be used in a wide array of applications, and therefore involve the entire spectrum of production-system and product-defining institutions.

Step 2B is a study internal mechanism to make efficient use of existing information, which is critical in a resource-limited study of wide-ranging subjects.

Step 6A, Technology Assessment User Information Transfer and Utilization Plan address the NSF requirement in this area (Reference 2).

SECTION 4

DEVELOPMENT OF SPECIFIC APPROACH

4.1 SEQUENCE OF DEVELOPMENT

Reference 3 makes the point that (1) the steps of a technology assessment can proceed concurrently; (2) there may be overlap in the steps; (3) the process is iterative; (4) the order may be varied; and (5) steps may be combined or skipped. Regardless, the methodology in that Reference was presented sequentially, and the following discussion is presented similarly, despite the non-sequential nature of the development process in relation to the "seven steps". However, insofar as the methodology development has been sequential, it is summarized in Figure 4-1.

4.2 STEP 1: DEFINITION OF ASSESSMENT TASK

The definition of the assessment task consists of three elements (per Reference 3):

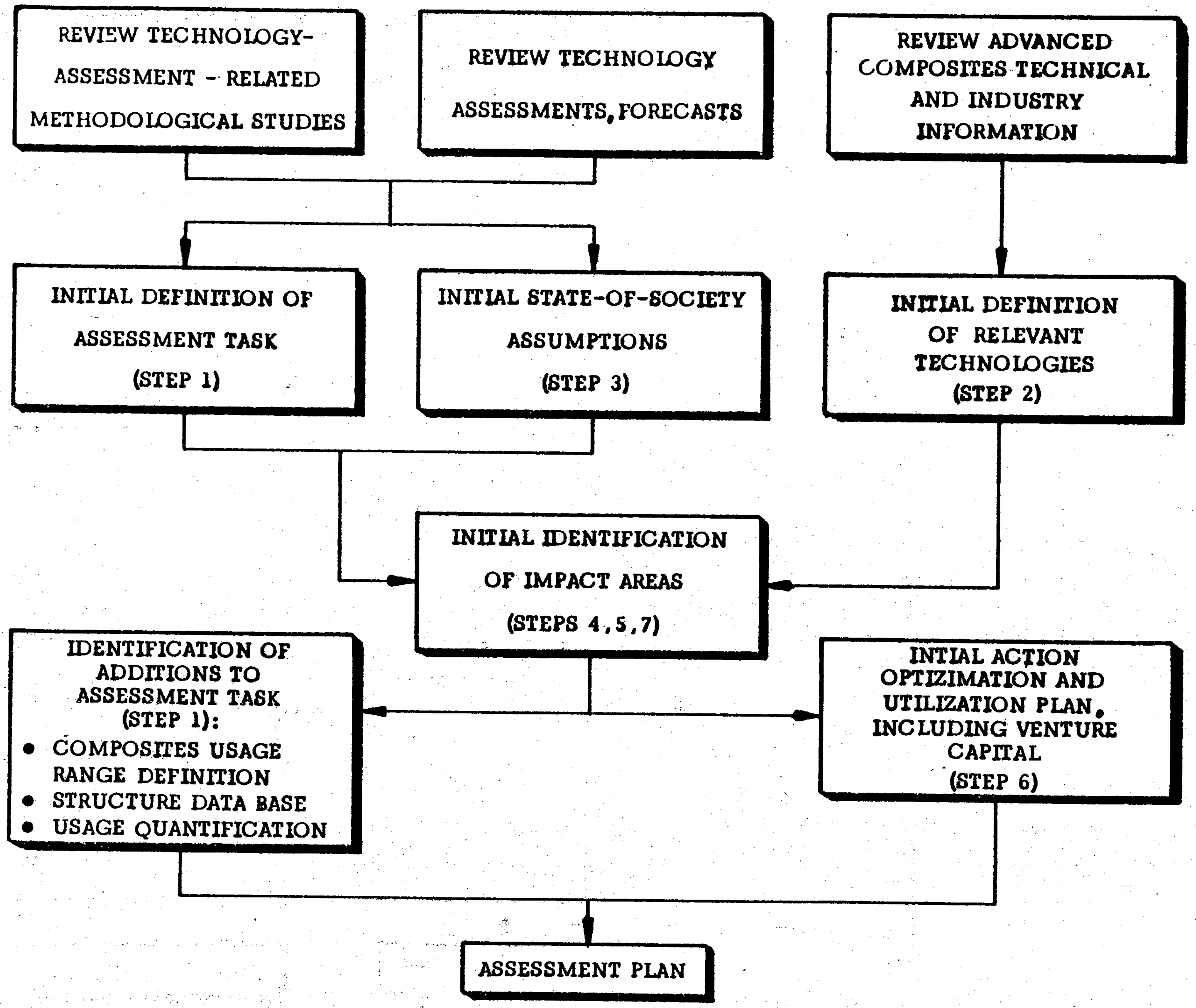
1. Initial discussion of relevant issues and/or major problems.
2. Establishment of scope (breadth and depth) of inquiry.
3. Development of project ground rules.

4.2.1 Relevant Issues and Problems

Relevant issues are regarded in this plan as applying to both (a) advanced composites, and (b) technology assessment methodology.

Basic technology assessment problems and issues in this project have been discussed previously and can be summarized as follows·

1. Should or can the Phase I and Phase II NSF RANN (Small Business Innovation) Project be structured to also serve as an incentive for venture capital? (See Section 1, and Figure 1-1 and Paragraph 2.3.3). Informal contact with a number of policy


REVIEW TECHNOLOGY-ASSESSMENT - RELATED METHODOLOGICAL STUDIES
REVIEW TECHNOLOGY ASSESSMENTS, FORECASTS
REVIEW ADVANCED COMPOSITES TECHNICAL AND INDUSTRY INFORMATION
INITIAL DEFINITION OF ASSESSMENT TASK (STEP 1)
INITIAL STATE-OF-SOCIETY ASSUMPTIONS (STEP 3)
INITIAL DEFINITION OF RELEVANT TECHNOLOGIES (STEP 2)
INITIAL IDENTIFICATION OF IMPACT AREAS (STEPS 4, 5, 7)
IDENTIFICATION OF ADDITIONS TO ASSESSMENT TASK (STEP 1):
• COMPOSITES USAGE RANGE DEFINITION
• STRUCTURE DATA BASE
• USAGE QUANTIFICATION
INTIAL ACTION OPTIZIMATION AND UTILIZATION PLAN, INCLUDING VENTURE CAPITAL (STEP 6)
ASSESSMENT PLAN

research and composites industry organizations (see Contact Summary, Appendix II) has led to the following conclusions·

a. Occasionally, a policy research organization will capitalize an independent venture in this field, but usually only to prepare itself for future contract studies.

b. As an alternative, a policy research organization (company, foundation, or university) will usually hire people or subcontract for help to gain some added capability.

c. Material and product development organizations operate in essentially the same manner. In the early and mid-seventies, there was a temporary upsurge (Reference 115) in large manufacturing companies buying development companies,however, as the principals cashed in and left, time after time, this trend subsided, as has the possibility for venture capital funding for a "pure" technology assessment.

d. If a product-orientation can be included in the assessment process, the possibility of product fallouts might attract venture capital. To cover this possibility the technology boundary was expanded (see Figure 1-2) to include products, not just materials.

2. Comprehensiveness and depth: This requires establishing definitions regarding advanced versus non-advanced materials and expanding the technology boundary to include the complete production system. The broadest definition will be used. Another factor is selection of a qualitative or quantitative approach. A quantitative approach will be used to define technology assessment depth, in process.

Regarding advanced composite technical problems and issues, the Phase II Study is intended to address this subject in depth. Preliminary review of the literature (see References and Bibliography, Appendix I) indicates that many problems are thought to be with advanced composites as issues, but very few are addressed. Table 4-1 lists some of the current supposed problems and issues, segregated. Where a problem suggests an issue, it is included. Development of this listing was a factor that led to broadening the technology boundary to include products and standards. Obviously the issues are closely interrelated, in the sense that they could all be covered under the broad issue of government participation.

4.2.2 Scope of Inquiry

Table 4-2 takes the "scope of inquiry" checklist of Reference 3, and adapts it for the planned advanced composites technology assessment. The depths proposed by the table are consistent with an assessment of a technology that is advancing in a disaggregated set of institutions and with a wide range of potential applications. Some comments on this table are presented below:

1. Primary technology elements, including institutions are those previously summarized in Figure 1-2 and presented in more detail in Figures 2-2 and 2-4 through 2-10; in the full study these will be structured and covered in depth.

2. Supporting technologies are similar to those associated with conventional competitive materials and will be studied only where major differences occur. For example, material-characteristics supporting technology might involve appearance, aesthetic designability, smell, feel. Examples of distinctive supporting technology might be shelf life of raw material, aging, long-term solubility and polymerization, etc. These would not be factors with steel and aluminum, but would be with wood.

3. Competitive technologies (i.e., metallics) will be considered only to the degree that a technology-advancement response might be expected; issues will be comparative in nature, such as: "If funding or a standard or regulation is applied to composites, should it also be applied to metallics,

TABLE 4-1
ADVANCED COMPOSITES PROBLEMS AND ISSUES

TYPICAL PROBLEM	TYPICAL ISSUES
1. Composite matrices are more flammable and toxic than metal and wood, and if introduced in greater extent, may create more safety problems.	1a. Should government fund technology improvements in flammability/toxicity, to speed up introduction of composites to benefit from their "good" properties? or 1b. Should safety standards be relaxed at least partially, or not imposed if a new application not covered by a flammability standard is involved? or 1c. Should standards be set or maintained, with the burden of funding improvements falling directly on the product user, at purchase.
2. Some composites occasionally produce highly-conductive, hard to see debris (fibrous graphite) during manufacture, when damaged, and on disposal, which may cause short circuits in nearby electrical equipment.	2. Same as 1a, b, and c, as applied to standards and funding technology improvements.
3. Even with products designed to take maximum advantage of composites productivity properties; i.e., well beyond "direct material substitution", and even considering maximum economics of scale, and production systems improvements, high performance composites will remain an order of magnitude more expensive in most applications in the forseeable future.	3a. Should additional product standards be set by government to force the use of composites to take advantage their good features as regards weight? and 3b. Should government expand funding of technology improvements? if so 3c. Should similar funding be given to competitive industries?

Continued ...

TABLE 4-1 (Continued)
ADVANCED COMPOSITES PROBLEMS AND ISSUES

TYPICAL PROBLEM	TYPICAL ISSUES
4. Generally educational institutions produce people who can very directly design and produce metallic products as most texts and courses are based on use of homogeneous materials with isotropic properties; conversely, design of optimum composite structures is relatively sophisticated, involving multiple tradeoffs--- composites designers and other experts are in short supply and demand a premium.	4a. Should government fund training (or retraining) programs, similar to the "fallout and hardened shelter design" courses of the 1960's? or 4b. Should the free market solve the problem, with, inevitably, the disaggregated production system rapidly becoming concentrated into many fewer but much larger companies that could produce expertise internally.
5. As advanced composites manufacturing technology is commercialized, and becomes more similar to fiberglass manufacturing technology, the small job shops now predominant in fiberglass, with their low-paid labor, will out-compete the larger companies. As this becomes apparent, an entire set of labor problems can arise (i.e., skills obsolescence, union vs. nonunion, automation vs. hand labor).	5. Are these non-direct "fallouts" from forced development of advanced composites fully explored on an industry-wide basis?
6. Lighter parts in machines and tools mean more productivity, for a variety of reasons related to energy input and control response. This could cause a whole set of problems in relation to management versus union labor standards.	6. Is a national policy on productivity necessary to control or encourage the entry of new machinery into the market; should it go deeper than just tax incentives (i.e., become analogous to mileage standards in cars)?

TABLE 4-2
SCOPE OF STUDY

Breadth of Study	Depth to Which Study will Cover Topic	
	MAJOR	MINOR
● Range of Technologies		
- Primary	X	
- Supporting	X	
- Competitive		X
● Range of Topics		
- Technology Forecasts		X
- State-of-Society	X	
- Action Options	X	
● Groups Affected		
- Beneficiaries	X	
- Sponsors	X	
- Third Parties	X	
● Time Period Analyzed		
- Extent Retrospective		X
- Extent Futuristic	X	
● Types of Impacts		
- Economic	X	
- Social		X
- Environment	X	
- Political	X	
- Legal	X	
- Institutional	X	
● Levels of Impacts		
- Primary	X	
- Higher Order	X	
● Impact Measurements		
- Qualitative	X	
- Quantitative	X	
- Uncertainty Analysis		X

by the same institutional mechanism?

4. Technology forecasts of others will be used extensively so that effort will be primarily a synthesis into a common time frame and a statement of a median forecast levels of technology, from the many time-phased forecasts that are available, (References 38 through 118). Figure 4-2, extracted from an interim contract status briefing by AER in USBM materials study, summarizes the technology forecast task. Basically, a materials technology is advancing faster than the production system can absorb it, or standards in being can accommodate or promote it. Forecasting requires a synthesis at a point in time, of the continual flow of data.

5. Another way of stating this is that the means is or will be available to close any technology gap associated with advanced composite materials, if the state-of-society permits or required this. Hence, major emphasis is placed on state-of-society and action options.

6. In the case of groups affected, the term"beneficiaries" includes not just the structure producer who uses the advanced material, but also the end user, and third parties. This will also be the approach to levels of impacts. For example, a technology impact sequence might be postulated as follows:

a. A fiber advancement allows matrix application to graphite/ kevlar hybrid mat that, in turn,

b. Permits pultrusion of low cost standard sections that can now be used for

c. Cabs, panels, and rollover protective structures on construction equipment, resulting in

d. More productivity for the equipment user, hence more sales for the producer, and

e. More safety for the operator, leading to

f. Less cost to society from accidents,

g. And the other higher order impacts on third parties

7. Regarding impacts, all types noted will receive equal consideration except "social". Lifestyles, attitudes, values, etc. will be addressed only as they bear directly on the concept of traditional and legislated standards for products and materials. One exception may be in the area of demography, as

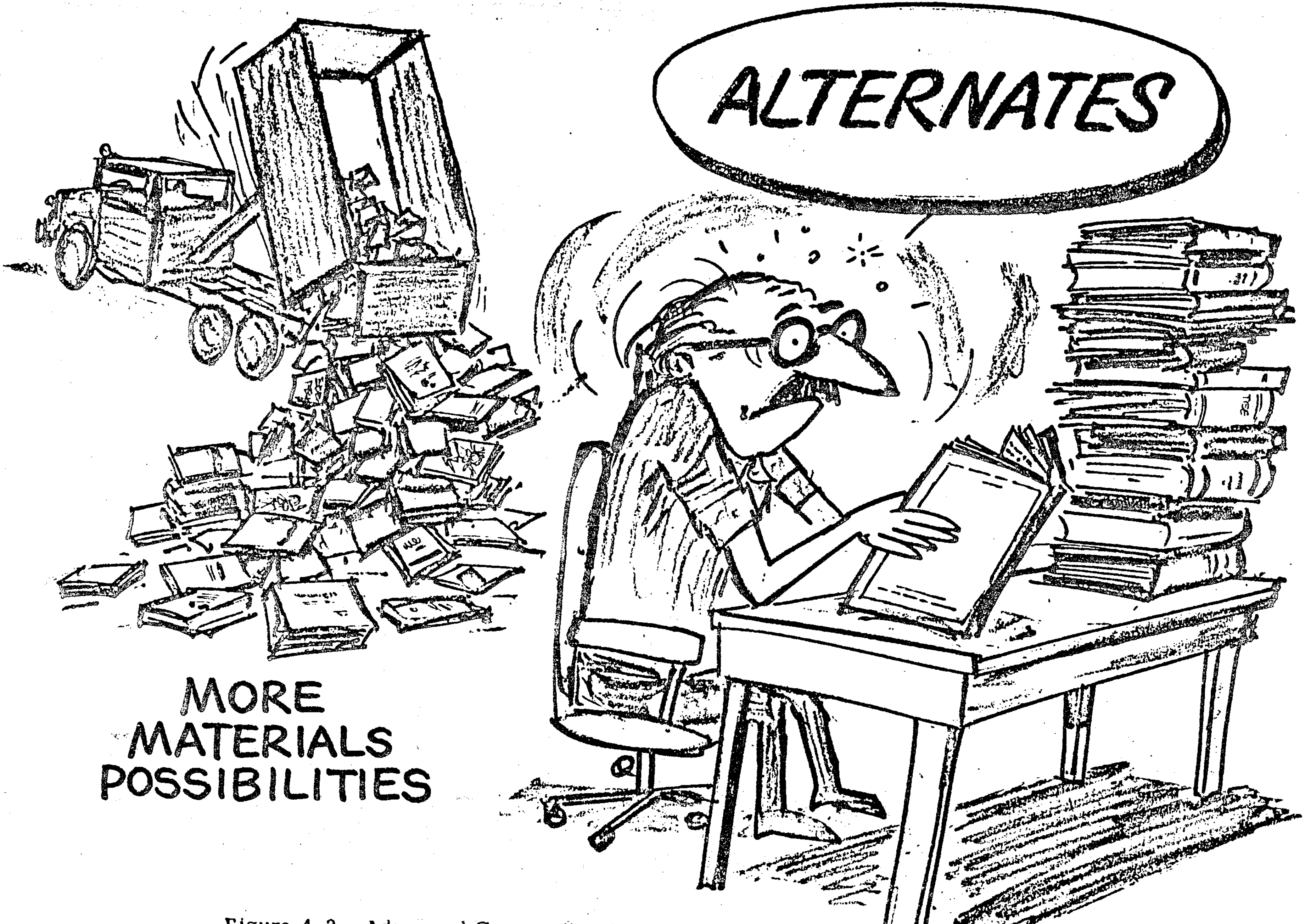


Figure 4-2. Advanced Composites Technology Forecasting

some level of physical and organizational disaggregation of the industrial sector is suggested by increasing use of composites, with effects on the labor force, and consequent population dispersion.

8. Time period analyzed will be retrospective to the extent that introduction rate of plastics and aluminum in the past may be indicative of the future pace of composites. Based on this criterion, the "futuristic" time period to be examined will extend from now to the year 2020, some 40 years.

Figure 4-3 presents a conceptual "material introduction cycle", showing analogous events and activities in aluminum and composites development (based on References 9,11,110,115 and 117. From this analogy it is projected that, the year 2020 appears to be a reasonable point in time to expect the full utilization of composites. The widespread use of plastics also closely parallels the deployment pace of aluminum. One study task will be a more detailed examination of this approach to forecasting the pace of technology introduction.

Finally, both qualitative and quantitative impact measurements will be given equal and major study emphasis. This measurement activity will be a two-way, input-output process, aimed at accomplishing the following:

1. Using quantitative measures of materials consumption (amounts and type) to indicate possible qualitative impacts.
2. Using quantitative measures as a tool for assigning a significance to a qualitative impact.

This concept is schematically shown in Figure 4-4. Preliminary quantitative measures of usage could include such parameters as:

1. Increase in product types using reinforced plastic in place of other materials.
2. Increase per year in percent of poundage produced relative to total materials produced.

These measure also can be used on an application-by-application basis. Where usage is great, impacts may be measured by such typical parameters as:

