DOE AUTOMOTIVE COMPOSITE MATERIALS RESEARCH

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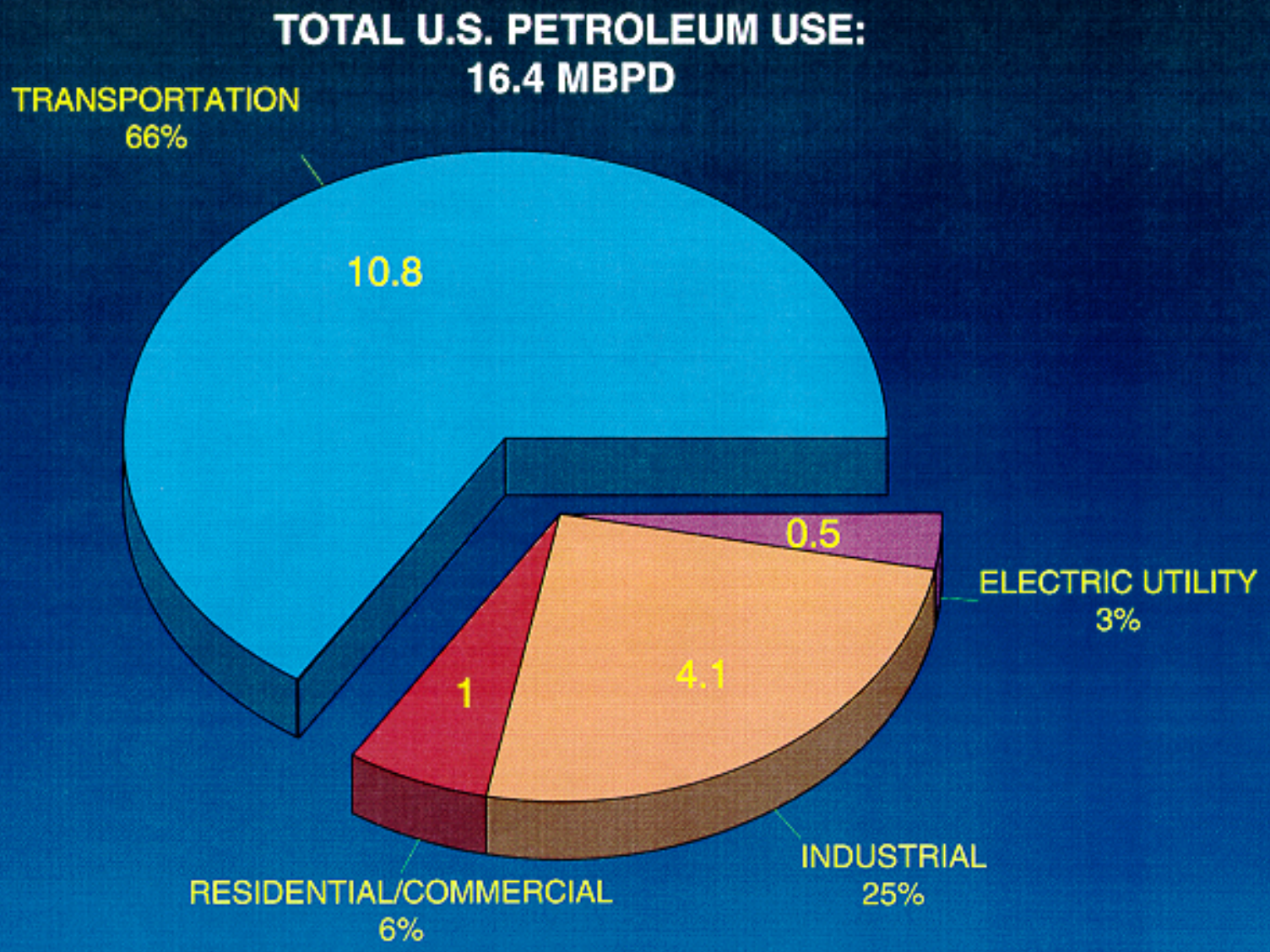
CHALLENGE - TRANSPORTATION ENERGY USE

- IN 1994, THE U.S. USED 16.4 MPBD OF PETROLEUM
  - U.S. PRODUCTION EQUALED 8.8 MBPD
  - U.S. IMPORTS EQUALED 7.5 MBPD
- IMPORTS MAY EXCEED 63% OF TOTAL USAGE BY 2010
- IN 1994, U.S. TRANSPORTATION USED 10.8 MBPD OF PETROLEUM

U.S. PETROLEUM DEPENDENCE, 1994
TRANSPORTATION SECTOR IS KEY CONTRIBUTOR

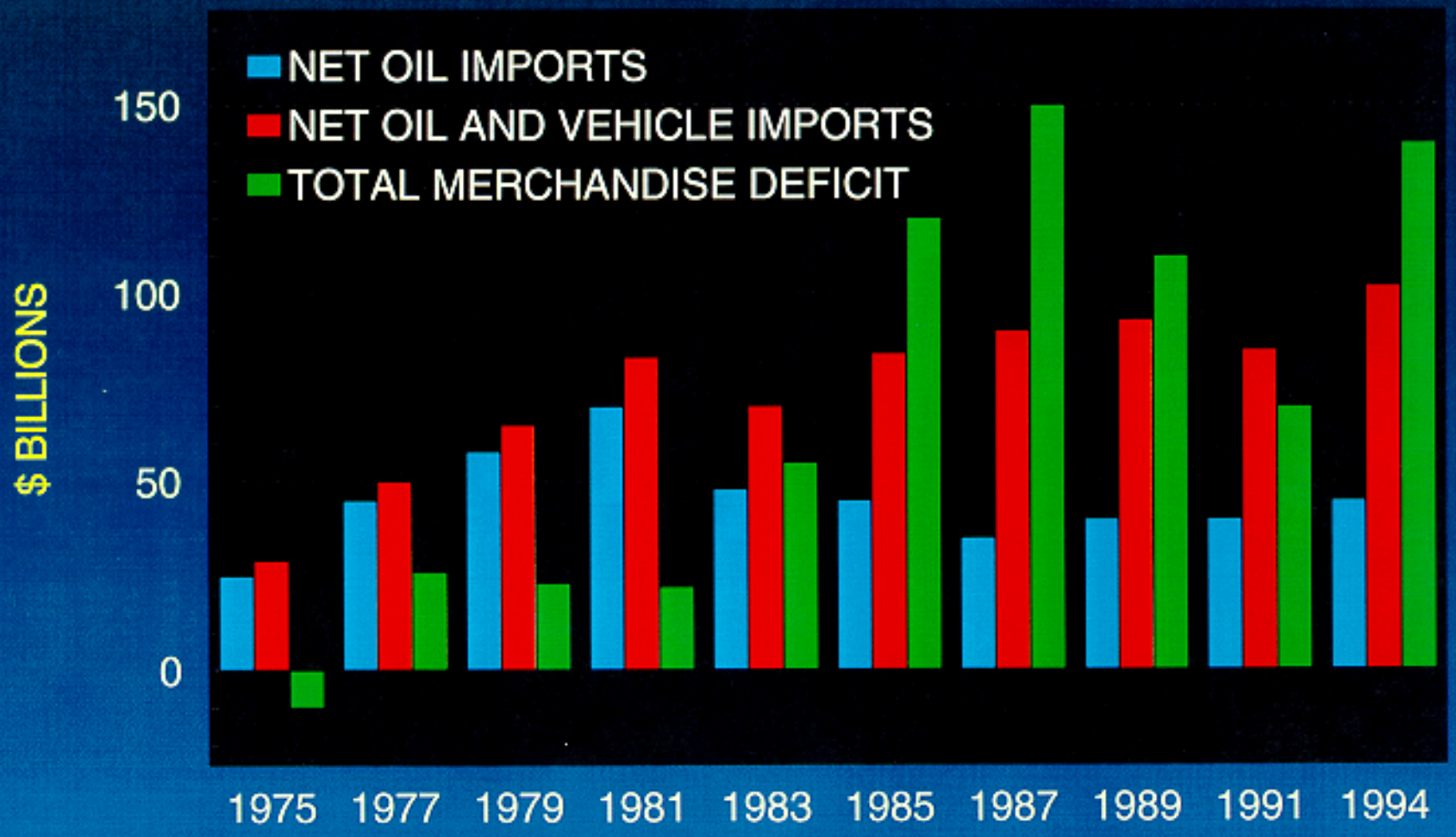


SOURCE: MONTHLY ENERGY REVIEW, AUGUST 1995
DOE ENERGY INFORMATION ADMINISTRATION

U.S. OIL DEPENDENCE IS A GROWING PROBLEM

- U.S. OIL IMPORTS ARE INCREASING
  - ABOUT 50% OF CONSUMPTION NOW
- WORLD WIDE OIL DEMAND IS GROWING
- OPEC STILL HOLDS THE VAST MAJORITY OF IDENTIFIED AND UNDISCOVERED RESERVES
- OPEC SHARE OF THE WORLD MARKET INCREASING
  - PROJECTED TO EXCEED THE HISTORICAL PEAK SOMETIME AFTER THE YEAR 2000
- **INCREASED U.S. VULNERABILITY TO EXTERNAL EVENTS AND OIL SHOCKS**
- **MASSIVE TRANSFER OF WEALTH TO OIL EXPORTING COUNTRIES**
  - **U.S. OIL TRADE DEFICIT OF $45 BILLION IN 1994**

U.S. MERCHANDISE TRADE DEFICIT: DOMINATED BY OIL AND VEHICLE IMPORTS



SOURCE: MONTHLY ENERGY REVIEW, AUGUST 1995, DOE ENERGY INFORMATION ADMINISTRATION.
AMERICAN AUTOMOBILE MANUFACTURERS ASSOCIATION, ECONOMIC INDICATORS, SECOND QUARTER: 1995.

OAAT MATERIALS PROGRAM GOALS

1. Significantly improve national competitiveness in manufacturing.
   - Agile/Flexible manufacturing
   - Reduction of costs
   - Reduced environmental impact
   - Improved quality