1. Change in first cost

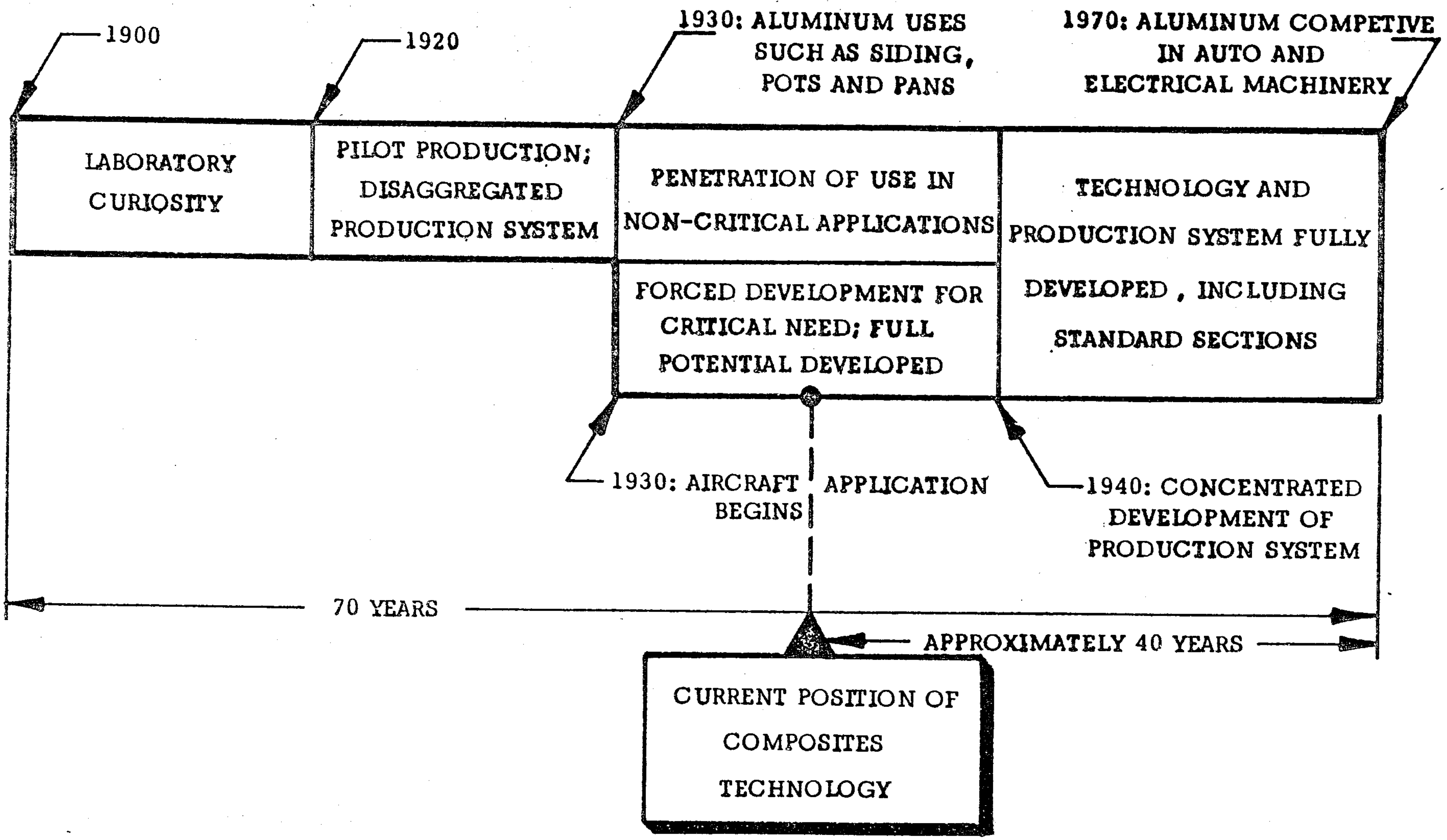


Figure 4-3. Technology Assessment Time Frame

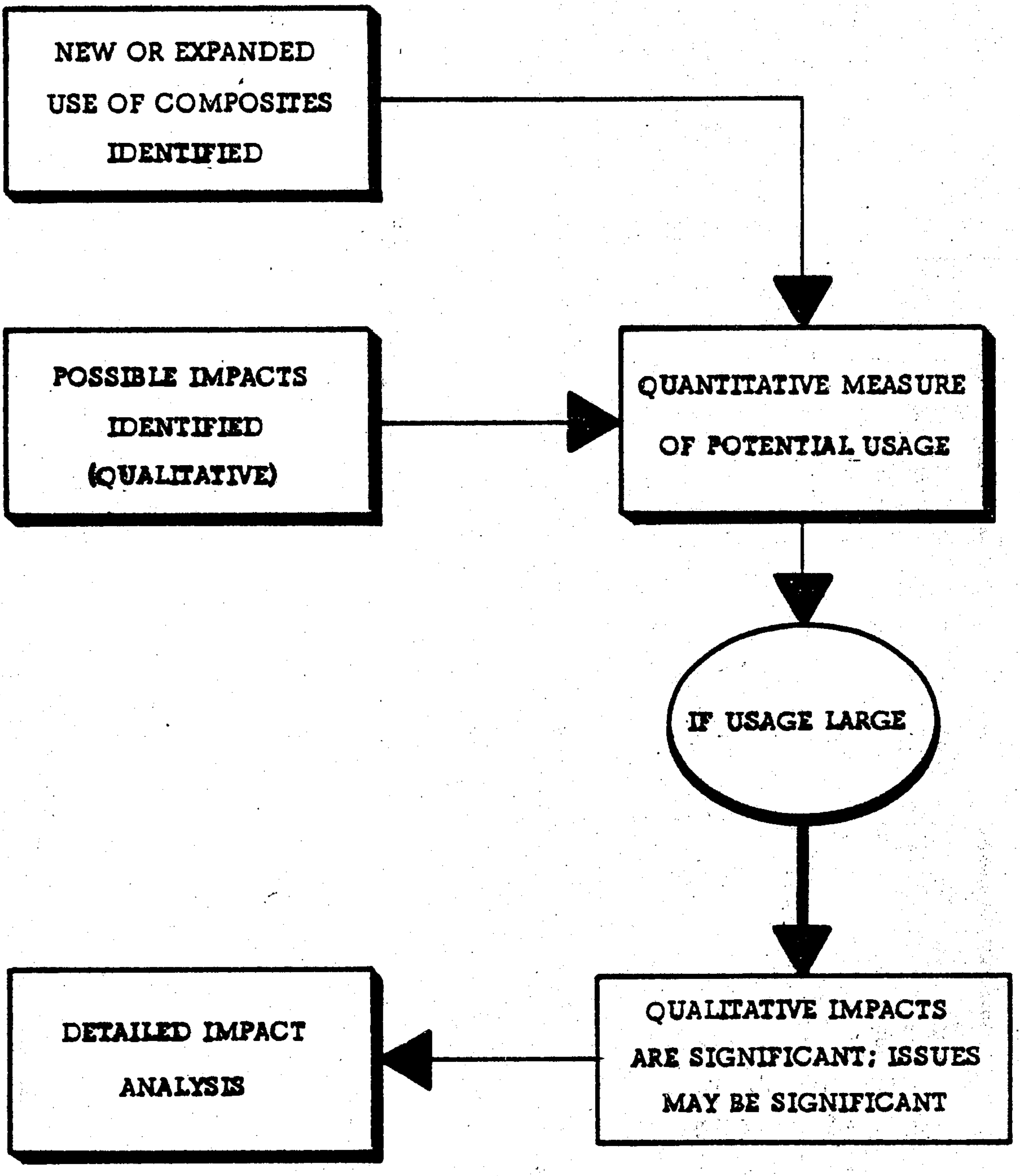


Figure 4-4. Use of Qualitative and Quantitative Measurements

2. Change in operating cost
3. Change in life cycle cost
4. Machines or workers displaced
5. Machines or workers added
6. Organizations displaced
7. Organizations added.

The first-level impacts noted lead directly to secondary and tertiary impacts on demography, financial institutions, etc.

4.2.3 Development of Project Ground Rules

The major project ground rule is the previously discussed exclusion of transportation-specific applications and impacts , except to the extent that (1) information on those applications is critical to project forecasts on material costs and production system capacity, and (2) the information is not available from existing studies. Other ground rules are covered as appropriate in individual topics in this report.

4.3 STEP 2: DESCRIPTION OF RELEVANT TECHNOLOGY

This task involves the following:

1. Physical and functional description
2. Current state of the art
3. Influencing factors
4. Related technologies
5. Future state of the art, including timing
6. Uses and applications

A further expansion of this list, in the form of a coverage checklist, is contained in Reference 3. Items 1, 2, 3, and 4 have been previously defined in summary in Sections 1 and 2, as the contents within an "advanced composites technology boundary", that included:

1. Material system characteristics
2. Production system description
3. Traditional standards
4. Legislated standards.

The Phase II task is to expand this basic structure into additional detailed, specific components, as a checklist of candidate items for technology advancements, leading in turn to uses and applications.

Figure 4-5 is an expansion of composite matrix and fiber possibilities for technology advancement and potential expanded use, with competitive materials also noted. Figure 4-6 shows fiber form possibilities, while Figure 4-7 treats possibilities in production technology sub-components, assembly and processing. Figure 4-8 expands on another production technology sub-component, basic fabrication, showing advantages and disadvantages added, based on consensus in the literature. Similar arrays can be easily structured from the literature for other technology components. Reference is a good basic source for advanced composites information of this sort. The advantages combined with technology advancements in the area of the disadvantages, represent possibilities for added use.

A specific example of combining relevant technology advancements is shown on Figure 4-9, where the total advance consists of a simultaneous change in three elements of technology (product standards, manufacturing and material). A matrix of all of the combinations of individual present and future technology elements should produce many potential applications, with advancements postulated in any one element. What is not shown in Figure 4-9 is a formal process for going from Point "A", the possibility, to Point "B" the requirement. The Phase II task will be further expanded into a formal process, labeled "Step 2A" on Figure 3-5.

4.4 STEP 2A: IDENTIFY POTENTIAL USES

4.4.1 Functional Analysis

In addition to transportation applications, composites such as fiberglass already have been extensively applied in product categories that are perceived by many technical and planning personnel as "static load-bearing structures". Conventional standards that are thought to apply are first cost, stiffness, strength, and corrosion resistance. When these applications are viewed in terms of the larger industrial system, they are "dynamic", and other

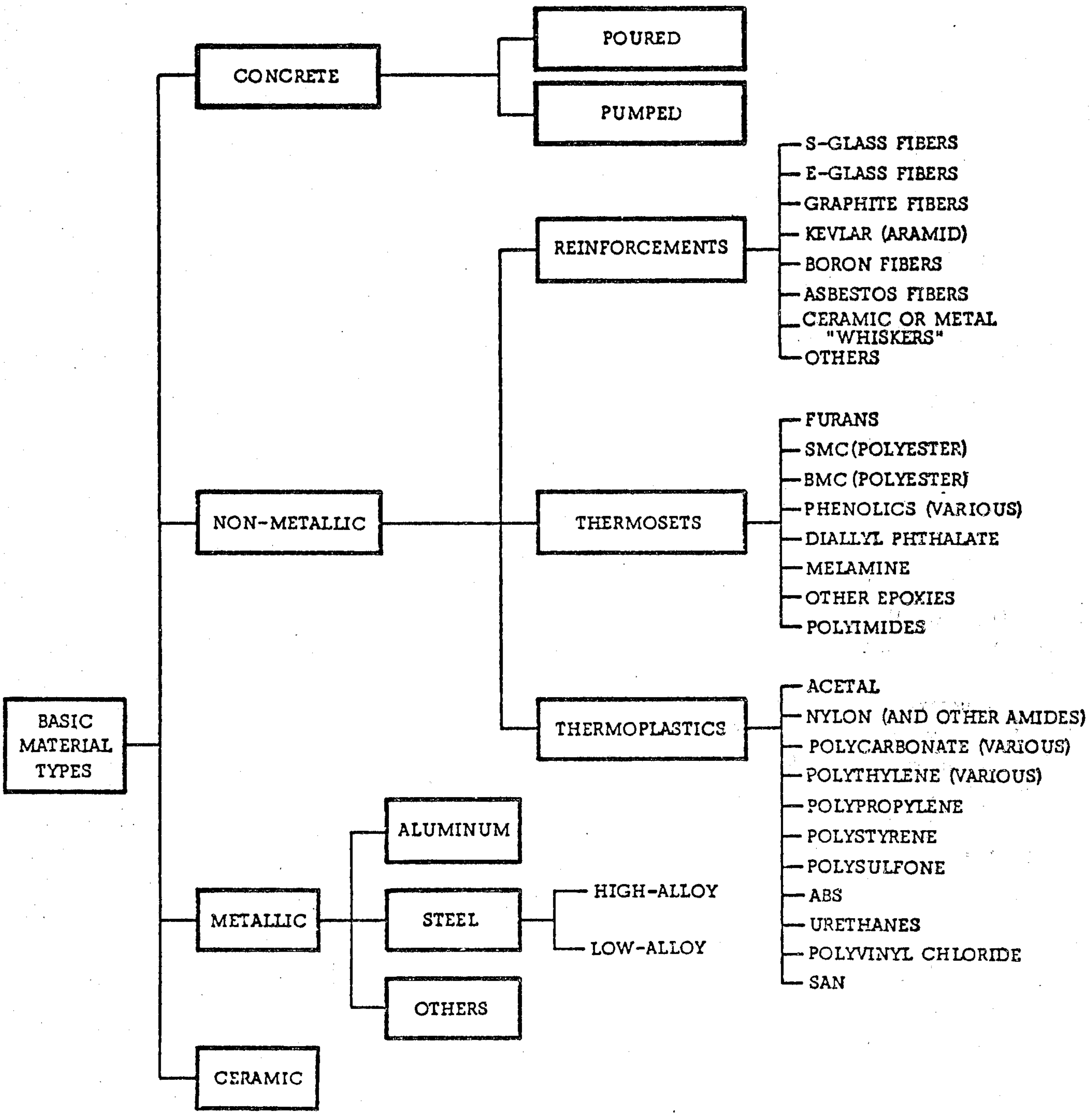


Figure 4-5. Material Technology Subcomponents - Fibers and Matrices

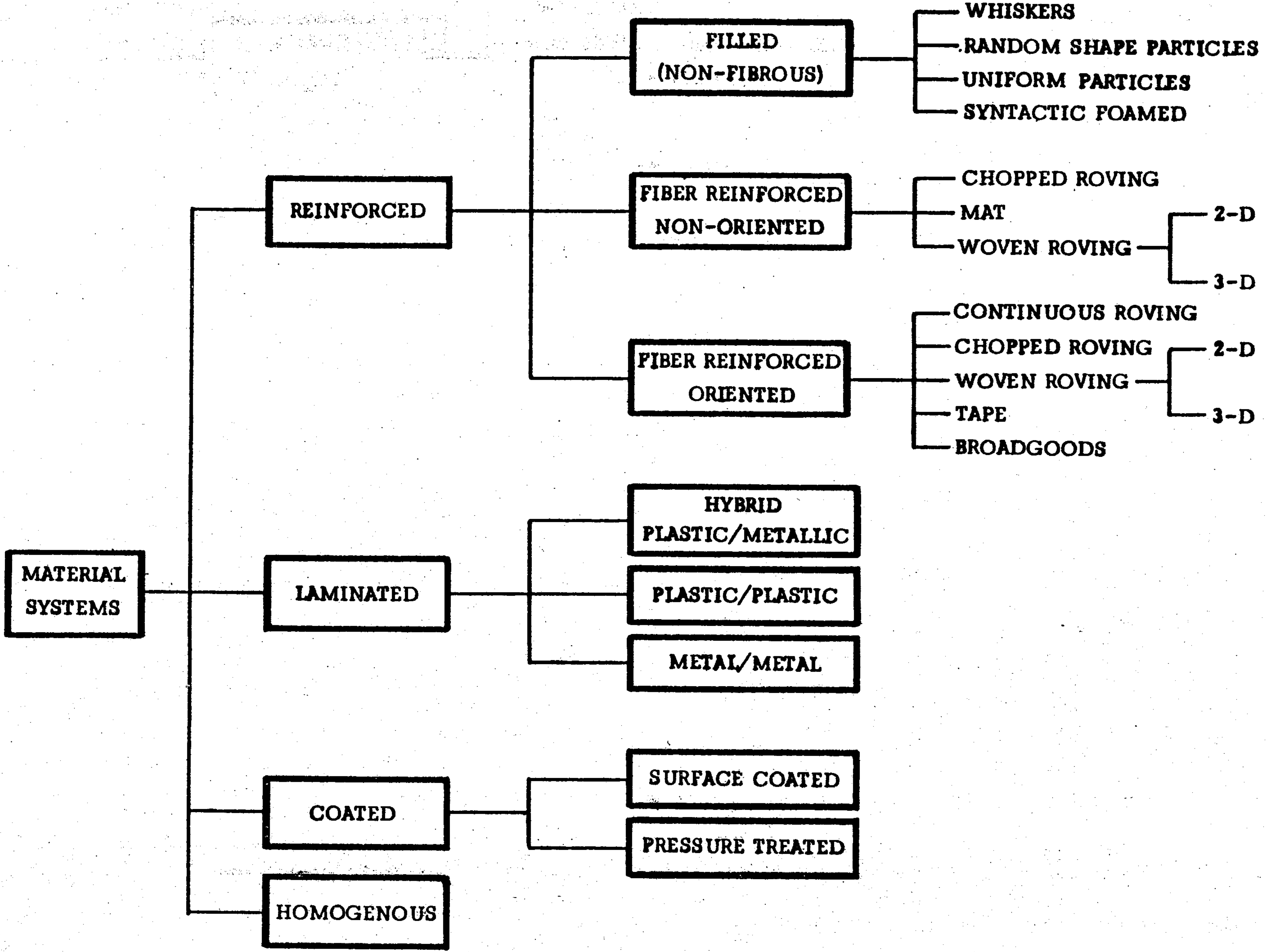


Figure 4-6. Material Technology Subcomponent - Fiber Forms

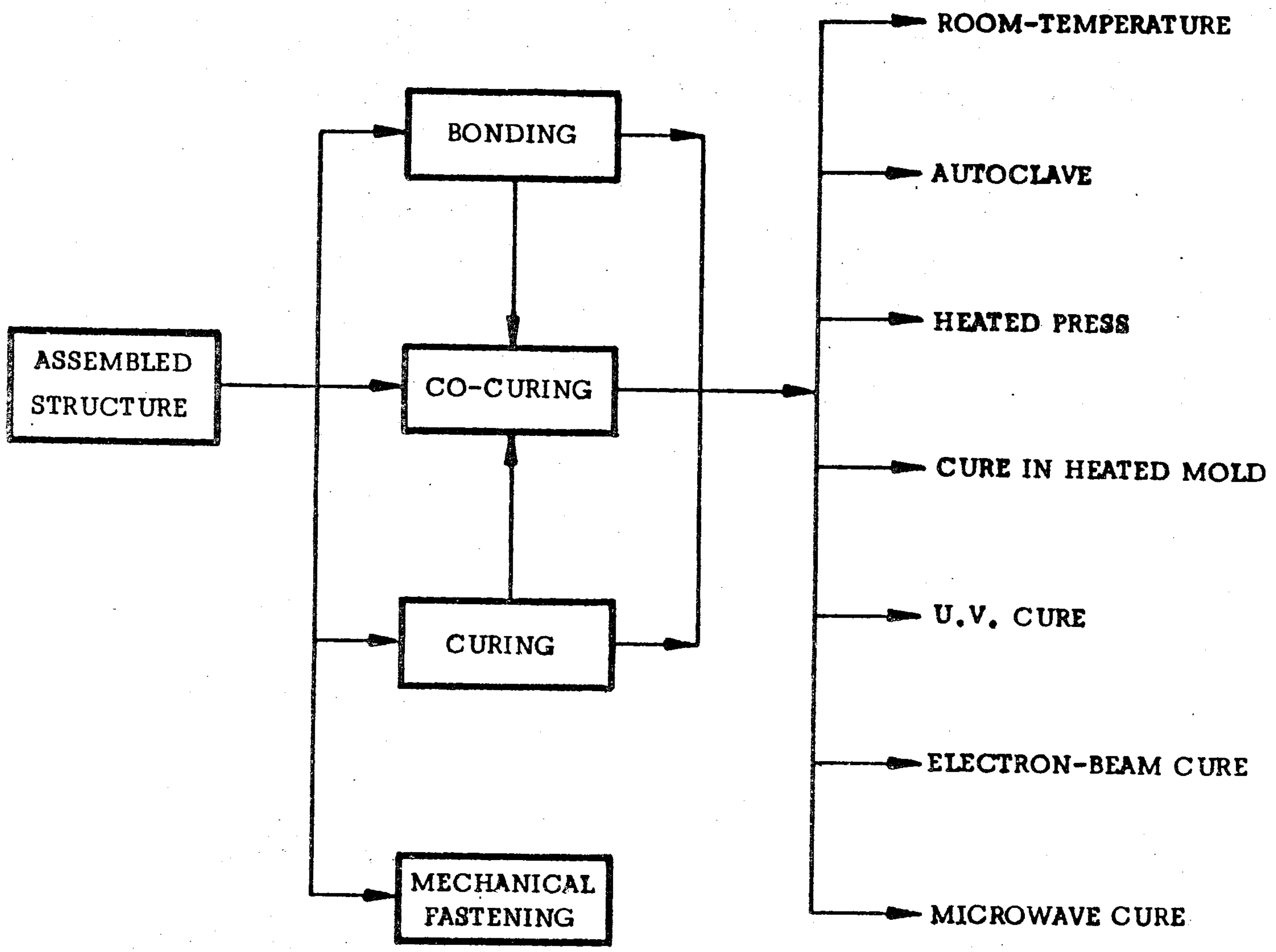


Figure 4-7. Production Technology Subcomponent -Assembly and Cure

OVERALL METHOD	MAJOR ADVANTAGES	LIMITATIONS
HAND OR MACHINE LAYUP OF TAPE OR BROAD GOODS	● BEST FOR OPTIMUM PERFORMANCE (ie: CUSTOMIZED PLY ORIENTATION)	● HIGHEST LABOR COST
FILAMENT WINDING	● AUTOMATED ● HIGH FIBER/MATRIX VOLUME RATIO ● GOOD FIBER ORIENTATION CAPABILITY	● RELATIVELY HIGH TOOLING AND MACHINERY COST
PULTRUSION	● HIGH FIBER/MATRIX VOLUME RATIO	● RELATIVELY HIGH MACHINERY COST ● LIMITED FIBER ORIENTATION
SPRAYUP OF HAND-FORMED MAT	● LOWEST COST TOOLING & MACHINERY	● POOR CONSISTENCY OF PROPERTIES ● LIMITED CONFIGURATIONS
COMPRESSION MOLDING	● HIGHLY AUTOMATED ● MODERATELY GOOD PROPERTIES	● SOMEWHAT LIMITED IN CONFIGURATIONS
CENTRIFIGUL CASTING	● AUTOMATED ● MODERATELY GOOD PROPERTIES	● LIMITED PLY ORIENTATION ● RELATIVELY HIGH MACHINERY COST
INJECTION MOLDING	● SAME AS COMPRESSION MOLDING	● SAME AS COMPRESSION MOLDING
FOAMING	● HIGHLY AUTOMATED	● LIMITED PROPERTIES LEVELS
BONDING OF STANDARD COMMERCIAL SECTIONS	● GOOD FOR SHORT PRODUCTION RUNS AND R & D PROGRAMS	● RELATIVELY HIGH LABOR COST

Figure 4-8. Production Technology Subcomponent - Basic Fabrication

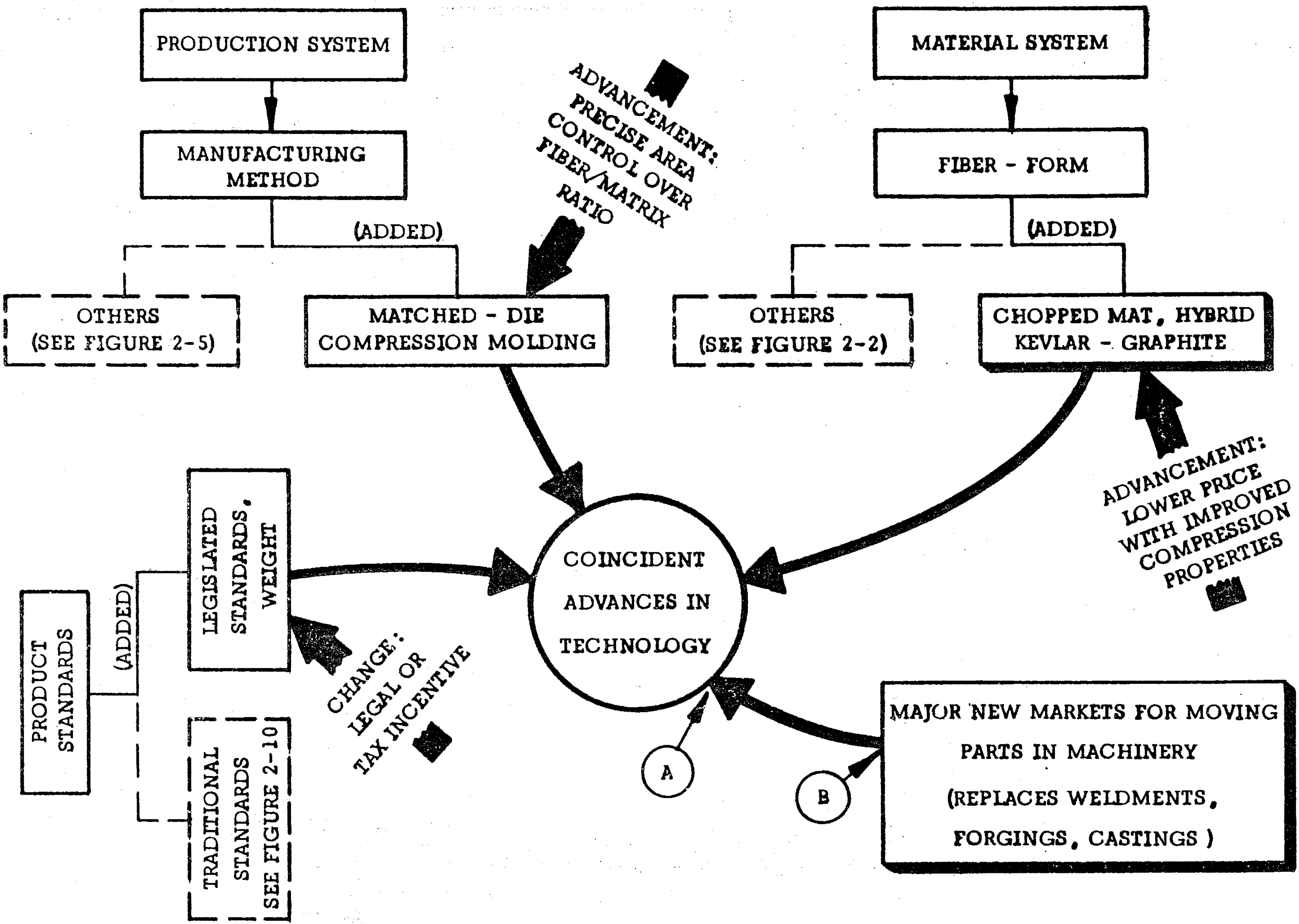


Figure 4-9. Example-Expansion of Relevant Technology

characteristics are of equal importance in material systems selection, such as producibility and weight.