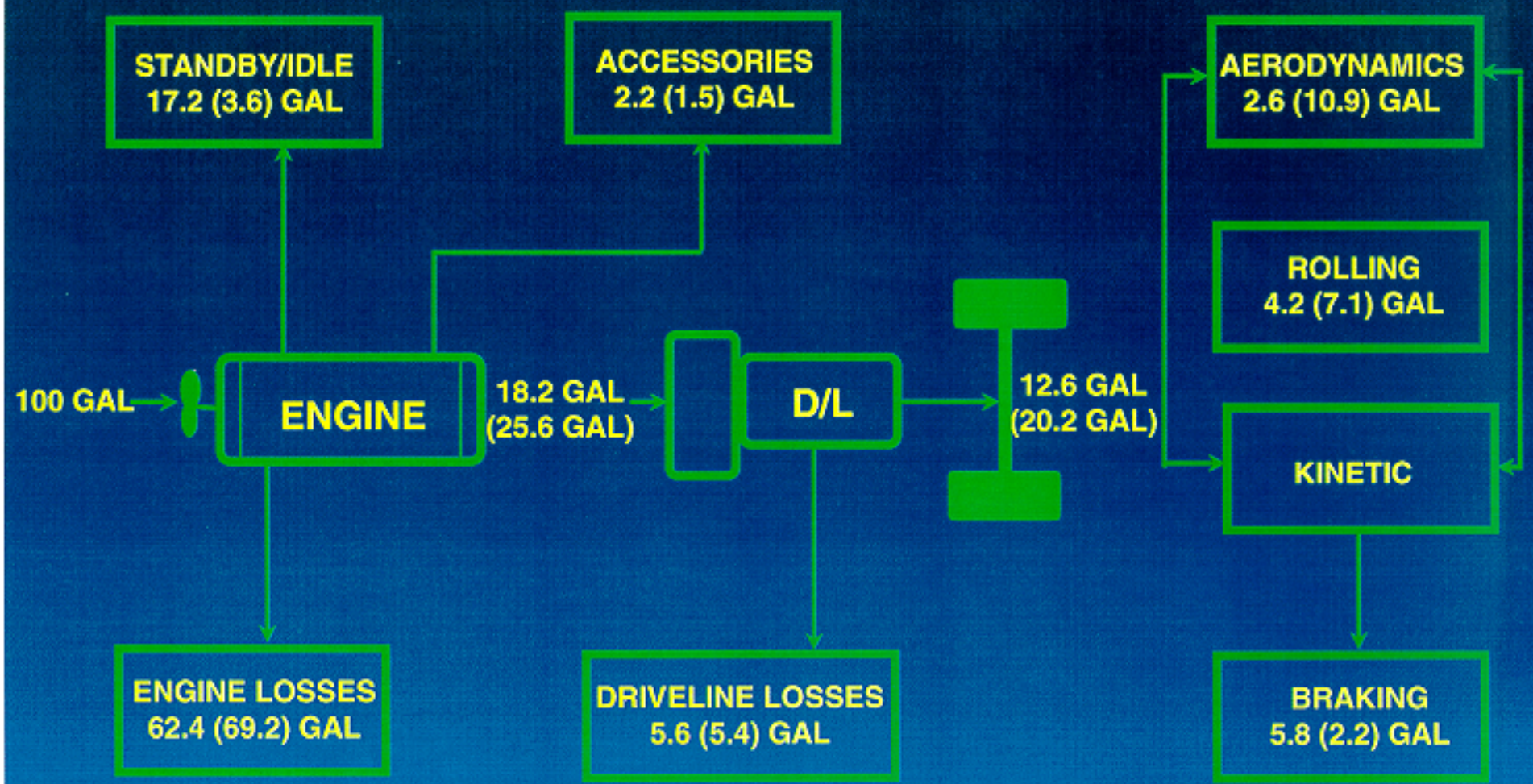
2. Implement commercially viable innovation from ongoing research on conventional vehicles.
   - Reduced emissions
   - Improved safety
   - Increased thermal efficiency
   - Reduce drivetrain losses

3. Develop a vehicle to achieve up to 3X fuel efficiency of today's comparable vehicle. (Chrysler Concorde, Ford Taurus, Chevrolet Lumina)
   - 80 mpg BTU equivalent
   - Equivalent consumer cost to own and drive
   - Comparable size, performance & utility

4. Develop advanced technologies beyond the PNGV time frame.
   - >80 mpg equivalent
   - Advanced materials and processing technologies