The second step in a broad examination of potential uses for composites, given the basic array of advanced technology elements developed as described in Paragraph 4.3, is to characterize and structure product traditional and potential standards. As an example, the top level of functionally-organized approach is shown on Figure 4-10, where the "function" is in the context of the total product life. It is notable that operations researchers, life-cycle cost-estimators, and society cost/benefit analyzers regularly operate with the life-function concept, but design application of the concept is relatively rare. Figure 4-11 relates a variety of structure characteristics to product functions.

As shown, weight, and therefore characteristics-to-weight ratio, are key parameters in selecting a material. The general characteristics noted on Figure 4-10 can be related to specific material properties, design approaches, and manufacturing processes. Product candidates can also be examined individually in the manner shown on Figure 4-11. Table 4-3 presents a selection of product applications that are candidates for improved composites.

TABLE 4-3 Typical Product Candidates

1	Underground Pipelines
2	Drill Pipe (rock drills, oil rigs)
3	Construction Equipment Booms, Buckets, Cabs, Mechanisms
4	Ladders, Scaffolds, Temporary Supports
5	Hand Tools
6	Anchor Cable, Dredge Cable
7	Portable Buildings, Hangar Doors

Table 4-4 presents some specific functional requirements for these candidates.

Lists like those in Tables 4-3 and 4-4 must be developed intuitively. Risk of missing a significant opportunity for a new application or a major expansion possibility is lessened by maintaining a continuous review process over promotional material, where there is no lack of speculative applications.

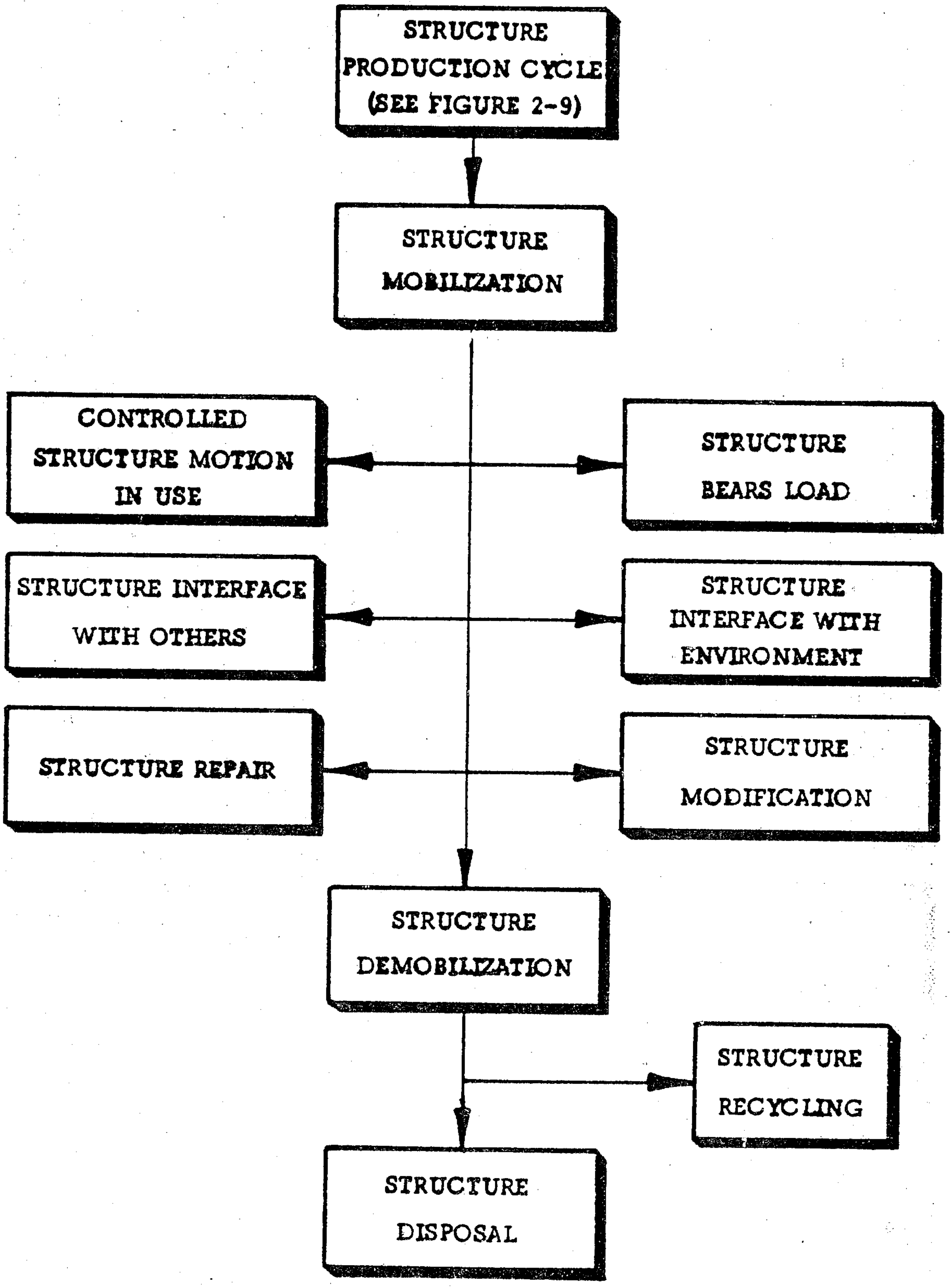


Figure 4-10. Structure Function

X = CHARACTERISTIC
TO BE CONSIDERED

STRUCTURE CHARACTERISTIC	PRODUCTION	MOBILIZATION	MOTION IN USE	LOAD BEARING	INTERFACE STRUCTURE	INTERFACE ENVIRONMENT	REPAIR	MODIFICATION	DEMOBILIZE	DISPOSE	RECYCLE
PART COUNT	X						X	X			
PECULIAR SHAPE	X				X		X	X			
SIZE - COMPACT		X			X				X	X	
WEIGHT		X	X		X		X	X	X		
STRENGTH				X	X						
STIFFNESS			X	X	X						
PRODUCIBILITY (CONFIGURATION)	X										
IMPACT RESISTANCE			X			X					
DAMAGE TOLERANCE				X		X	X				
REPAIRABLE PARTS							X	X			
REPLACEABLE PARTS							X	X			
CHEMICAL RESISTANCE						X					
FLAMMABILITY						X					
CONDUCTIVITY						X					
ODOR						X				X	
APPEARANCE						X					
ISOTROPIC PROPERTIES				X	X						
PRODUCIBILITY - DEGREE HAZARDOUS	X									X	X

Figure 4-11. Structure Characteristics Related to Product Functions

TABLE 4-4 TYPICAL PRODUCT APPLICATIONS-FUNCTIONAL REQUIREMENTS

Product	Functional Requirement (In Addition to Strength)	Benefit of Applying Composites
Drill-Pipe	● Lightweight ● Corrosion resistance ● Dynamic Response Characteristics	● Less power and greater speed of drilling ● Directional control of drilling
Trench Boxes, Bracing and Falsework, etc.	● Lightweight ● Compact ● Easily Modified and Adjusted/Cut	● More consistent use if easier and faster to install ● Faster to install and remove
Mobile Mining Machinery Protective Structures; Mine Shields	● Compact ● Corrosion resistance ● Stiffness ● Lightweight	● Added safety and productivity because compactness interferes less with operations
Mining Cable; Dredge Cable; Prestressing Cable	● Flexible ● Lightweight ● Corrosion resistance	● Less power for handling ● Added safety in handling
Construction Equipment Booms, Arms, etc.	● Lightweight ● Stiffness Characteristics	● Control response ● Energy reduction from less dead weight
Hand Tools	● Lightweight	● Productivity from lightweight and controllability
Portable Buildings, Hangar Doors, etc.	● Lightweight ● Fewer parts ● Field repairable ● Corrosion and rot resistance	● Longer life ● Lower first cost ● Lower mobilization cost

The representative candidates listed in Tables 4-3 and 4-4 are arbitrary selections using the general criteria that

1. Mobilization of the product is repetitive.
2. Controllability in use is a factor.
3. Some design approaches in use seem to consider tailored shapes, compactness, low energy input, tailored stiffness.
4. Large national market, measured in pounds of material used.

4.4.2 Material System Evaluation

The next step in the analysis of product-usage potential is a rapid but quantitative evaluation of material and process alternates for the applications. The evaluations will identify the most likely composite material, if any, that could fill the requirement, and also identify the property or processing shortfall(s). The necessary technology advancements to fill the gaps will be thus identified.

Evaluations will be of four types:

1. General assessments of material and process suitability; suitability will be judged in qualitative terms such as; advantages vs. disadvantages, first cost, complexity of manufacture, relative property values. Figure 4-7 is an example.
2. Rank order assessment of material systems; rank ordering will be related to individual properties, complexity factors, relative costs, etc. Figure 4-12 is a representative array of properties of interest while Figure 4-13 is a typical rank-ordering on one property. The rank-ordering process is a basic tool that indicates composites suitability; the selection will be examined for sets of properties.
3. Tradeoff assessments of competitive material systems; Figure 4-14 presents a specific weight vs. specific-stiffness comparison. Other property tradeoffs will be developed during Phase II to support rapid material evaluations.

Resin system	% fiber glass by weight	Specific gravity	Density lb/in^3	Heat distortion °F, 264 psi	Continuous heat resistance °F	Thermal coeff. of expansion psi x 10^{-6}	Thermal conductivity BTU/hr/ft^2/°F/ft	Specific heat BTU/lb °F	Flammability (UL)	Rockwell hardness
THERMOSETS										
SMC (Polyester)	15-30	1.7-2.1	.061-.075	400-500	300-400	8-12	1.3-1.7	.30-.35	94VO	H50-112
BMC (Polyester)	15-35	1.8-2.1	.065-.075	400-500	300-400	8-12	1.3-1.7	.30-.35	94VO	H80-112
Phenolic	5-25	1.7-1.9	.061-.069	400-500	325-350	4.5-9	1.1-2.0	.20-.30	94VO	M90-99
Diallyl phthalate	20-40	1.6-1.8	.058-.065	330-540	300-400	10-36	0.5-15	-	94VO	E80-87
Melamine	30	1.8-2.0	.065-.072	400	300-400	15-17	1.5	-	74VO	-
THERMOPLASTICS										
Acetal	20-40	1.55-1.69	-	315-335	185-220	19-35	-	-	94HB	M78-94
Nylon	6-60	1.47-1.7	.049	300-500	300-400	11-21	-	.30-.35	94HB	-
Polycarbonate	20-40	1.24-1.52	-	285-300	275	17-18	-	-	94V1	M75-100
Polyethylene (H.D.)	10-40	1.16-1.28	-	150-260	280-300	17-27	-	-	74HB	-
Polypropylene	20-40	1.04-1.22	-	230-300	270-300	16-24	-	-	94HB	R95-115
Polystyrene	20-35	1.20-1.29	.045-.048	200-220	180-200	17-22	-	.25-.35	94HB	M70-95
Polysulfone	20-40	1.38-1.55	-	333-370	-	12-17	-	-	94VO	M85-92
PPO (Modified)	20-40	1.20-1.38	-	220-315	240-265	10-20	-	-	94VO	M95
ABS	20-40	1.20-1.36	-	210-240	200-230	16-20	-	-	94HB	M75-102
SAN	20-40	1.22-1.40	-	190-230	200-220	16-21	-	-	94HB	M77-103
Polyester (thermoplastic)	20-35	1.45-1.61	-	380-470	275-375	24-33	1.3	-	94HB	R118-M70
Polyphenylene sulfide	40	1.64	-	425	-	22	-	-	94VO	R123
Polyvinyl chloride	20	1.49-1.58	-	170-180	400-500	-	-	-	94VO	M80-88
Urethane Elastomer (thermoplastic)	20-40	1.33-1.55	-	200-220	-	14-45	-	-	-	R45-55

Resin system	% fiber glass by weight	Flexural strength psi x 10^3	Flexural modulus psi x 10^5	Impact strength (Izod).ft lb/in notch	Tensile strength at yield psi x 10^3	Tensile modulus psi x 10^5	Ultimate tensile elongation,%	Compressive strength psi x 10^3
THERMOSETS								
SMC (Polyester)	15-30	18-30	14-20	8-22	8-20	16-25	0.3-15	15-30
BMC (Polyester)	15-35	10-20	14-30	2-10	4-10	16-25	0.25-0.6	14-35
Phenolic	5-25	18-24	30	1-6	7-17	26-29	0.25-0.6	14-35
Diallyl phthalate	20-40	11-19	25-33	0.4-15	6-11	14-22	2-5	25-35
Melamine	30	15-23	-	0.6-18	5-10	24	0-5	20-35
THERMOPLASTICS								
Acetal	20-40	15-28	8-13	0.8-2.8	9-18	8-15	2	11-17
Nylon	6-60	7-50	2-26	0.8-4.5	13-33	2-20	2-10	13-24
Polycarbonate	20-40	17-30	7-15	1.5-3.5	12-25	5-17	2	14-24
Polyethylene (H.D.)	10-40	7-14	2-6	1.2-4	6.5-11	4-9	1.5-3.5	-
Polypropylene	20-40	7-11	3.5-8.2	1-4	6-10.5	4.5-9	1-3	6.8
Polystyrene	20-35	10-20	8-12	0.4-4.5	10-15	8.4-12.1	1-1.4	13.5-19
Polysulfone	20-40	21-27	8-16	1.3-2.5	13-20	15	2-3	21-26
PPO (Modified)	20-40	17-31	8-15	1.6-2.2	15-22	9.5-15	1.7-5	18-20
ABS	20-40	23-26	8-13	1-2.4	8.5-19	6-10	3-3.4	12-22
SAN	20-40	22-26	8-18	0.4-4	8.5-20	4-14	1.1-1.6	12-23
Polyester (Thermoplastic)	20-35	19-29	8.7-15	1-2.7	14-19	13-15.5	1.5	16-18
Polyphenylene sulfide	40	37	22	8	21	11.2	3	-
Polyvinyl Chloride	20	15.8-21	8-10	1-1.6	11.8-14	10-18	2-3	9
Urethane Elastomer (Thermoplastic)	20-40	5-7	1.5-3.6	10	5-10	3-7.5	20-30	-

Figure 4-12. Mechanical and Physical Properties of Fiber Reinforced Plastics

Rating	Type	Tensile Strength (10^3 psi)	
		High	Low
1	Glass Fibers	220	200
2	Cellulosic Fibers	155	20
3	Nylon Fibers	128	59
4	Polyester Fibers,	126	67
5	Cotton Fibers	109	44
6	Asbestos Fibers	100	80
7	Polyethylene Fibers	90	11
8	Plastic Laminates, Low Pressure	85	8
9	Acrylic Fibers	57	26
10	Fluorocarbon Fibers	47	-
11	Vinyl Fibers	45	12
12	Vinylidene Chloride	40	4
13	Plastic Laminates, High Pressure	37	7
14	Nylon, Glass-Filled	31	19
15	Polyester, Glass Reinforced	30	-
16	Silicone, Asbestos Filled	28	-
17	Polyester Film	28	17
18	Cellophane	19	7
19	Epoxy, Glass Reinforced	17	-
20	Nylon 6, Film	17	13.8
21	Polystyrene, Glass-Filled	17	11
22	Epoxies (molded)	16	5
23	Polyvinylidene Chloride Film	15	7
24	Nylon 66 and 610	12.6	7.1
25	Epoxies (cast)	12	0.1
26	Nylon 6 and 11	12	8.5
27	Polystyrene Film	12	7
28	Modified Polystyrenes	11	3
29	Polyvinyl Formal	11	9
30	Acrylics (molded, extruded)	10.5	5.5
31	Acetal	10	-
32	Alkyds, Impact	10	6
33	Ethyl Cellulose Film	10	6
34	Melamines, Phenolics (molded)	10	3.5
35	Polyesters (cast)	10	0.9
36	Polypropylene Film	10	5
37	Polyvinyl Alcohol Film	10	6
38	Ureas	10	5
39	Polycarbonates	9.5	9
40	Phenoxy	9.5	9
41	Hard Rubber	9.3	2
42	Phenolics (cast)	9	2.5
43	Polyvinyl Chloride	9	1
44	ABS Resins	8.5	3
45	Cellulose Acetate	8.5	1.9
46	Polyvinyl Butyral	8.5	4
47	Polyvinyl Chloride Film, Rigid	8.5	6.5
48	Acrylics (cast), General Purpose	8	6
49	Cellulose Nitrate	8	7
50	Polyethylene Film	8	1.6
51	Polystyrenes, General Purpose	8	5
52	Cellulose Propionate	7.5	1.5
53	Acrylics, High Impact	7.3	5.5
54	Diallyl Phthalate	7	4
55	Ethyl Cellulose	7	3
56	Cellulose Acetate Butyrate	6.8	1.9
57	CFE Film	6.6	6.3
58	Chlorinated Polyether	6	-
59	Rubber Hydrochloride	6	5
60	Urethane Rubber (gum)	75	-
61	CFE Fluorocarbons	5.7	4.6
62	Polypropylene	5	-
63	Polyvinyl Alcohol	5	1
64	Polyvinyl Chloride Film, Nonrigid	5	1
65	Silicones (molded)	5	4
66	Natural Rubber (blakc)	4.5	3.5
67	Nitrile Rubber (blakc)	4.5	3
68	Polyethylene, High Density	4.4	2.9
69	Polyallomer	4.2	3.5
70	Alkyds, General Purpose and Electrical	4	3
71	Neoprene Rubber (blakc)	4	3
72	PVC - Nitrile Rubber Blend Film	4	1.5
73	Styrene-Butadiene Rubber (black)	3.5	2.5
74	TFE Fluorocarbons	3.5	2.5
75	Butyl Rubber (black)	3	2.5
76	TFE Film	3	2
77	Polyethylene, Medium Density	2.4	2
78	Viton Rubber (gum)	2	-
79	Fluorinated Acrylic Rubber (gum)	1.2	-
80	Urethane Foamed-in-Place, Rigid	1.2	0.01
90	Polysulfide Rubber (gum)	1	-
91	Silicone Rubber (gum)	1	0.6
92	Polyethylene, Low Density	0.9	0.5
93	Polyethylene Foam, Flexible	0.67	-
94	Prefoamed Epoxy, Rigid	0.65	0.05
95	Vinyl Foams, Flexible	0.2	0.01
96	Prefoamed Polystyrene, Rigid	0.19	0.03
97	Prefoamed Cellulose Acetate, Rigid	0.18	0.11
98	Polystyrene Foamed-in-Place, Rigid	0.13	0.03
99	Neoprene Foams	0.01	0.02
100	Butadiene-Styrene Foams	0.08	-
101	Phenolic Foamed-in-Place, Rigid	0.075	0.004
102	Butadiene-Acrylonitrile Foams	0.04	-
103	Natural Rubber Foam	0.02	0.01

Note:

a. Values represent high and low side of a range of typical values. Conversion Factor: to obtain °C, subtract 32 and multiply by 5/9.

b. Values represent high and low sides of a range of typical values at room temperature. Strength varies greatly with different fillers and reinforcements. Nylon, for instance, varies from 7,000 to 30,000 psi, depending on type and filler.

Figure 4-13. Tensile Strength[a] of Common Matrices and Reinforcements

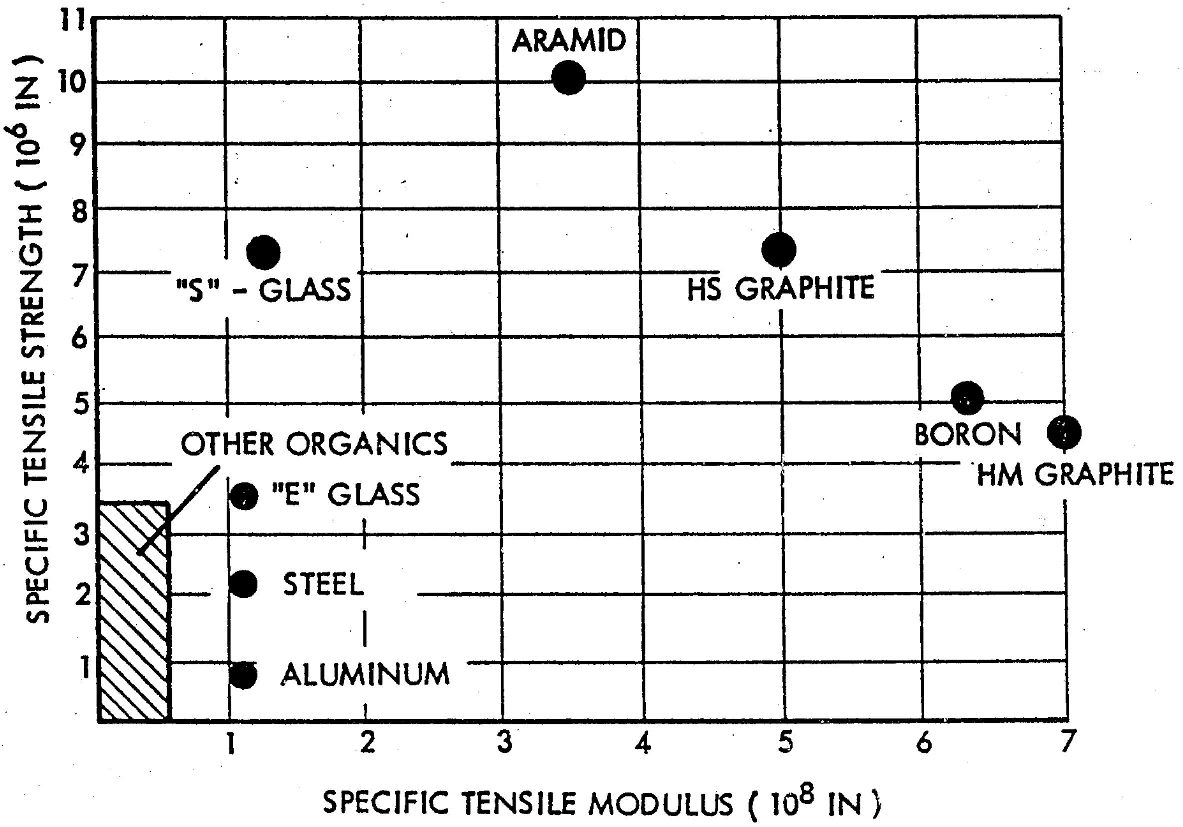


Figure 4-14. Specific Tensile Strength versus Specified Tensile Modulus for Various Material Systems

4. Cost-weight-performance merit function assessment, to illustrate the change in "merit" of a structure when a material is substituted, at some postulated acceptable cost increase for a performance increase.

Strength, stiffness, damage tolerance, and life are primarily reflected in the weight of each material system concept, while materials and manufacturing methods are reflected in the cost of the concepts. In addition to weight and cost efficiencies, performance factors such as technology advancement, margins on integrity, and reliability must be considered in total in the final selection of a concept exhibiting the greatest payoff. To assist in the evaluation of candidate material system concepts and in the identification of optimum concepts, a quantitative and objective concept rating procedure will be established and utilized.

Weight, cost, and the aggregate of factors labled "performance" will be considered in all concept evaluation effort. A method of determining which of the candidate concepts offers the best structural and manufacturing cost relationship is necessary to provide a criterion for selection of the concept that optimizes weight, cost and performance. A simple approach to relating performance, weight, cost and weight/cost tradeoff value by use of "merit function" is described by:

$$\Phi = W + C/V + C/P$$

where,

Φ = Weight-cost performance merit function

W = Weight of structural concept, lbs.

C = Unit Cost of structural concept, dollars per pound

V = Weight/Cost tradeoff value, dollars/lb of weight saved

P = Performance/Cost tradeoff value, dollars/unit performance improvement score per paragraph 2.3.2

With estimated normalized values of W and C and P, values of Φ may be calculated for various values of V and P and/or plotted as shown schematically in Figure 4-15. It is then left to the structure user to determine the value he places on a decrease in weight or increase in structural

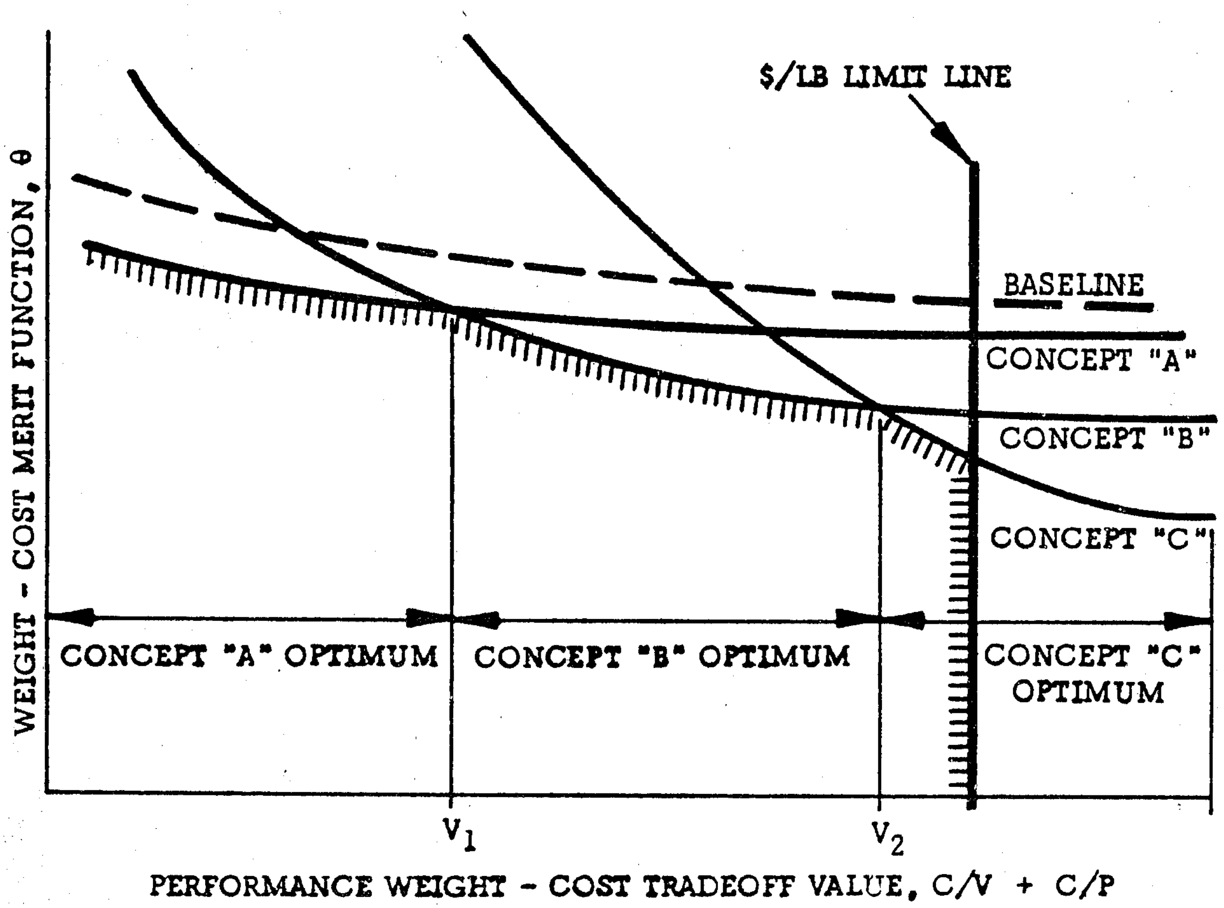


Figure 4-15. Typical Weight/Cost Effectiveness Plot

performance.

For a given performance weight/cost tradeoff value of C/V + C/P, the concept with the minimum merit function is the optimum design. Figure 4-15 shows schematically how the merit function can vary over a wide range of tradeoff values for different concepts. Concept A is performance-weight-cost effective up to tradeoff values V_1. Concept B becomes cost effective from V_1 to V_2. Concept C is not cost effective until the tradeoff value exceeds V_2. This type of plot will be utilized to assist in establishing the ratings of the candidate concepts.

4.4.3 Evaluation Process Summary

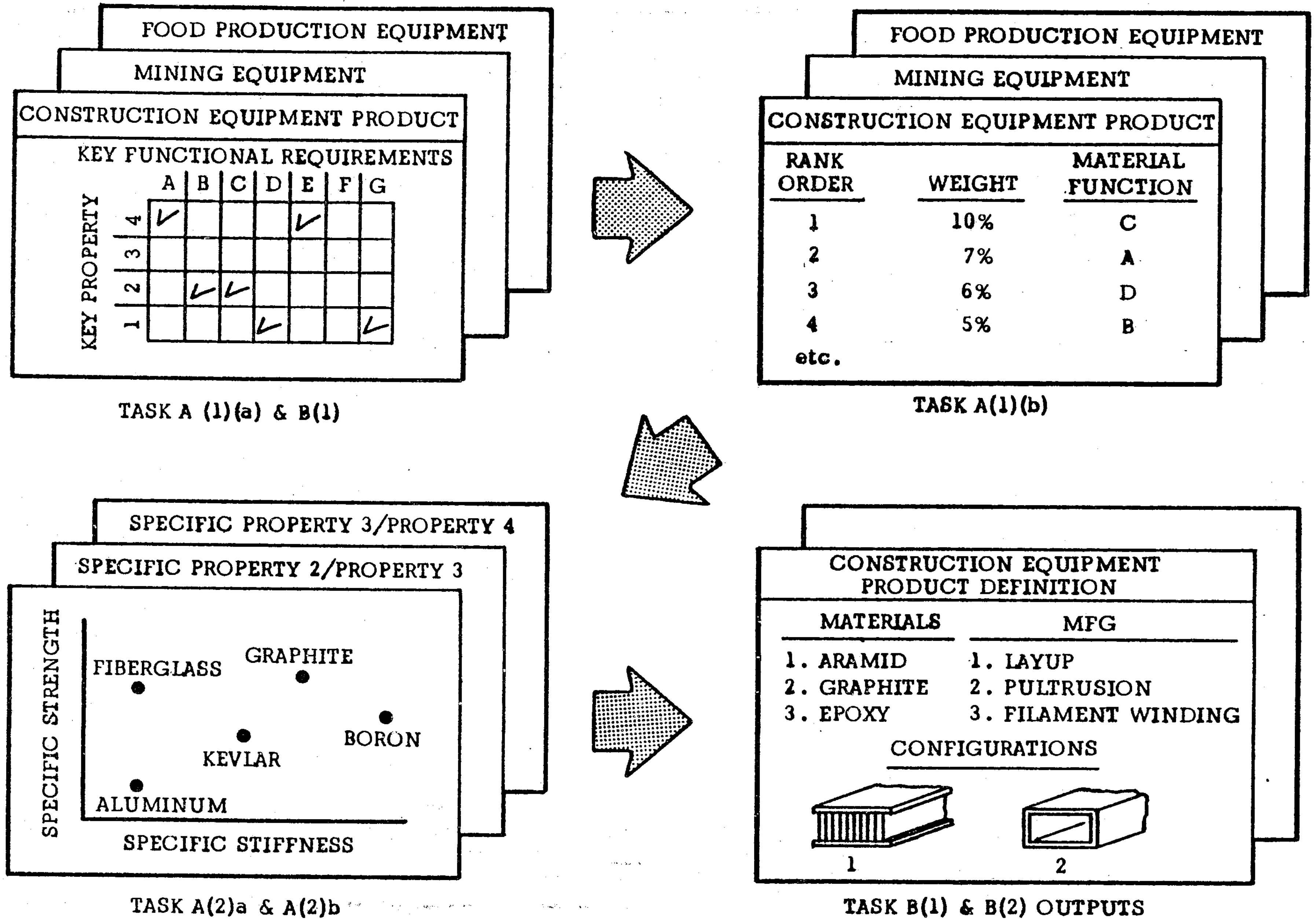
Figure 4-16 summarizes the material and production system evaluation process described above. It will result in an array of potential applications for advanced composites, with forecast discrete advancements in material and/or production system technology. The related cause-effect impact analysis of traditional and legislated standards is discussed later in Paragraph 4.6.

4.4.4 Example of Evaluation

Appendix III is a detailed example of the process described in Paragraphs 4.4.1 and 4.4.2, for a possible composite-material application. In summary, functional considerations in mine temporary roof support were used to identify the following characteristics of the product that are over and above those of supporting a dead load:

Function	Product Characteristic
1. Mobilization	1. Light Weight
2. Interface - Structural	2. Shallow Beam Depth
3. Load Bearing Interface	3. Contoured Beam
4. Environment Interface	4. Damage Resistance

As noted in the Appendix, the superior technical choice was an advanced composite. Cost and manufacturing problems, under the current state of technology, indicated aluminum as the preferred solution. However, with the following highly probable advancements and/or changes in relevant technology,



TASK A (1)(a) & B(1)

TASK A(1)(b)

TASK A(2)a & A(2)b

TASK B(1) & B(2) OUTPUTS

Figure 4-16. Schematic of Task Outputs (Material and Product Assessments) advanced-composite beams would probably capture a significant share of the approximately 200,000 beam-per-year market:

1. Cost analysis approach by mine owners that would more strongly favor total cost of ownership, or cost/benefit factors.
2. Legislated requirements for use of non-conductive lightweight beams, for safety.
3. Improvements in filament winding techniques to allow lower production costs.
4. Lower cost composite fibers.

Finally, with the postulated technology advancements in mind, the impacts and issues from this new use of composites would become more evident and be seen to include the following:

1. Mine productivity
2. Mine safety
3. Union attitudes on labor practices and crew sizes
4. Funding availability for beam acquisition
5. Legislation requiring beam usage
6. New market for filament winding machines and workers
7. Market decrease for wood beams
8. Mine engineer's knowledge required to properly use new beams.

From even this cursory list, second order impacts on the industrial system become evident.

4.4.5 Technology Advancement Forecasts

As noted above, a basic advanced composite usage-predictor element to be used is the prediction of relevant technology advancements or changes that will fill the gap between a functionally-determined need and an available material or production system. An overall approach to rationalizing the predictions and postulations is as follows:

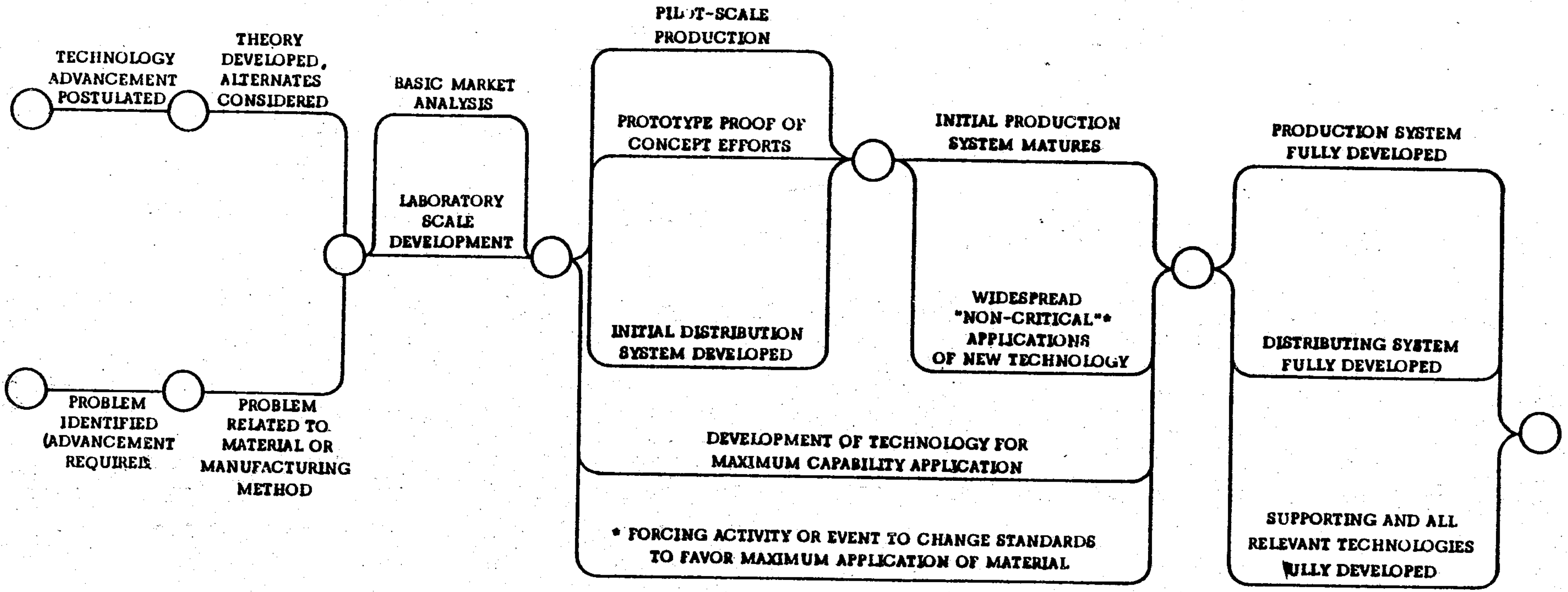
1. Predictions-types and timing. These will be an integration of the predictions of others, formalized by documentation and correlation during the study. Further comments on benefits and dangers of use of secondary-source information are presented in Paragraph 4.5.
2. Postulated advances - types and timing rationalized by analogy and trend correlation.

In the traditional and legislated standards elements of advanced composites technology, trend extrapolation will be the forecast method. The five classes of forecasting methods, using the system of Reference 3 are:

1. Intuition (i.e., such as Delphi)
2. Trend extrapolation
3. Trend correlation
4. Statistical models
5. Analogy

Figure 4-3, presented a summary-level technology advancement process and time cycle for aluminum, and made an analogy to the corresponding cycle for composites. During Phase II, this analogy will be further examined and individual process and time-cycle charts will be developed for matrices, fibers, fiber forms, manufacturing methods, labor source development, material source development, technology-development infrastructure, and for supporting elements for the relevant technology such as inspection methods, distribution channels, and financing.

Figure 4-17 shows a more detailed version of the technology advancement cycle summarize in Figure 4-3. The origin of an advancement can be technology driven or problem driven. Acknowledging that the version shown is somewhat simplistic, omitting sub-loops and more-complex dependents known to exist, nevertheless, the basic dependencies are analogous to the observed process for aluminum and current state of the art reinforced plastics. Time estimates (by analogy) can be adjusted to examine alternate scenarios. The postulated advancement of problem-in process-of-being solved will be placed on the timeline by analogy, and time-remaining forecast by analogy.



*SEE PAGE 76 FOR DEFINITIONS AND EXAMPLES

Figure 4-17. Advanced Composites Technology Advancement Process

In Figure 4-17, the term "non-critical application" is used to describe a material system or production system application which is either (1) limited in market size somewhat; or (2) uses only a small number of the beneficial properties of the process or material. A "forcing activity" could be an external event that changes standards. Examples of these definitions are:

	Aluminum	Composites
1. Non-critical application	o Pots and pans o Component of paint	o Sporting goods o Patio covers
2. Forcing event	o World War II	o Energy shortage

4.5 STEP 2B: STRUCTURE EXISTING DATA AND FORECASTS

Referring back to Figure 3-1, Basic Approach Alternates, the use of existing data and forecasts for technology definitions and state-of-society assumptions was indicated. Figure 3-5, Additions and Interpretations of Basic Technology Assessment Methodology, showed the intended use of basic existing information as the starting point in identifying impact areas and performing preliminary and complete impact analysis. This approach has the following major benefits:

1. Capitalizes on an extensive existing data base, which frees technology assessment resources for application to future rather than retrospective efforts.
2. Uses existing definitions of terms and methods, which will ultimately make the technology assessment information transfer to the specialist end of the spectrum more efficient and convincing.

The procedure has also been used, almost of necessity, because all-new source data, at the beginning of this technology assessment, would be massive because of the large and dis-aggregated nature of both the relevant technology and the production/regulatory infrastructure.

The approach was selected in spite of full awareness of the pitfalls of using secondary references for a data base. Reference 33 , "Some Fallacies in Futures Research", discusses this aspect, pointing out that "technology assessment (using) the existing data base is .... building on quicksand", and that other dangers exist in futures research.

Nevertheless, the existing data will be used, and original source data will be pursued only during Step 7, Complete Impact Analysis, in areas of particular opportunity developed during the study process.

The Step 2B major effort will be structuring and screening information. Information acquisition is essentially complete in the sense that either (1) information is in hand (i.e., see Appendix I, References and Bibliography), or (2) sources producing recurring reports of interest are identified, contacted, and a continuing screening effort is in progress (i.e., see Appendix II, Contact Summary). The structure used for the data base will be an index formatted to match the relevant technology definition described in Section 2.

4.6 STEP 3: DEVELOP STATE-OF-SOCIETY ASSUMPTIONS

The development of state-of-society assumptions involves the following:

1. Identifying major and specific categories of state-of-society attributes.
2. Defining the attributes
3. Selecting units of measure for each attribute.

The following discussion presents an initial identification of attributes, and examples of measurements of the attributes. There appears to be a fairly direct effect on advanced composite technology of well accepted state-of-society attributes. Phase II effort in this area will be (1) a more detailed and extensive identification of attributes, (2) a rationalization of the attributes by use of trend extrapolation, which is a forecast based on the assumption of the continuation into the future of some discerned past trend.

4.6.1 Major State-of-Society Attributes

Major attributes are subdivided into (1) threshold attributes, and (2) national conditions. Table 4-5 is a composite from References , ,

TABLE 4-5 MAJOR STATE-OF-SOCIETY THRESHOLD ATTRIBUTES

Attribute	Measure Related to Advance Composites
1. There will be no major war in the period studied but U.S., NATO, and Japan will continue upgrading and standardizing weapons, including joint development and manufacture.	• Number and type of weapons replaced in time period that use composites.
2. There will continue to be a gradual shift in the balance of power between government and private decision-making towards federal and state government.	• Increase in number of regulations and laws that relate at least indirectly to material usage and product performance.
3. Worlwide political and economic situation will continue to keep oil prices and/or supply sources essentially in the same status as today.	• Oil price • Percent of U.S. energy supplied by oil • Total domestic oil consumption and percent foreign-supplied.
4. Foreign industrial competition and oil prices will provide an increasing national incentive to find alternate energy sources and to increase industrial productivity.	• Increase in number of regulations that relate to product resource consumption and recycling. • Increase in tax incentives or other premiums for recycling and low resource consumption and for introduction of new machinery.
5. While relative population proportion of affluent vs. non-affluent will remain stable, a larger percent of income from all population segments will be spent on leisure activities.	• Relative increase in percent income spent on leisure products such as tennis rackets, boats, golf clubs, etc.
6. U.S. leads the way in voluntary self-imposition of rigorous standards of pollution control and occupational safety.	• Increase in number of regulations relating to environmental quality.

of threshold attributes. Table 4-6 is a composite of national conditions. An intuitive trend extrapolation was used to rationalize these assumptions. The measurements of the attributes will be refined in Phase II.

4.6.2 Specific Categories of Attributes

Below the gross-level attributes there are many facets of society that will affect how much impact a particular technology will have. A classification system suggested in Refernce 3 is:

1. Values and goals
2. Demography
3. Environment
4. Economics
5. Social Factors
6. Institutional factors

A detailed checklist of sub-attributes is also presented in Reference 3 and is considered to be suitable for use in Phase II. The concept of categories of attributes is also extended into the realm of micro-level attributes, and for the state-of-society is the interface between society and the relevant-technology boundary. An example of the hierarchy of attributes is presented in Figure 4-18. The interface with advanced composites technology is shown and in the example the state-of-society micro-level attributes tend to accelerate the establishment of advanced technology. Figure 4-19 is an example of the hierarchy of state-of-society attributes that would discourage more extensive introduction of advanced composites.

From a technology impact and action option standpoint, both figures also suggest the issues that can be raised if technology is forecast to advance, i.e., assuming an available improved technology is possible, such as lightweight, producible composites, should the government and industry subsidize its introduction or legislate its introduction? If so, should equal treatment be given to competitive material? With a new materials hazards known, such as toxicity and flammability of matrices, and abrasiveness and conductivity of fibers, should standards be relaxed to obtain other benefits of composites?

TABLE 4-6 MAJOR STATE-OF-SOCIETY NATIONAL CONDITIONS

Attribute	Measure Related to Advanced Composites
1. U.S. population in 2020 will be approximate 325 million.	● Number of consumers.
2. GNP will increase annually by 3% after adjusting for inflation.	● GNP growth rate.
3. Federal spending will shift by about 2% per year into civilian programs.	● Percentage and dollare increase into civilian programs.
4. Federal spending will increase by about 5% per year on energy safety, industrial, health and productivity research.	● Dollar increase, by type of program.
5. The national, state, professional-society, and educational-system originated standards for product safety, efficiency, biodegradeability, and occupational and user health will result in an increasing percent of product cost attributable to these factors.	● Percent of product costs attributed to those factors. ● Dollar value of those attributes.
6. The fraction of occupationally trained students of total student output will remain the same.	● Number of candidates annually for design and manufacturing-related occupations.
7. Developing energy self efficiency will continue to be encouraged by cost-sharing by government for major capital projects, and legislation favoring domestic energy source development.	● Dollar amount for construction attributable to national energy goal.