ENERGY DISTRIBUTION

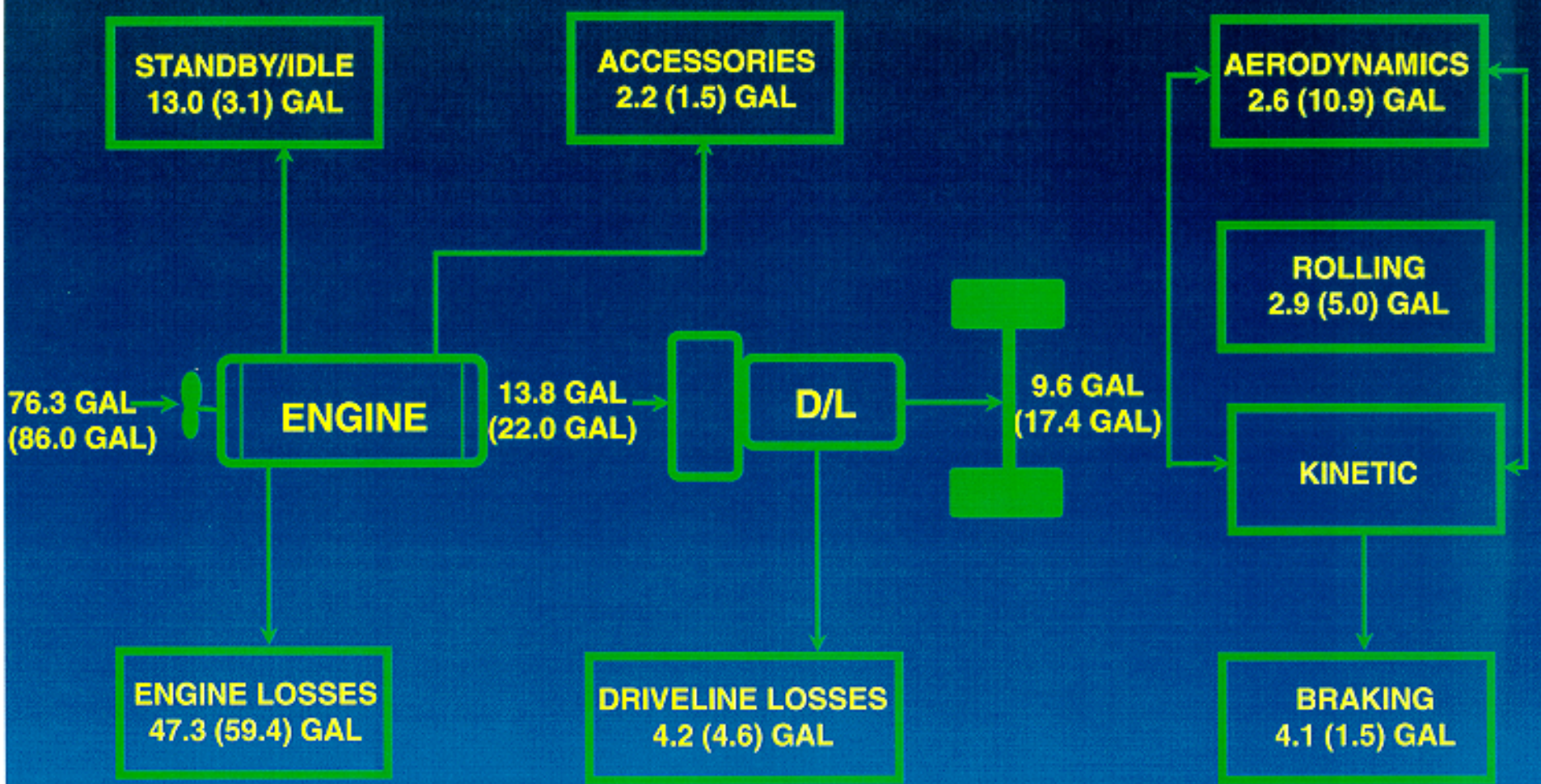
TYPICAL MID-SIZE VEHICLE



URBAN (HIGHWAY)