Continued ...

TABLE 4-6 MAJOR STATE-OF-SOCIETY NATIONAL CONDITIONS (Continued)

Attribute	Measure Related to Advanced Composites
8. Federal government and state government will, by legislation, subsidies, and by paying premium prices , attempt to limit further aggregation of manufacturing, service, and educational enterprises, either by horizontal or vertical integration.	● Profile of business size (sales, capitalization, employees) versus number of businesses.
9. Federal government and state government will attempt to limit further movement of industrial concentration from state-to-sate.	● Businesses, and size-of-businesses-profile, state-by-state.

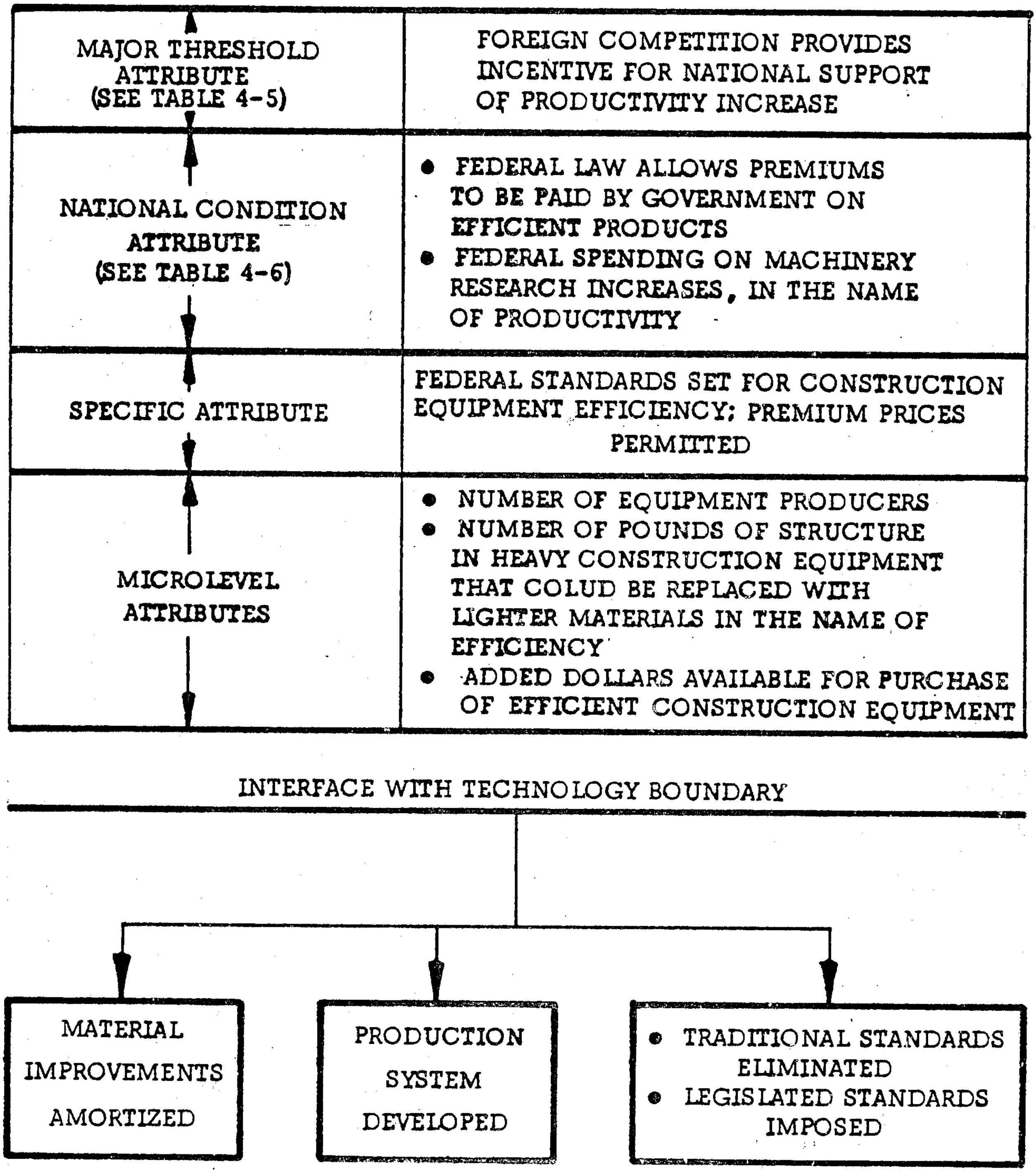


Figure 4-18. Example of Micro-Level Society Attributes on Technology - Acceleration

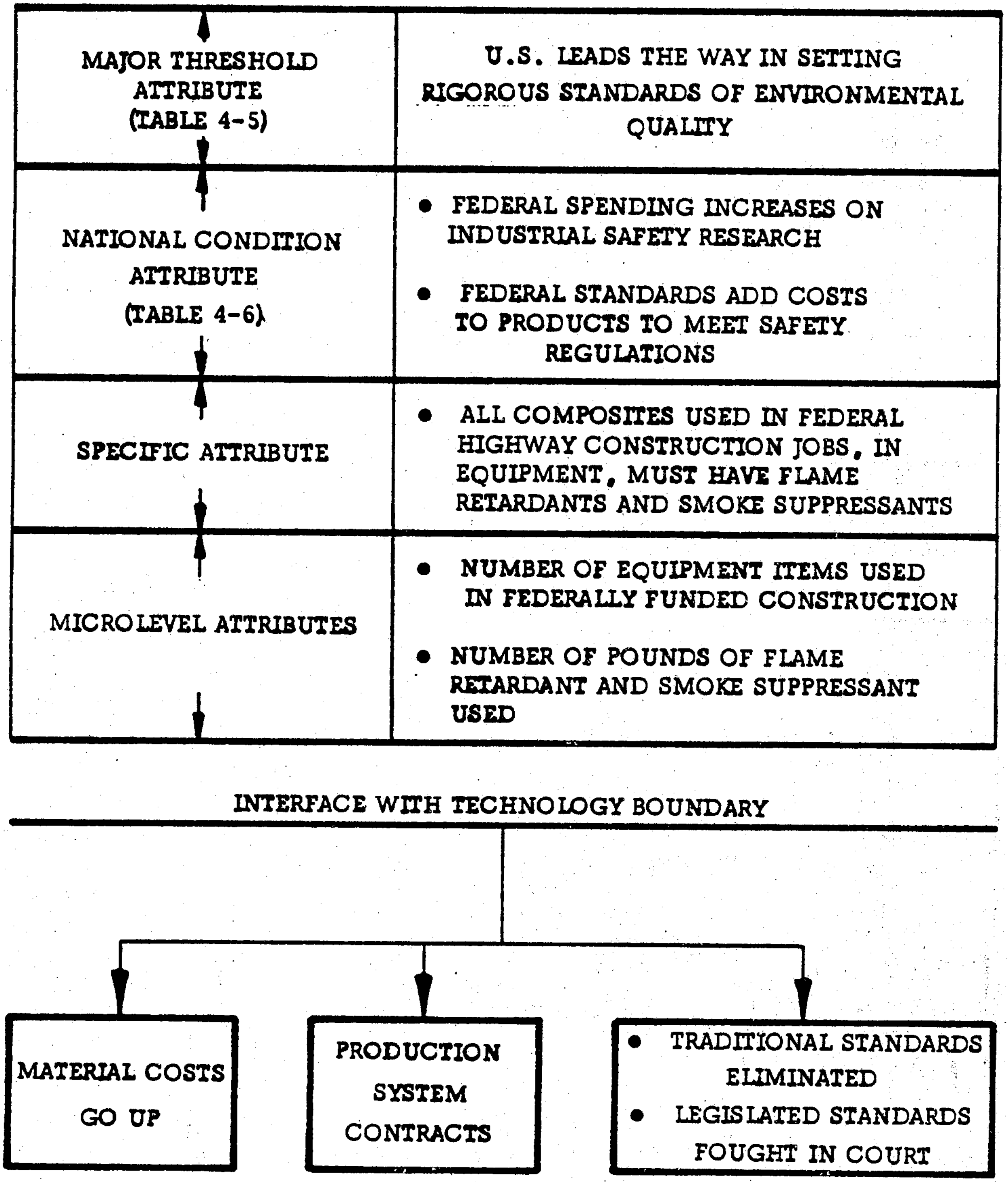


Figure 4-19. Example of Micro-Level Attributes on Technology - Deceleration

Should metallics designers be retrained? Should a disposal surtax be placed on composites?

The joint use of the state-of-society attributes and the relevant technology boundary to identify impact areas and perform an impact analysis is discussed in the following paragraphs.

4.7 STEP 4: IDENTIFY IMPACT AREAS

The identification of impact area task comprises the following:

1. Identifying the overall categories of impacts
2. Further subdividing the categories into types and sub-types.
3. Selecting units of measure for the impacts
4. Establishing a process for systematically cycling through the combinations of relevant technology possible advancements and deciding which impact areas will be involved.

Items 1, 2, and 3 above are the same steps used to establish state-of-society attributes. Reference 3 suggests that the overall categories of impacts be parallel to the state-of-society specific categories, and further subdivides the categories into types and subtypes. The categories and types from Reference 3 are repeated as Table 4-7. For the purpose of Phase II, several types are added to the Reference 3 basic list:

1. Financing (Economics)
2. Educational (Institutional Factors)
3. Industrial Organization

The impact areas can be further subdivided into micro-level categories. For example the industrial organization impact area type can be subdivided into material production system organizations and structure production system organizations. On a micro-level, the structure production system will be further subdivided into service and product-oriented categories, by screening the one thousand Federal Government Standard Industrial Classification code.

TABLE 4-7
MAJOR IMPACT CATEGORIES

Categories	Types
Values and Goals	Personal Community National Other
Environment	Air Water Open Space Quiet (Noise) Olfactory Weather Sunlight
Demography	Total Major Segments Rates
Economics	Production Income Employment Prices Trained Manpower Natural Resources Inventory Financing
Social Factors	National Security Economic Growth Opportunity (Class Relations, Poverty) Health Education Safety (e.g., Crime) Transportation Leisure-Recreation Other Amenities
Institutional Factors	Political Legal Administrative Industrial Organization Custom-Tradition Religious Educational

4.7.1 Identifying Impacts

The developed impact area list will be used as a checklist to identify possible impact areas for each path or sequence of projected technology advancements. This is essentially what is suggested in Reference 3.

The process of cycling through all combinations of possible technology advancements and deciding which advancement will lead to an impact is a three-path process, because of the boundary chosen to enclose the relevant technology. This is because impacts can result from expanded use of the material, changes in the product production system, and also from the resultant different product performance. Figure 4-20 illustrates the parallel paths to the overall impact categories. If (1) the institutions involved in composites were more aggregated, and if (2) the product use potential, even on a direct-substitution basis, was not as broad, the approach suggested in Reference 3 might suffice, ".... the common sense rule is that the impacts that appear to be the largest and most sensitive should be researched most thoroughly". Yes-no decisions will be made in Phase II, and in effect will say that "if a product was improved it would be used, there would or would not be an impact".

A parallel effort, described in Paragraph 4.4, will be conducted to rationalize the yes-no decisions, on a product generic basis; therefore, the "if a product was improved" assumption will be validated by studying the question "can a product be improved and will it be used?"

4.7.2 Significance of Identified Impacts

The expected result of the impact area identification is that there will be a tremendous number of possible impacts that, individually, seem to be relatively minor in magnitude because other parallel technology advancements may seem to be overriding in importance.

For example, even an optimistic projection (References 42, 44) of total composites usage in the automobile industry would only displace four percent of the metallics currently used and reduce structural weight by an additional five percent over 1977 weights, and contribute only two percent of

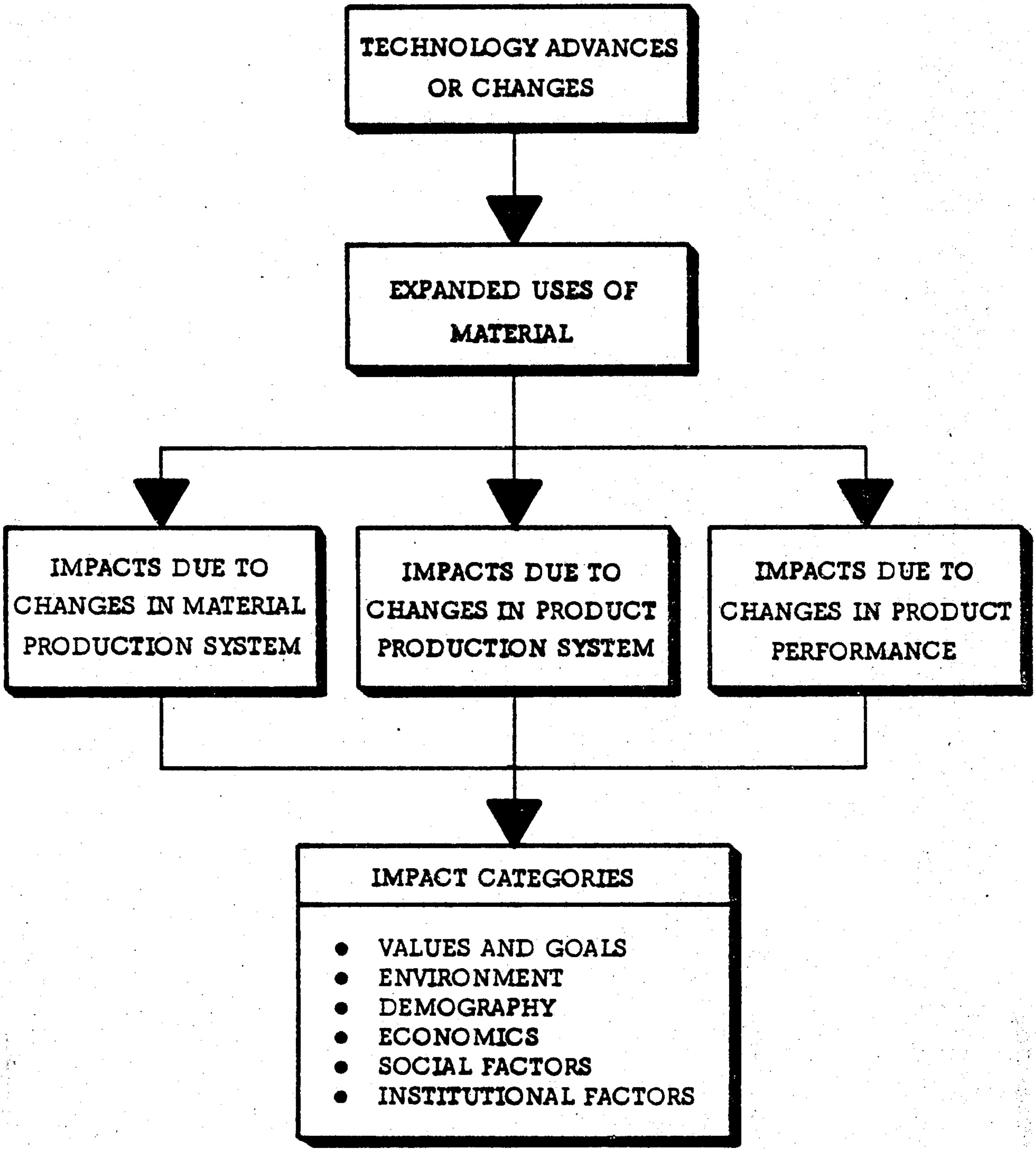


Figure 4-20. Divergent Paths to Impacts

the fuel consumption decrease. The majority of fuel savings is attributed to overall car size reduction and engine modifications. Increased use of composites is less than the forecast increase in non-reinforced plastics usage and aluminum. Does this support that a technology assessment is more in order for aluminum and carburetors? Not when it is considered that total auto composites usage will be significant (i.e., millions of pounds) annually and impacts should be added to those in many other applications, mostly non-automotive. This quantity of material usage, although a small percent of total automobile usage of material, would create major needs for capital investment in composites production, and probably drive technology development in a very broad and rapid manner. Many new industrial participants would enter the market.

Accordingly, potential issues involving safety and productivity would be major. The test of this proposition is the selection of impact measurements and a detailed impact analysis.

Similarly, there are many possible advanced composite applications which are very large in magnitude within a product area, but where those national impacts seem limited or trivial. For example, Table 4-8 analyses some qualitative impacts that might be associated with a major penetration of the fishing rod market by advanced composites of lower costs. These could almost completely displace fiberglass and bamboo rods not only because of superior feel, action and weight. However, the existing production system is already directly accommodating a change of material with no new entries or exits. The impact of making thousands of fisherman slightly happier but poorer is probably of little national importance. Even the assumption of more fisherman because rods are better, seems debatable, so that environmental effects noted on the table are somewhat doubtful. Further, even with all sporting goods applications totaled, the total usage would probably not significantly affect material prices. (i.e., only thousands of pounds, annually).

In summary, looking at individual composites in isolation may suggest some misleading conclusions.

TABLE 4-8 EXAMPLE: POSSIBLE IMPACTS FROM A SPECIFIC PRODUCT - FISHING RODS

Categories	Types	Possible Impact
Values and Goals	Personal	More personal enjoyment from fishing
	Community	None
	National	None
Environment	Air	More travel to fishing areas
	Water	" " " " "
	Open Space	" " " " "
	Quiet	" " " " "
	Olfactory	" " " " "
	Weather	None
	Sunlight	None
Demography	Total	None
	Major Segments	None
	Rates	None
Economics	Production	Slight Increase
	Income	Same per capita involved
	Employment	None
	Prices	Slightly higher
	Trained Manpower	None
	Natural Resources	Small change because fiberglass or composites usage for rods is small percentage of total.
	Inventory	
	Financing	None
Social Factors	Per Table 4-7	None
Institutional Factors	Per Table 4-7	None

4.8 STEPS 5 AND 7: PRELIMINARY AND COMPLETE IMPACT ANALYSIS

The overall impact analysis task includes the following steps:

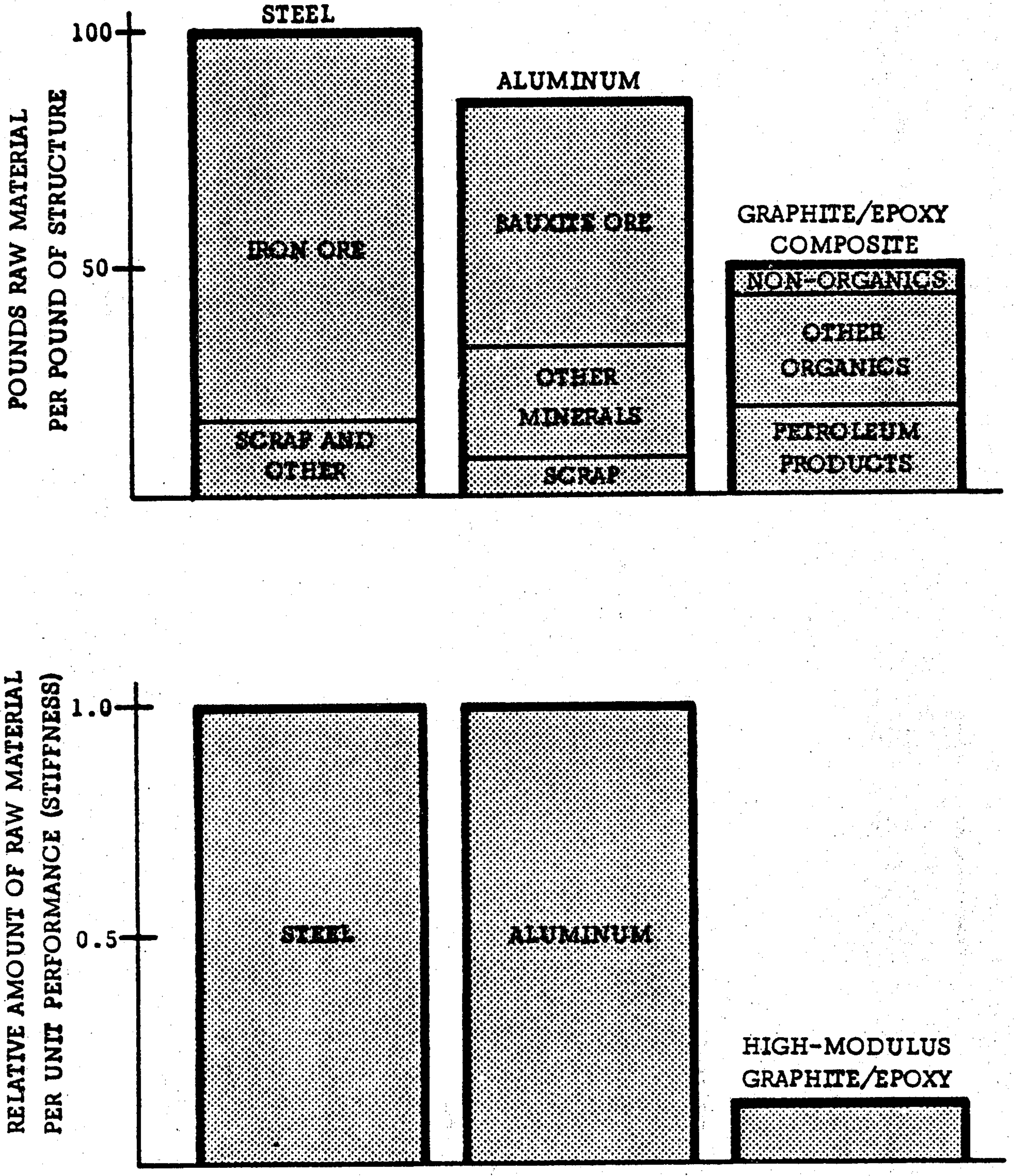
1. Establish one or more measurements of impact for the areas identified in Step 4. This is Step 5.
2. Estimate the quantities of composites usage, machinery required, labor required or eliminate, financing required, and other appropriate measures that apply to the particular technology advancement and application, in each applicable element of the relevant technology. Similarly list the specific changes in standards that are involved. This comprises Step 5A.
3. Sum the impacts for each composites advancement and do the same for each similar application. Summation will be on both an industry and a national basis. This is Step 7.

A decision to be made at this point is, what level of impact is significant, in the sense that an action should be considered. Discussion of this is covered in Step 8, Utilization Plan.

It is understood that impacts should be traceable and should correlate with (1) quantity of usage of material system components, (2) number of products affected, and (3) performance changes in products. This correlates to Figure 4-20, showing that impacts die to expanded use of materials in the material production system and product production system are material-quantity sensitive. Impacts due to changes in product system are also sensitive to number of products. Those due to changes in product performance can be related to weight, but also be sensitive to other characteristics, such as listed in Figure 4-11.

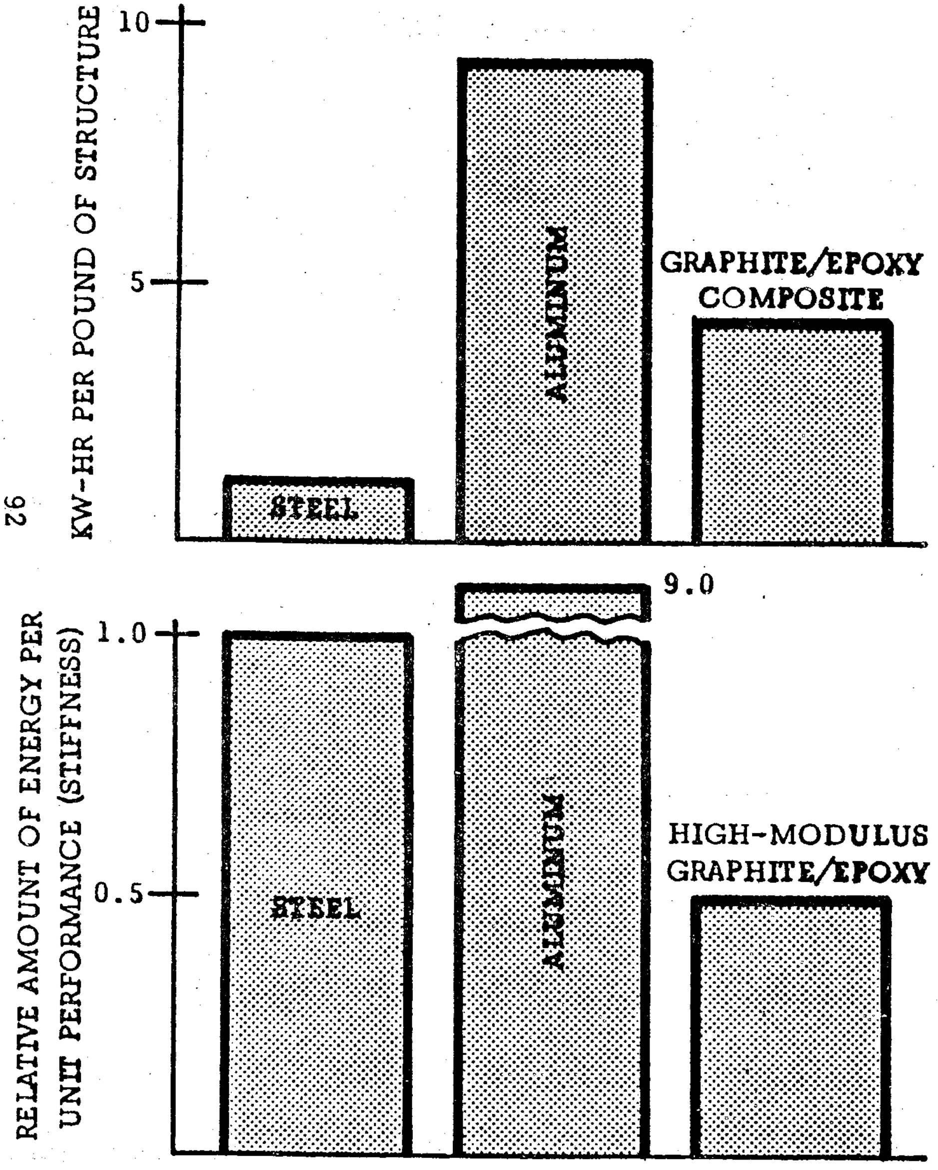
On a macro-level, there are a number of well-accepted parameters for measuring the impact of an increase or decrease in material usage. Several are shown in Figures 4-21 through 4-25:

1. Figure 4-21 suggests a measurement of national impact, based on material usage, transportation requirements, displacement of earth in mining, and other raw-material related impacts or decreases of raw material usage as a function of composites substitution for metallics.



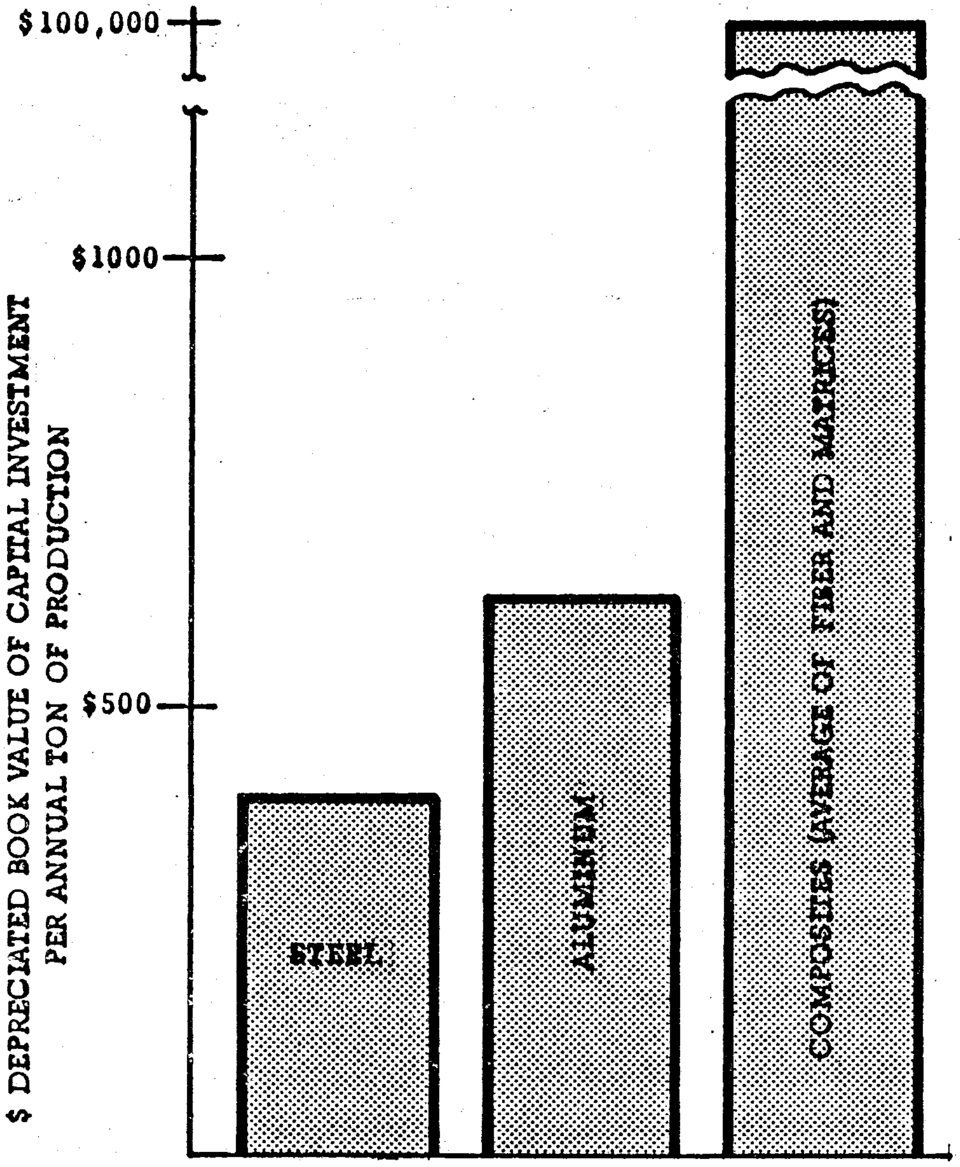
*BASED ON REFERENCE

Figure 4-21. Comparison of Raw Material Quantities Used for Structure* (Not including Energy Input for Processing)



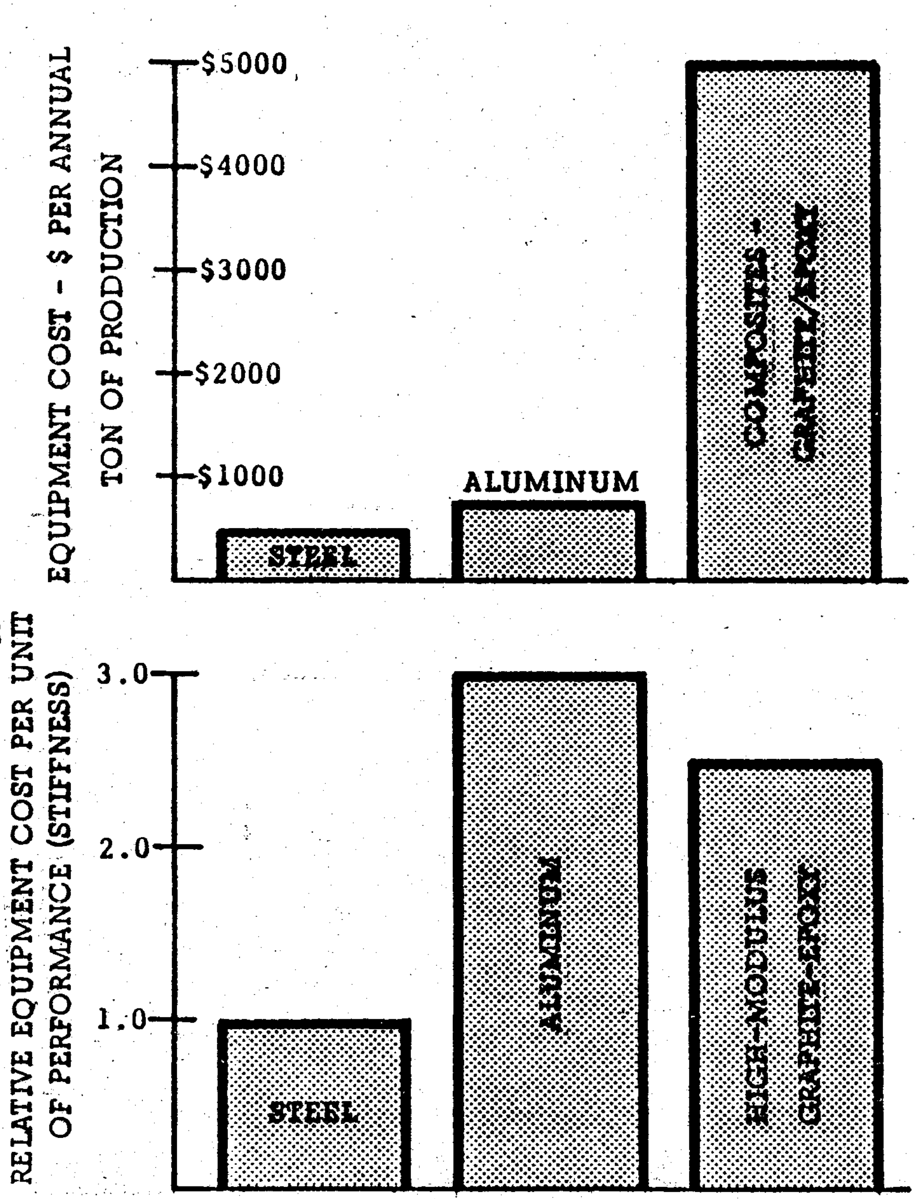
* BASED ON REFERENCE

4-22. Comparison of Energy Input *Used for Material Production



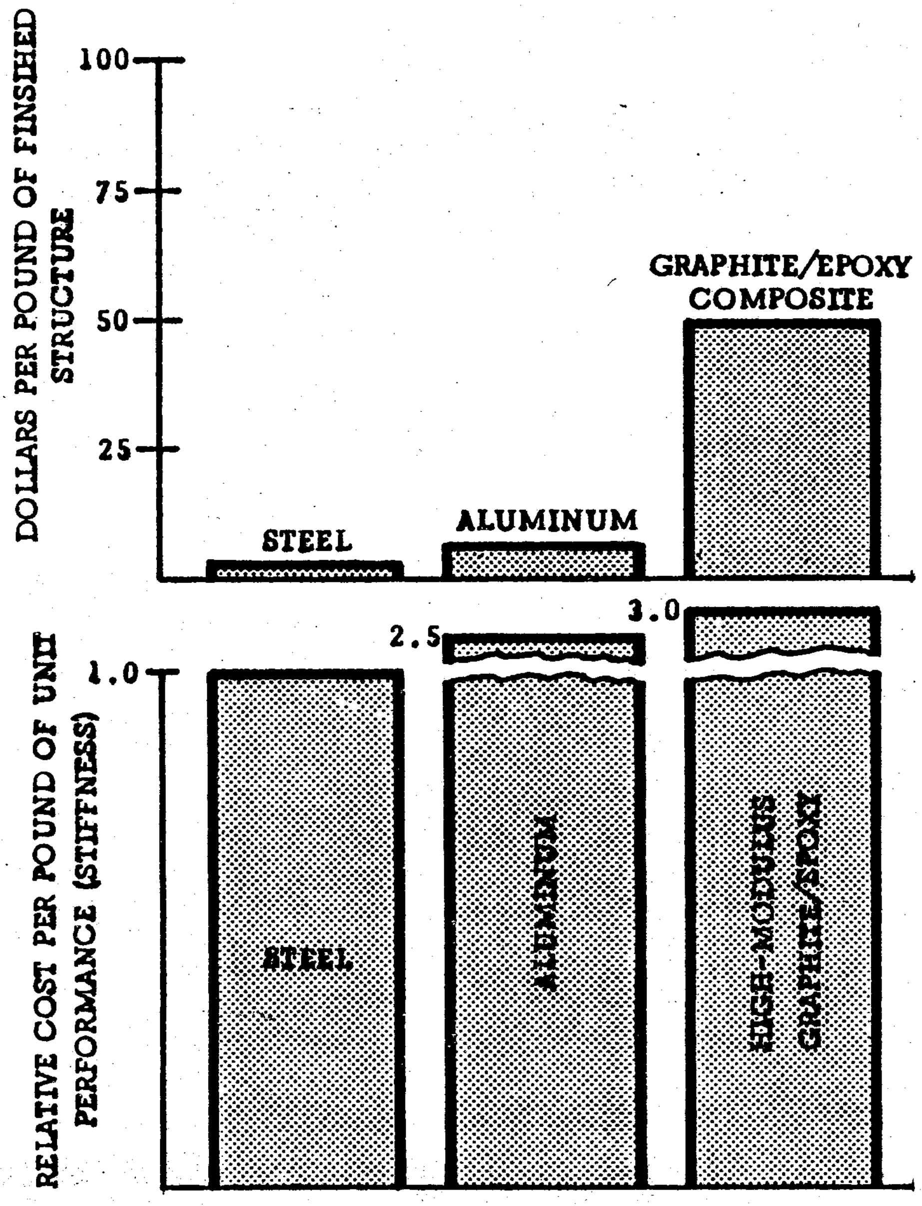
*BASED ON REFERENCE

Figure 4-23. Comparison of Investment Cost for Material Production*



* BASED ON REFERENCE

Figure 4-24. Comparison of Investment Cost for Structure Production*



* BASED ON REFERENCE

Figure 4-25. Comparison of Structure Production Costs *(1977 Prices)

2. Figure 4-22 implies a national-level impact measurement on production energy usage of composites substitution for metallics.
3. Figure 4-23 suggests the gap to be filled in production technology for composites to bring its production costs down. When it is considered that steel and aluminum are produced at a rate of about 140 million tons per year, compared to about 1/2 million tons per year of all composites, including fiberglass, a significant capital requirement would be created if extensive material substitution is to be accomplished.
4. Figure 4-24 shows a similar national measure of investment impact for structure production.
5. Figure 4-25 compares structure production costs; significantly, for the baseline structure used in this cost comparison (see Appendix III), graphite/epoxy is already comparable to aluminum.

Similar comparisons can readily be made for numbers of employees, number of producers, for the various primary types of composites. The overall point illustrated with foregoing examples is that composites impacts based on usage must consider structural performance (stiffness , in the examples shown), not just pounds on a direct substitution basis. As with the application analysis, a functional analysis of potential products must be the starting point in quantifying impacts.

4.9 STEP 6: IDENTIFY POSSIBLE ACTION OPTIONS

An action option is defined as a possible public or private intervention into a technology development and application process in an effort to accelerate, slow, or redirect its apparent course.

Figure 2-26 is a matrix of potentially controllable types of impacts, and of action options. Because, frequently, one person's problems are another's opportunities, the action options will be placed accordingly. Opportunities are impacts where intervention would make it possible to maximize benefits of anticipated new technology. Problems are impacts where intervention might lesson or offset the anticipated bad results of a new technology.

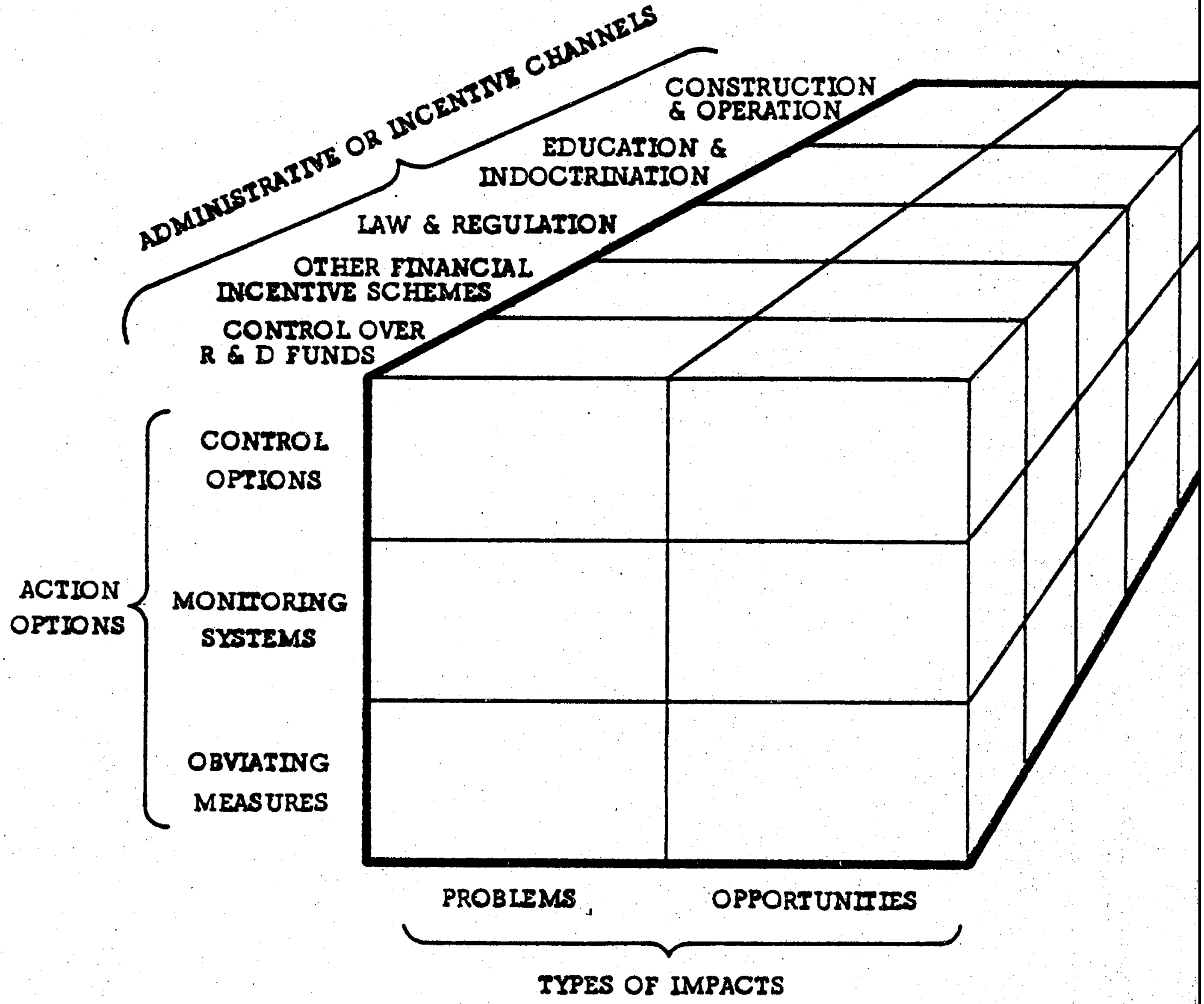


Figure 4-26. Action Options and Channels

The purpose of a control option is to accelerate or decelerate an anticipated technology application. A monitoring system tracks or measures an anticipated application, to minimize uncertainty regarding technology impacts. An obviating measure counteracts the impacts of a technology rather than trying to control it.

Figure 4-26 also identifies five general channels through which an action option can be implemented:

1. Control over R&D funds
2. Other financial incentive schemes
3. Laws and regulations
4. Exhortation and indoctrination
5. Construction and operation.

Table 4-A is a further breakdown, by administrative channel, of many specific mechanisms for action. In the composites field there are already some unusual uses of certain action options that affect composites, such as:

1. Premiums paid for military aircraft parts based on pounds of weight saved.
2. Limits on production-technology information transfer back to countries from whom composite fibers are purchased.
3. Mandatory gasoline economy standards.
4. Banning from sanctioned track and field competitions the use of vaulting poles made of composites.
5. Government funding of structural optimization computer programs for composites.

Another point regarding Figure 4-A and Table 4-A is that the action mechanisms and action channels shown are generally available on a number of levels:

1. National
2. State
3. Local
4. Industry-wide
5. Company

TABLE 4-A
TYPICAL MECHANISMS FOR ACTION

Major Categories	Classes
Control over R&D Funds	Priority (whether something is funded) Allocation (how much it gets funded) Purpose (funds ear-marked as to specific use) Matching Grants
Other Financial Incentive Schemes	Taxes (to discourage use) Tax Deferment or Abatement Subsidies Depreciation and Depletion Allowances Government Grants or Contracts Loans on Favorable Terms Compensation for Damages Off-Peak, Load-Leveling Schemes College Scholarships
Law and Regulations	Legislation Court Decisions, Injunction, etc. Cease and Desist Orders Licenses Monopoly Privileges Mandatory Standards State Police Powers Eminent Domain Inspection Requirements Fines and Punitive Damages Registration and Mandatory Reporting
Exhortation and Indoctrination	Education Publicity Public (e.g., Congressional) Hearings State Technical Services Political Lobbying Propaganda ("Smokey the Bear") Consumerism Conferences, Symposia Technical Society Standards
Construction and Operation	Government Stockpiles Government or Industry-Group-Operated Research Centers and Testing Labs Technical Information Services

6. Professional
7. Educational institutions

On the surface, then, it appears as though a control or obviating measure established at the national level would have a fairly direct effect on institutions. One example is the national standards governing auto fuel economy. While the resistance from major institutions was initially strong, the standards are now rapidly being achieved. It is much less clear that the institutions involved in composites would move so rapidly in unison, because of their disaggregation and relatively small size. Another aspect of this possibility is suggested by the relative complexity of the product design process for composites. The educational system that produces steel designers required no revisions to produce aluminum designers. Whether these schools could turn out composites designers as rapidly is problematical.

The fragmentation of the institutions and relative complexity of the technology make it necessary that a technology assessment utilization plan not only include a data base but also an information transfer plan that will operate effectively and with good coverage. The entire field of plastics is filled with examples of business and technological surprises, such as unforeseen toxicity, random failures, non-uniform standards, ill-matched production capacity and low quality. A positive action plan should be designed to operate in this environment.

4.10 STEP 7B: DEVELOP UTILIZATION PLAN

Three aspects of composites technology bear directly on the user oriented utilization plan that will be developed during Phase II:

1. The relevant technology includes many and diverse elements, as discussed in Section 2 of this report.
2. The organizations in this technology are small, numerous and scattered, as suggested in Figure 2-9 for the production system, and they are oriented to both materials and end-products.

3. The state-of-technology is in a condition of rapid change, in a development phase, as suggested in Figures 3-2 and 4-3.

The above can be re-stated as a problem of transferring information to many organizations, each of which is interested in only a small aspect of the assessment, and will be impacted at different times in the future.

The Phase II effort will prepare a utilization plan by incorporating three elements:

1. Hierarchy of utilizers, on a time base.
2. Mechanisms of information transfer
3. Evaluation design.

4.10.1 Assessment Users

Figure 4-27 analyzes the users of technology assessment, in the following items:

Users	-are individual and business consumers of products made of composites.
Producers	-are the elements and sub-elements of the production system defined in Section 2.
Controllers	-are government bodies
Legislative	-elements are policy, regulation, and law-making bodies
Operations	-are the laboratories, funding agencies, and inspection agencies involved
Professions	-are groups as ASME, SAMPE, etc.

In general, each element of the hierarchy has immediate use for an assessment of near term impacts (0-5 years, and retrospective), that is, a structuring of today's problems with today's composites, especially in the health and safety area. Except for product users, each level of the hierarchy can beneficially use an assessment of medium-term (5-20 years) impacts in the following ways:

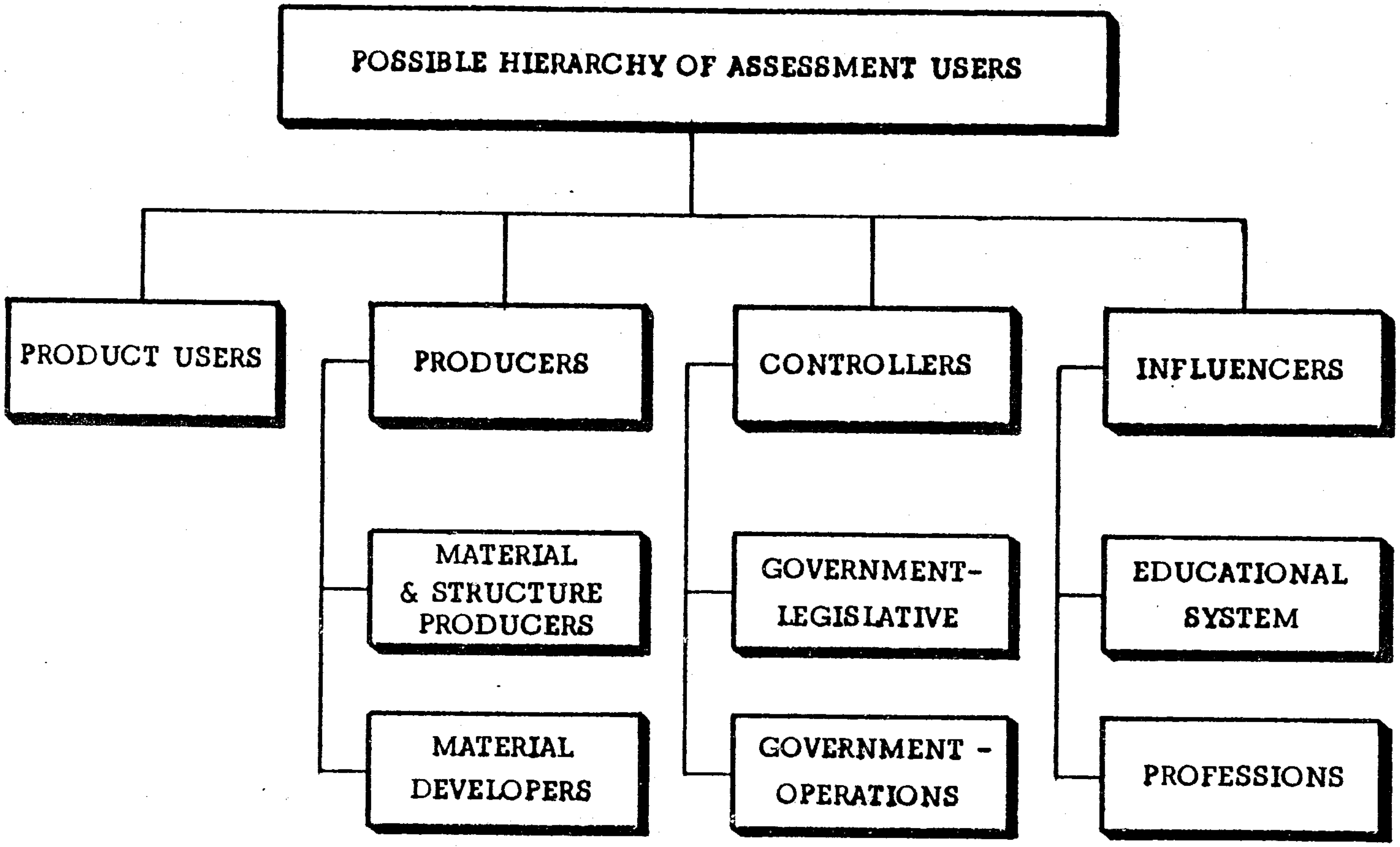


Figure 4-27. Hierarchy of Assessment Users

1. Producers can use the information for marketing and other aspects of strategic business planning.
2. Controllers and influencers can set in motion the control measures that often take years to design and implement. These would include tax law changes, government funding, curriculum changes, new professional standards, etc.

Influencers and controllers could use the assessment of longer-range impacts for long range planning; (20-40 years) even though their needs are not immediate. Instead, a baseline long-range assessment along with some sort of evaluation plan should be developed and implemented over a 5 to 10 year time frame.

4.10.2 Information Transfer

If near and medium-range impacts are estimated to be particularly severe, a centrally-sponsored program of information transfer could be initiated. Mechanisms could include:

1. Inter-agency funding of pilot demonstration programs for beneficial applications of composites, with a parallel aggressive publication program; such activities traditionally attract strong interest, from product users and producers.
2. Funding of impact-related symposiums and workshops to be conducted by SAMPE, Reinforced Plastics Institute, etc.

Beyond this, individual companies and industry associations, and legislative bodies, have been left to their own initiative to act on assessment type information.

4.10.3 Evaluation Design

An evaluation design would probably be very complex because of the dis-aggregation of the industry. Phase II will explore this area, probably through a series of individual detailed evaluations of specific impacts. Their relation to micro-level societal attributes would be the best evaluation of the Phase II assessment, and provide the most user-oriented feedback.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL CONCLUSIONS ABOUT APPLICATION OF COMPOSITES

New and expanded uses of advanced composites are foreseen as taking three forms:

1. Replacement of low performance plastics and composites with higher-performance composites, in existing applications.
2. Replacement of steel, aluminum, and other metals by composites, in existing applications.
3. Creation of new products based on both current appreciation of composites properties and as-yet-unperceived combinations of characteristics.

This conclusion is based on a continuation of a trend in materials usage that has been in process for 30 years, and on present advancements in composites technology. In addition, national laws and technical influences regarding productivity of products and efficiency of resources usage, in being now and forecast to become more pervasive, support the conclusions about expanded use. Expanded use will continue in both transportation and other applications. The greater growth potential, in percentage terms and absolute amounts, is in non-transportation applications. The "new products" category will be the most difficult to forecast and assess, and no conclusions have been made in this area.

Impacts on society from any single individual class of application of composites will be minor, and so may not be recognized by product users. In the aggregate, however, the impacts should be significant.

5.2 TYPES OF IMPACTS

Throughout this report a number of benefits, problems, impacts, and issues associated with advanced composites have been noted to illustrate the proposed technology assessment approach. The following list collects these items in one place, but does not attempt to list them in priority.

1. Benefits of composites compared to metallics:
   a. Possess many higher property-to-weight characteristics

b. Materials and structures can be customized in small quantities, with low non-recurring costs, to produce optimally efficiency structures, especially if weight is a design parameter.

c. Very good damage tolerance because of fibrous construction

d. Total production-energy imput for composites is lower than for metallics.

e. Total material quantity required in producing a composite structure with performance equivalent to metallic is generally lower than for metallics, therefore producing less by-products for control and disposal.

f. There are more basic options in composite material selection, which permits the designer to be more creative.

g. There are more structural configurations possible with composites, a design advantage.

h. In most specific jobs in the production system, less basic training is required for the unit operations involved, which opens up job opportunites for the less-trained.

2. Problems:

   a. Because most composites structures are made of customized material systems, with no national or industry standards, there is no recycling capability.

   b. If standardized composites come into general use, the benefits of optimum structures will be less.

   c. Composite structures are less damage resistant.

   d. Many matrices used now produce toxic by-products when burned.

   e. Basic material costs today are orders of magnitude more than metallics on a per-pound basis, and several times more expensive on a per-unit performance basis, except in very specialized, low-production applications such as aircraft structure.

   f. Composite structure design is more complex and costly than metallics design, because there are more design variables.

3. Impacts, assuming expanded and new uses:
   a. Increased machinery productivity because of lighter parts with tailored properties, which allows increased operating speeds and better control of motion. Examples which suggest whole classes of applications include: gears, drive chains, linkages, rotating shafts, in machines; booms, buckets, and cables in construction equipment; drill pipe and well casing; ladders, scaffolds, trench boxex, falsework, cables, in construction; rollover protective structures, support beams, in conveyor belts and mining equipment, especially continuous mining; relocatable pipelines and hoses; hand tools.
   b. Increased industrial safety, in the same types of products noted in 3(a), because of either better controllability or easier use because of lighter weight.
   c. Decreased power requirements, for same reasons noted in 3(a).
   d. Displaced workers and production equipment in metallics field, with a concentration in larger companies in the metallics field. (Because of the higher capital investment in metallics production, per unit of structural performance, the industry generally has become concentrated in fewer and larger companies).
   e. Decrease in by-products of metallics production.
   f. Increase in by-products of non-recyclable composite products.

g. Higher percent of basic components of structures will be of foreign origin (i.e., oil by-products are used in many matrices; fibers are available from European sources or are licensed by them for U.S. production. NATO standardization will also foster U.S. purchase of foreign aerospace products which in turn will help fund the expansion of European composites production).

h. The lower-skilled labor needed for composites structure production, in most applications, will keep the industry with numerous smaller-sized companies. This is because laminators, filament winders, etc. can generally undercut companies which apply numerical control and automated methods.

i. The continuing trend of legislated product performance in favor of low fuel consumption will encourage the expanded use of composites in industrial equipment, despite higher first-cost to the product purchaser. This will favor the larger, wealthier companies and discourage replacement of less-modern industrial equipment by smaller companies, because of higher first costs.

j. More industrial health problems because of toxic by-products of manufacture and flammability.

k. Government funding of composites research will be at the expense of metallics research.

l. New standards will be written for applications of composites structures (such as fire ratings, durability, product, life, environmental effects, etc.) because of obvious problems in these areas. Similar problems with the equivalent metallic structures will thus be highlighted, and even more standards will be applied, of the OSHA variety.

m. Higher first cost for composite structures will tend to encourage longer use of products, and cause many related side impacts, such as a whole new service and repair industry. Servicing for the metallics field (small machine shops, weld shops, sheel metal shops) will further contract, together with the basic training ground for high-skilled machinists and technicians. As a result the older skilled machinist in the U.S. will command even higher premiums than now, and large companies will become even less competitive in precision work with European and Japanese companies.

n. Universities will overproduce engineers trained in metallic-structure designs, and conversely, composites designers will draw an increasing premium. This factor, plus the impact noted in 3(h), will tend to result in large companies controlling the design and marketing of products, with production increasingly subcontracted to smaller, more labor-intensive companies. In effect, compared to today's structure-producing infrastructure, something similar to a cottage-industry environment might result.

o. The trend in government to discourage growth of big businesses and to encourage small businesses, will reinforce the trend in 3(l).

5.3 RECOMMENDATIONS

The macro-level policy issues suggested by the benefits, problems, and impacts of composites are basically centered around whether to continue and increase financial legislative incentives that encourage increased composites usage, expecially if the incentives, which could include small-business protection and relaxation of industrial health standards, are not matched by "equal opportunity" for metallics.

Unfortunately, the size and overall breadth of macro-level impacts is unknown primarily because of the technical and industrial fragmentation of the composites field. A micro-level study will quantify many aspects of the impacts for at least one future scenario (i.e., see Paragraph 4.6). Therefore, Phase II is recommended and a summary work plan for it is presented in the next section.

SECTION 6
PAHSE II SUMMARY WORK PLAN

6.1 TECHNICAL APPROACH

The technical approach for Phase II has been described in Sections 2,3, and 4 of this report, and is essentially a micro-level study and expansion of the topics discussed in those sections.

Phase II work will invlove:

1. Developing additional substantiating analyses and data in each task area (i.e., Steps 1 through 7 as summarized in Figure 3-5) especially regarding possible application of composites, problems and benefits involved, impacts within the basic future enabling scenario, and issues.
2. Preparing an alternate analysis with two different scenarios; one which will assume that the worldwide and national political situation will evolve in the direction of lower energy costs in the U.S. with no increase in legislation related to health, safety, and productivity, the other scenario will assume that a long-term worldwide economic decline will begin in the near term, limiting severely major R&D and capital investment in new technologies.

6.2 SCOPE OF WORK

The scope of work is generally defined in Sections 2, 3 and 4. The user orientation of the analysis will be developed by starting the impact identification process with product identification.

Transportation applications and first-order impacts will not be included, but can be integrated or added.

6.3 TECHNICAL DISCIPLINES INVOLVED

With the approach chosen for an advanced compsoites technology assessment, several disciplines will be required. A combination of different backgrounds such as the following would be suitable:

1. A senior-level system analyst, with experience in directing large, multi-disciplinary studies, as Project Director.
2. Structures and product-oriented composites specialist, with added experience in manufacturing technology, to forecast and assess material and product design aspects of technology.
3. Production-system specialist, probably an MBA-level management-oriented industrial planner or business analyst with added experience in labor matters, in distribution systems, and plant location factors, to assess micro-level impacts on industry.
4. Operations research and parametric estimating specialist, to assess product related impacts of technology such as productivity and safety.
5. Economist, to assess macro-level impacts of production system and product changes from use of composites.
6. Legislative analyst, to assess the legal and regulatory aspects of the assumed state-of-society.

In addition, the use of a technology forecaster and assessment methodology specialist, and an environmentalist, on a consultant basis should be considered.

6.4 WORK PLAN TASK SCHEDULE

Figure 6-1 is a summary task schedule for Phase II, for an 18-month effort. The 18 months allows for several review cycles of approach and progress. The reviewers would be conducted as round-table discussions with project personnel, NSF personnel, and industry and government specialist with interest and knowledge in some aspect of the technology. The review objective would be to modify the direction and/or emphasis of the study at several key points in the program (see Figure 6-1).

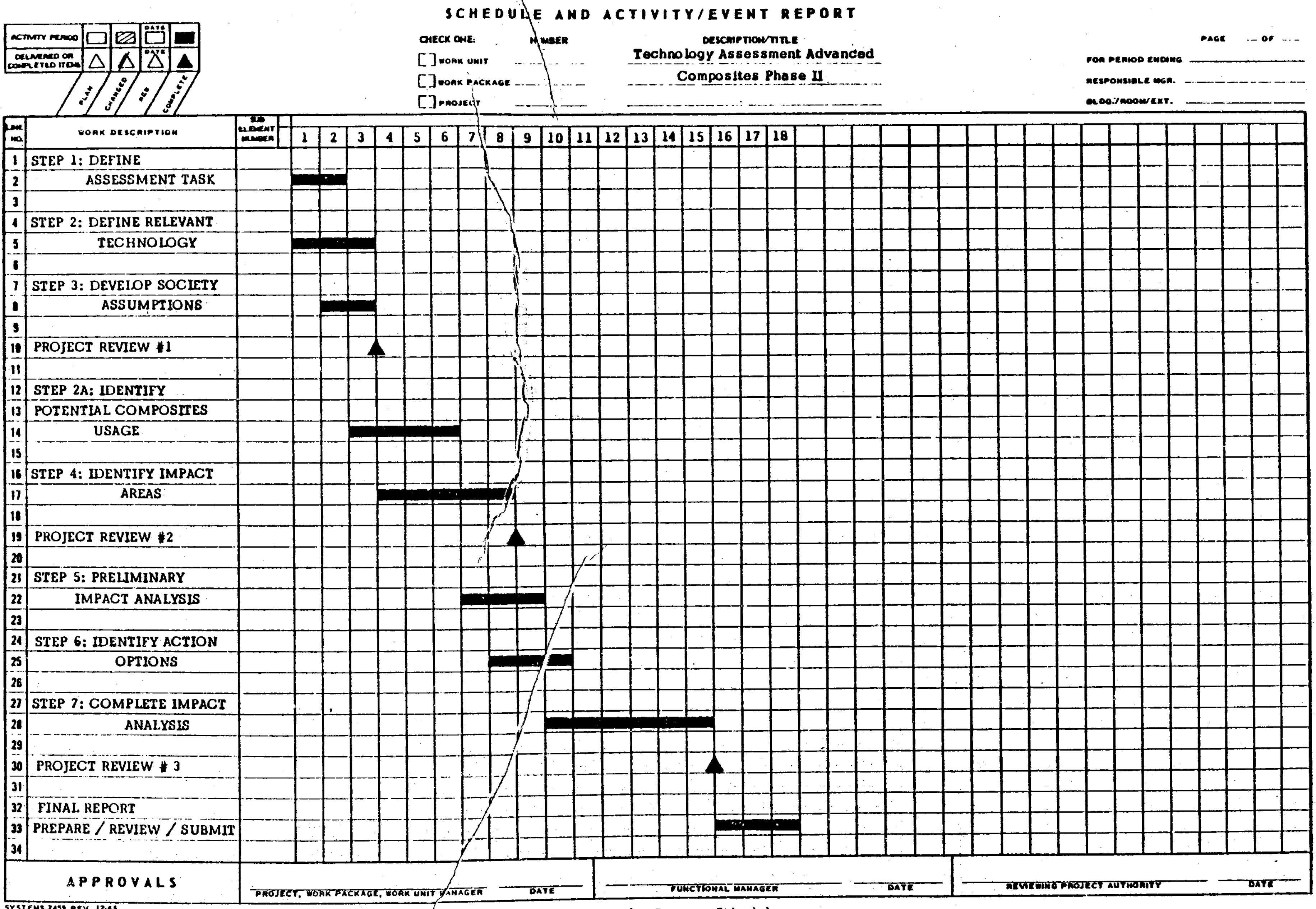


Figure 6-1. Program Schedule

APPENDIX I

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APPENDIX II
CONTACT SUMMARY

The following is a summary of the meetings and more-significant telephone contacts made during the duration of the study period, for the purpose of gathering impressions from technical experts on possible changes in composites technology. The contacts were not structured; rather questions were usually concerning some publication of the person contacted. The inventory of individuals noted represent a cross-section of potential technology assessment process participants and/or users.

CONTACTED		SUBJECT
R. Wandmacher G.M. Corporation Warren, Michigan	(T)*	Composites applications to automobiles
R. Ravenhall General Electric Co. Cincinnati, Ohio	(I)	Low cost hybrid composites in rotating machinery
P. Roy Aldila Corporation San Diego, Ca.	(I)	Sporting goods applications of composites
A. Jackson Lockheed California Burbank, Calif.	(T)	Analysis methods for composites structure design
E. Crossland Hercirles, Inc. Magma, Utah	(L)	Materials optimization opportunities and difficulties
E. Hoffman NASA Langley Hampton, Virginia	(T)	Structures manufacturing advances and limits

* T = Telephonic
I = Direct
L = Letter

CONTACTED		SUBJECT
R. Blatt G.M. Corporation Warren, Michigan	(T)	Structures manufacturing advances and limits
B. Martin Douglas Aircraft Long Beach, Ca.	(I)	Techniques for inspection of composites
G. Johnson Fiberite Corporation Winona, Michigan	(I)	Non-transportation applications for composites
A. Guasualdi NARNCO Div, Whittaker Corporation Costa Mesa, Ca.	(T)	Commercial markets for composites
A. Verrette 3M Company St. Paul, Minnesota	(T)	Capital and operating costs for plastics and composites production
R. Schneider Dow Chemical Torrance, Ca.	(I)	Environmental and occupational health and safety standards and practices in plastics industry.

APPENDIX III

EXAMPLE ADVANCED COMPOSITE MATERIAL APPLICATION EVALUATION:

MINE ROOF TEMPORARY SUPPORT BEAM

CONTENTS

III-1 BEAM GENERAL SPECIFICATIONS

Purpose: To provide temporary roof support in coal mines.

Total Length	15.33 ft.
Span	15 ft.
Type of supports	Simple
Type of loading to support roof	Uniform required
Working load	196 lb/ft.
Maximum deflection at working load	4 in.
Ultimate load	550 lb/ft.
Weight	Minimum, to encourage frequencies

Environment:

- Coal Mines
  - Moisture
  - Rough handling
  - Moderate temperatures
  - Abrasion due to rough handling and contact with mine roof.
  - Random contact with bare electrical circuits

Beam cross section envelope	4" x 4" maximum
Fire retardant and low smoke production	

Note:

It is desirable to minimize cost, weight, and deflection.

It would be desirable if the outside of the beam were contoured so that preloading the beam against the mine roof would produce a uniform load on the beam, preferably approaching the working load of 196 lb/ft.

III-2

TEMPORARY ROOF SUPPORT BEAM EVALUATION

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TEMPORARY FACE SUPPORT SYSTEM BEAMS

1. Introduction

The TFSS beams are primarily designed to be used with the carrier and subsequently emplaced against the mine roof as temporary support. The beams can also be emplaced manually without the carrier by mating them with posts which are capable of applying the preload.

Because of the limited vertical height in many coal seams and the requirement that continuous mining machines be able to pass underneath the carrier, there is a stringent limitation on the allowable depth of the beams. Similarly , the width of the beams must be limited in order to minimize the length of the carrier. Of these two dimensional limitations, the allowable depth is the more severe since the strength of a beam varies as the square of its depth and the stiffness as the cube of its depth.

There are several design goals for the beams in addition to the requirements imposed by the carrier. One is that they be as light as possible for easier manual handling. Another important goal is that the beams apply a uniform upward load into the roof along their span when preloaded at their ends by the posts. This condition is not achieved by a straight beam pressed against a flat roof, but requires either a contoured shape, or a pre-curved beam. Figure 1 depicts the load distribution along the roof due to a properly contoured preloaded beam.

Closely allied to the uniform preload distribution goal is that of deflection. The preload on each post has been specified as 1500 lb, and therefore, in order to produce a total uniform load in the roof of 3000 lb, the deflection under this load must be less than the depth of the beam, otherwise the beam must be curved which consumes additional vertical space.

It is the deflection requirement under roof loads which , along with the cost, has diminished the attractiveness of fiberglass as a beam material. The specific strength of fiberglass is very good, but its specific stiffness is not as good as that of steel or aluminum. Fiberglass beams are discussed more fully in a later section.

Strength requirements for temporary roof supports are set by the Federal Code of Requirements which specify that the beams must be at least equivalent in strength to 3 x 8-inch hardwood members. The TFSS beams are therefore required to be stronger than 3 x 8 maple planks as well as lighter.

The above requirements, and carrier/mine considerations, result in the following design criteria:

Beam Design Criteria:

A. Geometry	
a. Span	15 ft.
b. Overall length	15 ft. 4 in.
c. Depth, max.	4.25 in.
d. Width, max.	4.0 in.
e. Bottom of the beam must be flat.	
B. Weight: Less than 3 x 8 maple beam	<108 lb.
C. Loads:	
a. Preload, total	3000 lb.
b. Ultimate (breaking) load greater than a 3 x 8 maple beam	>8430 lb.
D. Deflection: Under a 3000 lb. preload	≦4 in.

E. General:

  a. The beam should put a uniformily distributed load on the roof,as close as possible to 3000 lb., when the posts are installed with a 1500 lb. preload in each.
  b. The beam should have good corrosion resistance.
  c. The beam should be able to withstand rough handling.

2. Discussion

In this section, beams of various materials are discussed. The discussion includes comparisons of various beam materials and how they compare to the 3 x 8 maple reference beam and how well they meet the above design criteria.

The beam materials discussed are steel, aluminum, fiberglass, graphite and wood itself.

Table 1 compares the salient characteristics of the materials which have been considered for the TFSS beams. The first 5 columns contain the absolute values for quantities; while the last 2 columns contain the relative quantities: specific strength and specific stiffness which are measures of structural efficiency. Normally, one could use the structural efficiencies to evaluate and choose the beam materials in the absence of other considerations such as cost and geometry. It is interesting to note, for example, that both balsa wood and Douglas Fir compare favorably with steel in specific strength and specific stiffness.

Graphite composites are outstanding in structural efficiency, and a graphite beam meeting the design criteria weighs only somewhat more than 30 lb. However, with a basic raw material cost of $32/lb, and even with consideration of high volume production, a cost of about $2500 per beam exclusive of tooling costs results. The net weight savings of perhaps 30 lb. is probably not worth it for coal mining operations.

When the design criteria of the TFSS beams are applied, one discovers that the choice of materials is governed primarily by the deflection and space limitations in those cases where cost alone is not deciding. Thus, high specific stiffness coupled with high density determine the choice. Wooden beams do not fit into the required cross section required for carrier emplacement by a wide margin because of their low density in spite of their good specific strength and stiffness. Note also that unless the wooden beams are contoured, they do not give the desired load distribution in the roof. If they are contoured they grow even larger in cross section.

TABLE 1 Comparison of Beam Materials

				Flexural Strengths			
Materials	Cost per lb.	Density, γ, lb/in^3	Modulus of Elasticity, E, psi	Yield Stress, σ_y, psi	Rupture Stress σ_u, psi	Specific Strength, σ_u/γ, in.	Specific Stiffness, E/γ, in.
Wood							
Maple	$ .06	.025	1.83×10^6	9,500	15,800	$.632 \times 10^6$	73.2×10^6
Birch	$ .06	.025	2.07×10^6	10,100	16,700	$.668 \times 10^6$	82.8×10^6
Hickory	$ .06	.030	2.18×10^6	10,900	19,700	$.657 \times 10^6$	72.7×10^6
Douglas Fir	$ .06	.021	1.92×10^6	8,100	11,700	$.557 \times 10^6$	91.4×10^6
Balsa	-	.0051	$.50 \times 10^6$	-	2,200	$.435 \times 10^6$	98.9×10^6
Steel							
4130	$ .79	.28	30×10^6	135,000	150,000	$.536 \times 10^6$	107×10^6
Aluminum							
6061-T6	$1.18	.098	10×10^6	35,000	42,000	$.429 \times 10^6$	102×10^6
2219-T87	-	.101	10×10^6	57,000	69,000	$.683 \times 10^6$	99×10^6
Fiberglass							
E Glass, 0°	$1.00	.065	5.5×10^6	-	135,000	2.08×10^6	84.6×10^6
E Glass, ±45°	$1.00	.065	1.5×10^6	-	38,000	$.585 \times 10^6$	23.1×10^6
Graphite							
0°	$32.00	.055	17×10^6	-	160,000	2.91×10^6	309×10^6
±45°	$32.00	.055	2.3×10^6	-	22,000	0.4×10^6	41.8×10^6

The specific strength of fiberglass is several times better than that of aluminum or steel, but its low specific stiffness and density result in a weight penalty and additional cost. In order to meet the deflection criterion, the amount of material must be increased beyond that required for strength alone.

The roof preloading capabilities of a fiberglass beam are not as good as those of aluminum and steel both because of the low specific stiffness and because fabrication considerations limit how shallow the beam cross section can be made towards the ends. The cost of fiberglass beams is also several times that of steel and aluminum.

The points raised in the above discussion lead one to the consideration of aluminum and steel as the most promising candidates for beam materials. Of the two, aluminum is somewhat more attractive primarily because the wall sections are thicker than those of the steel designs and are less subject to being damaged by rough handling. The aluminum also offers better corrosion resistance.

The aluminum, steel, fiberglass, and graphite beam designs all have hollow rectangular cross sections and are contoured along their top surfaces. The contour is depicted in figure 1 showing a greater depth at the center than the ends. These are also constant strength designs, that is, for greatest efficiency, the bending stress is constant along the length until near the ends where shear strength considerations govern.

Aluminum -

The aluminum beam design has a rectangular hollow cross section with flanges and webs of constant thickness. It is fabricated from strips of sheet and plate and joined at the corners with full penetration welds. Heat treatment and aging follow welding in order to develop full strength.

The choice of alloys is limited to 6061 and 2219 because the higher strength alloys such as 2024 and 7075 are not arc or flame weldable. The strengths of 2219 and 6061 are:

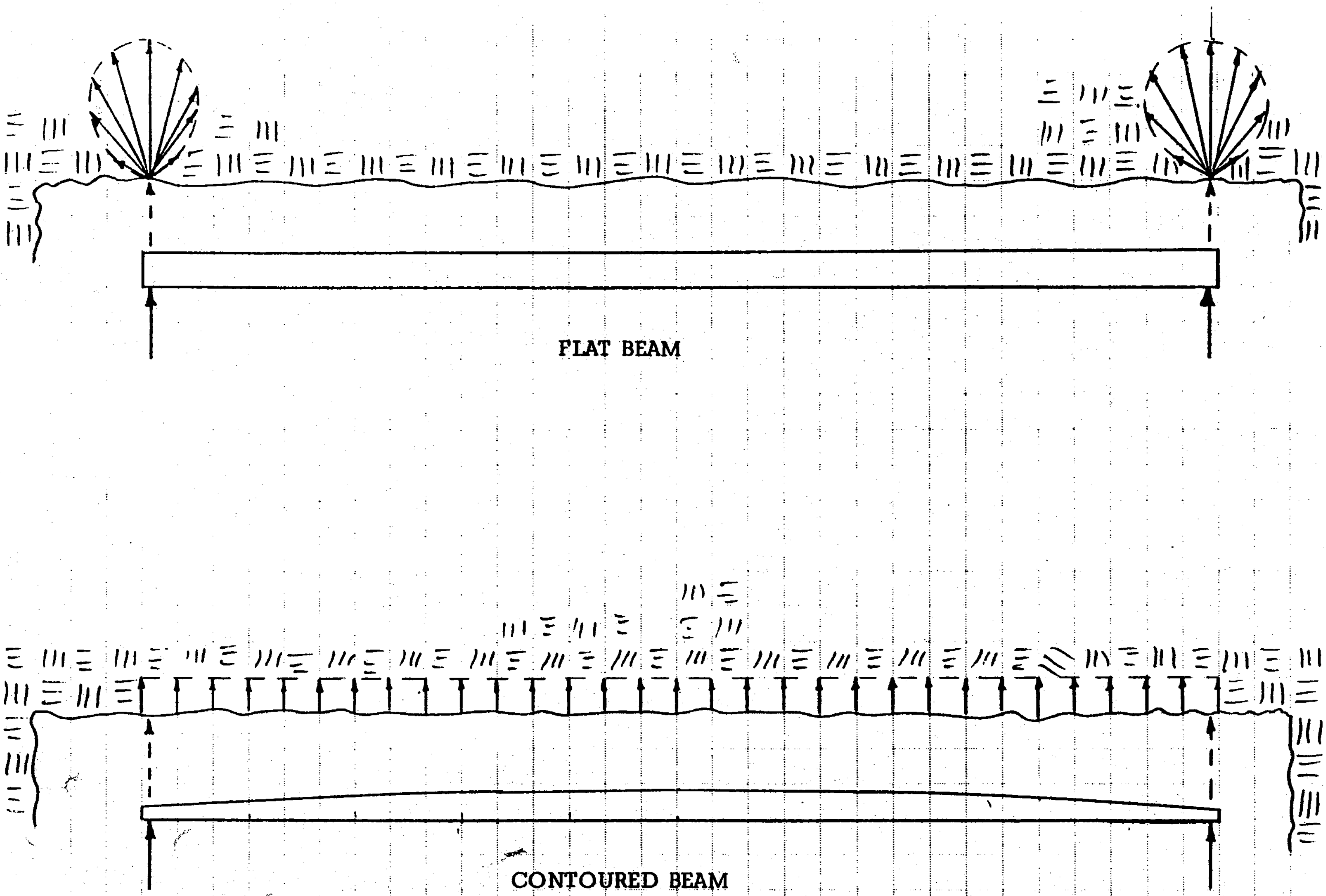

Figure 1. Roof Preload Distribution

Alloy	Condition	Yield Stress, psi	Ultimate Stress, psi	Elongation %
2219	T81,T851	46,000	62,000	10
6061	T6	35,000	42,000	12

Alloy 2219 is the more desirable of the two because of its higher strength, however, it is not readily available and must be ordered in 7000 lb. lots of each size from the mill. This would be acceptable for production unit beams, but is probably an excessive cost for 20 prototype units.

Alloy 6061 is readily available in any quantity and size and perhaps could be used for the prototype to prove the design with the knowledge that the 2219 production beams would be stronger. A compromise would be to buy 7000 lb of 2219 in one thickness and make the flanges and webs of equal thickness. The bottom of table 2 shows 4 examples of this.

The good specific strength of alloy 2219 is readily apparent in Table 2. A beam having 50% more strength than the reference 3 x 8 maple beam weighs less than half as much.

Thermal shock and distortion during quenching operations in heat treating can be minimized by leaving the ends open for the quenching fluid to cool the inside simultaneously with the outside. The end pieces can be welded on after heat treating since there is no bending stress there. This holds true for the steel designs also. The welding of these end pieces on the aluminum beams can be done before the artificial aging treatment.

Aluminum beams have good corrosion resistance and their thick wall sections provide protection from rough handling as well as local buckling under high loads.

Steel -

AISI 4130 heat treated to 165,000 psi ultimate and 150,000 psi yield strengths after welding is the steel alloy chosen for this design. These strengths can be increased somewhat if desired, but buckling of the compression flange will determine the failure above 200,000 psi.

TABLE 2 Aluminum Beam Designs

Thickness, in.					Strength Al./Str. Maple	
Flanges	Webs	Weight, lb.	Bending Stress at Preload, psi	Weight Al./ Weight Maple	6061	2219
.25	.100	45.	16,150	.42	.93	1.40
.25	.125	47.	15,760	.44	.95	1.40
.281	.125	51.	14,500	.47	1.03	1.52
.313	.125	55.	13,390	.51	1.12	1.65
.313	.160	58.	13,060	.54	1.15	1.69
.344	.160	63.	12,240	.58	1.22	1.80
.375	.160	67.	11,540	.62	1.30	1.91
.16	.16	38.	20,580	.35	-	1.07
.19	.19	45.	17,700	.42	-	1.25
.212	.212	50.	16,130	.46	-	1.37
.25	.25	58.	14,060	.54	-	1.57

Note: The maple reference beam is 3 x 8 in cross section

4130 is a readily available material with which fabricators and heat treater are very familiar.

Flange and web thicknesses along with weights and strengths for the steel beam designs are listed in Table 3. Both the aluminum and the steel designs have the same depth profile.

The thinness of the compression flange requires that a Z stiffener be welded to it in order to raise the critical buckling stress above the ultimate bending stress. This adds about 3 lb to the weight and increases the bending strength a small amount.

The thinness of the section walls raises some concern as to the susceptibility of the beam to rough handling damage especially to the thinner webs. It is somewhat difficult to quantify this fragility, but if a 0.0625 in. thick web is assumed to be a clamped-clamped beam of 4 in. span, the concentrated load required to dent it is about 200 lb. for a 1 in. wide strip. This is a very conservative calculation. If a 4 x 4 in. section of the web is assumed to act as a plate with clamped edges, the damaging concentrated load is 778 lb. This is an unconservative assumption, so the damaging load will lie somewhere between the two extremes. In thinking about the fragility of the thin steel sections, it should be kept in mind that this is heat treated steel alloy having a yield strength 5 times higher than that of ordinary structural steel and is thus very tough. The above discussion pertains to the 0.0625 in. wall thickness. The load required to dent a thicker section will increase as the square of the ratio of the thicknesses.

Fiberglass -

Several different methods of construction for fiberglass beams have been investigated. These include filament wound, layup, pultrusion, and filament wound plus longitudinal fibers. The filament wound designs generally have the fibers placed at ±45° to the longitudinal axis and the cross sections include both rectangular and round shapes. Of these, only the design with the filament wound core with the overlay of 0° (longitudinal) fibers meets the specifications.

TABLE 3 Steel Beam Designs

Thickness, in.					
Flanges	Webs	Weight, lb	Bending Stress at Preload, psi	Weight Fe/ Weight Maple	Strength Fe/ Strength Maple
.0625	.0625	52.	48460	.48	1.20
.0938	.0625	59.	36470	.55	1.61
.1046(12)	.0747(14)	67.	32510	.62	1.81
.1196(11)	.0747(14)	73.	29390	.68	2.00
.1345(10)	.0747(14)	78.	26870	.72	2.19
.125	.09375	80.	27320	.74	2.15

Note:

1. The maple reference beam is 3 x 8 in. cross section.
2. Compression flange stiffeners are required in all designs.
3. ( ) gauge thicknesses.

The other designs suffer from the reduced strength and stiffness caused by the construction methods. The ±45° filament windings are necessary to carry shear loads, but are poor for supporting the longitudinal bending stress and reduce the flexural strength and stiffness considerably below that of 0° longitudinal fibers. For instance, 50% of the flexural stiffness is lost due to the factor, $\cos^2 45°$, and the rest is lost due to a scissoring action of the fibers. Table 1 illustrates these strength and stiffness reductions due to the fiber angles.

Pultrusions and filament wound beams were generally found to be unable to meet the deflection criterion and/or had excessive weight. Table 4 lists a round tapered filament wound tube which meets the deflection, strength and envelope criteria but weighs 143 lb. It is also considerably more expensive than steel or aluminum beams even in large quantities.

In addition, the pultrusions have no roof preloading capability due to the lack of contour. The filament wound beams have poor preloading capability because of their limited contouring.

The preferable fiberglass beam design is shown in figure 2. It consists of ±45° filament wound core with 0° fibers top and bottom. The ±45° fibers carry the shear loads and the 0° fibers carry the flexural loads. The 0° fibers have a 0.75 in. depth at the center of the span and taper to 0.125 in. at the ends. This gives a curve to both the top and bottom of the beam. The beam is bent before oven-curing to make the bottom flat and put all of the contour on the top. This is beneficial because it leaves the top of the carrier/emplacer flat and it doubles the amount of preload that the beam is capable of putting into the roof. Even so, the preload amounts to only 1120 lb in the roof whereas the steel and aluminum beams can be made to put more than the nominal preload of 3000 lb in the roof if desired.

Note that in order to meet the deflection criterion, the beam has been overdesigned in strength by a factor of almost 6 and the weight has about doubled over that which would be required for strength alone.

TABLE 4 Fiberglass Beam Designs

Cross Section Shape	Weight, lb	Bending Stress at Preload, psi	Weight FG/ Weight Maple	Strength FG/ Strength Maple
Rectangular	70	8370	.65	5.74
Round	143	7850	1.32	1.72

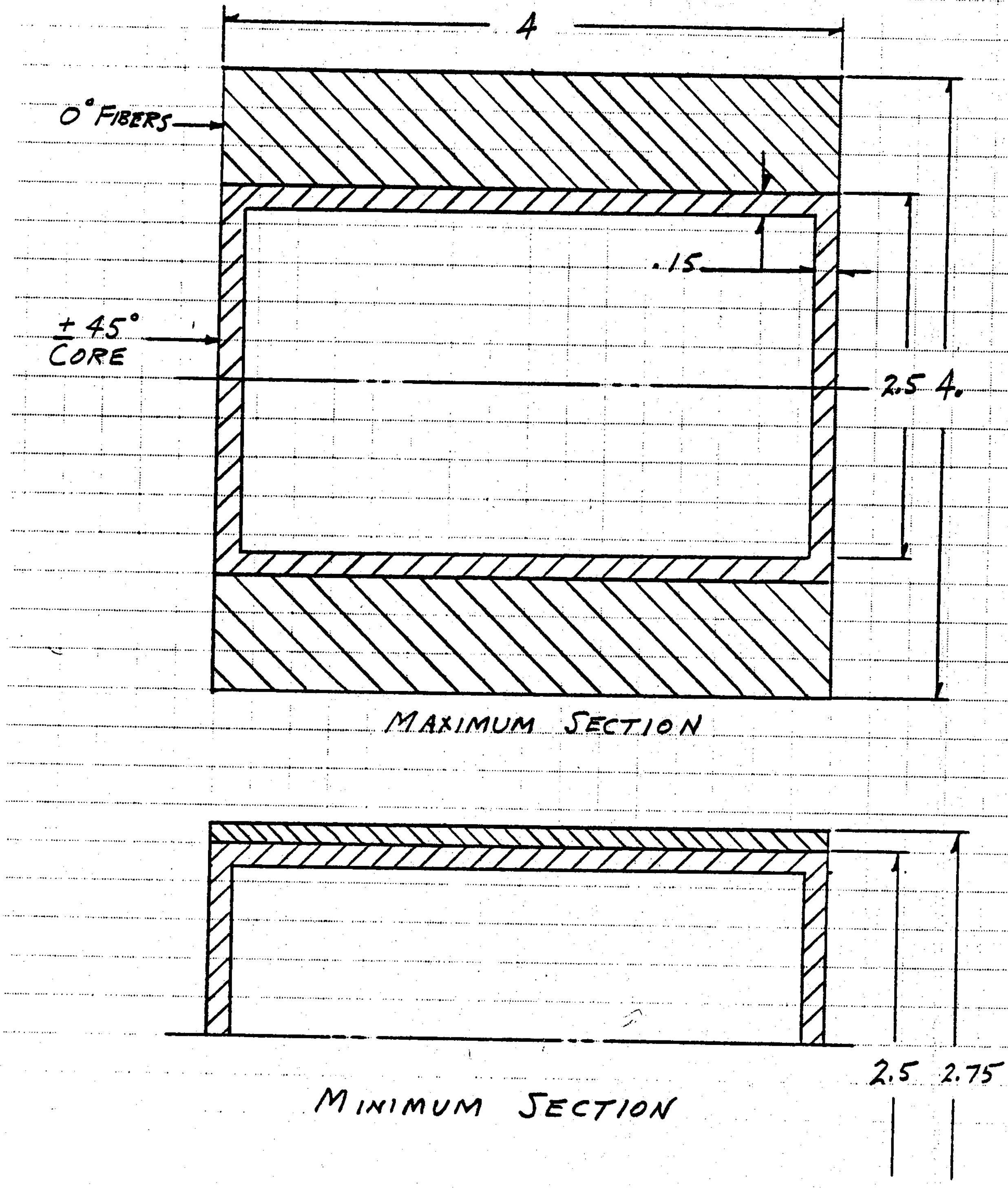

Figure 2. Fiberglass Beam Cross Sections, ±45° Core and 0° Flanges

Graphite Composite -

A graphite composite beam would be constructed similar to the fiberglass beam except that far fewer 0° fibers would be required. The result is a beam which would weigh less than 32 lb and be about twice as strong as the reference wood beam. Because of the minimal contouring, the roof preloading capability would be poor.

Wood -

Table 5 lists the pertinent characteristics of hardwood beams of typical cross sections. All but the 4 x 4 exceed the space requirements, but it is somewhat weaker than the reference beam and does not meet the preload criterion. Tapering the 4 x 4 to give it a roof preload capability would double its flexibility and result in a total roof preload of 776 lb.

The other wood beam sections exceed the space requirements considerably and are excessively heavy. Only a tapered 6 x 6 could properly preload the roof, but would still weigh over 86 lb and exceed the space requirements by 125%.

3. Conclusions and Recommendations

Fiberglass beams are attractive for their strength, but their flexibility results in poor roof preloading compared to aluminum and steel beams and incurs a weight penalty. The cost of fiberglass beams is on the order of 3 to 4 times more than aluminum and steel beams.

Graphite and composite beams are very light, strong and stiff, but are difficult to design so that they preload the roof to the desired degree. Their greatest drawback is the very high cost of the material in addition to the already high cost of fabrication.

Hardwood beams which can meet the strength requirements far exceed the available space and cannot put the desired preload into the roof even with the upper surface contoured. They are also excessively heavy in most instances. The principal asset of the wooden beams is their low cost.

Aluminum or steel is the recommended choice for beam materials and are the only ones which meet the design criteria and are moderate in cost.

TABLE 5 Hardwood Beams

Cross Section Depth x Width	Weight, lb	Bending Stress at Preload, psi	Strength/ Strength Ref. Maple	Deflection Under Preload, in.	Volume/ Req'd Volume
3 x 8 Ref.	108	5625	1.0	6.9	1.5
4 x 4	72	6326	.89	5.8	1.0
4 x 6	108	4219	1.33	3.9	1.5
6 x 6	162	1875	3.00	1.2	2.25

The 63 lb aluminum beam having 0.344 in. flanges and 0.160 webs is the recommended first choice. It has good strength and reasonably low weight and should withstand rough handling.

It is recommended that alloy 6061-T6 be used for the prototype beams with the understanding that 2219-T81 would be used for production beams. However, a search will be conducted to determine whether there are any odd lots of 2219 available in appropriate thicknesses.

Second choice, if the use of aluminum is not allowed, is a steel beam having 0.0938 in. flanges and 0.0625 in. webs and weighing 59 lb with flange stiffeners.

AISI 4130 heat treated to 165,000 psi ultimate tensile strength is the steel alloy recommended for these beams.