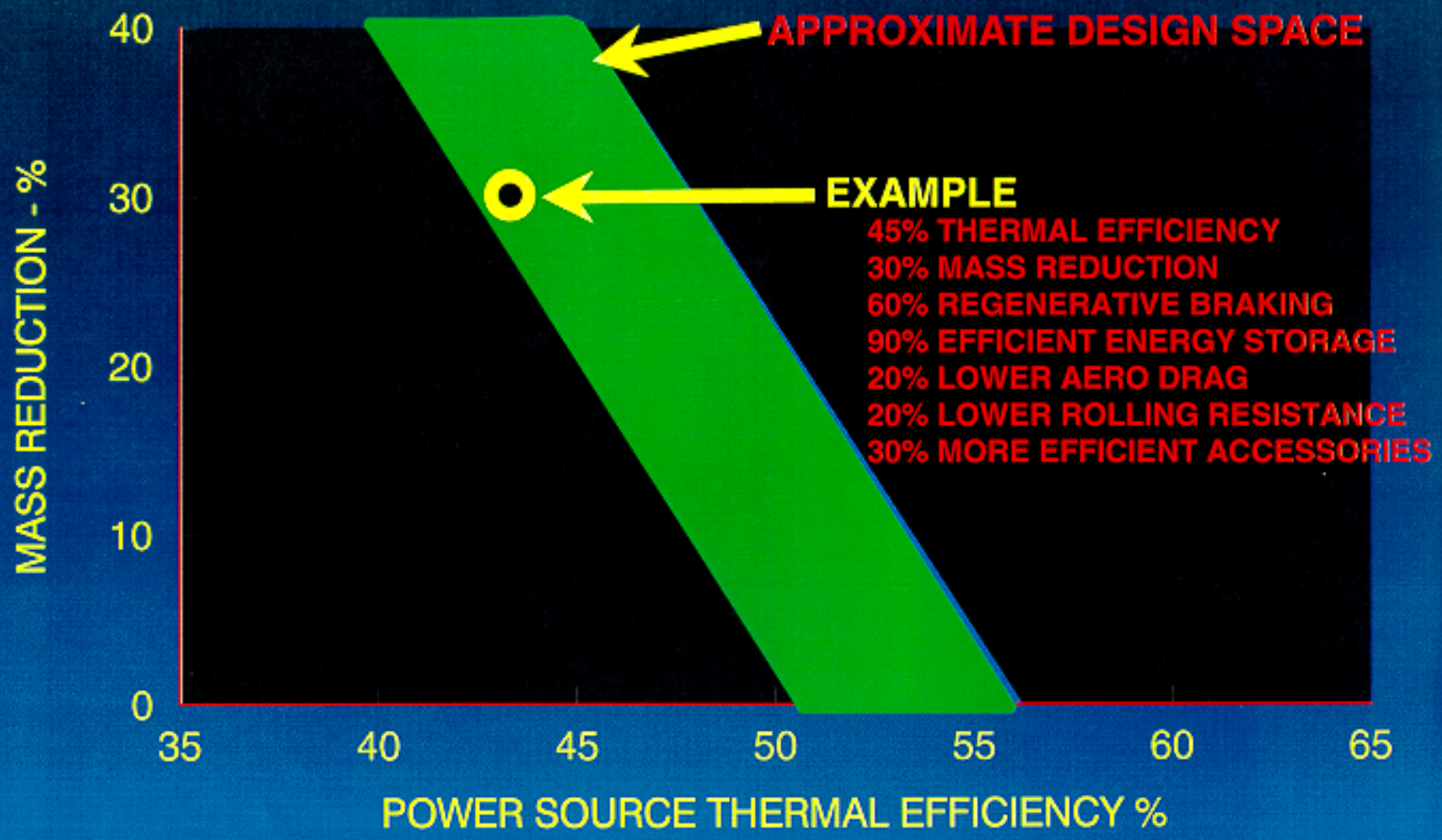
ENERGY DISTRIBUTION

TYPICAL MID-SIZE VEHICLE LESS 30% WEIGHT



URBAN (HIGHWAY)

"3X" DESIGN SPACE



Why Composites for Cars?

10% Weight Reduction in Body = 6% increase in Fuel Economy

10% Weight Reduction in Body = 5-7% Weight Reduction in Power Train

	Body Weight Savings Potential
Glass Fiber Composites	20-30%
Carbon Fiber Composites	40-60%

Weight Reduction = Fuel Economy = Emission Reductions

Composite Material Advantages

	Density (lb/cu. ft.)	Strength (Kpsi)	Modulus (Mpsi)
Automotive Steel	480	60-200	30
6061 Aluminum	167	30-40	10
Glass Fiber Composite	93	30-100	5-8
Carbon Fiber Composite	79	60-150	10-35

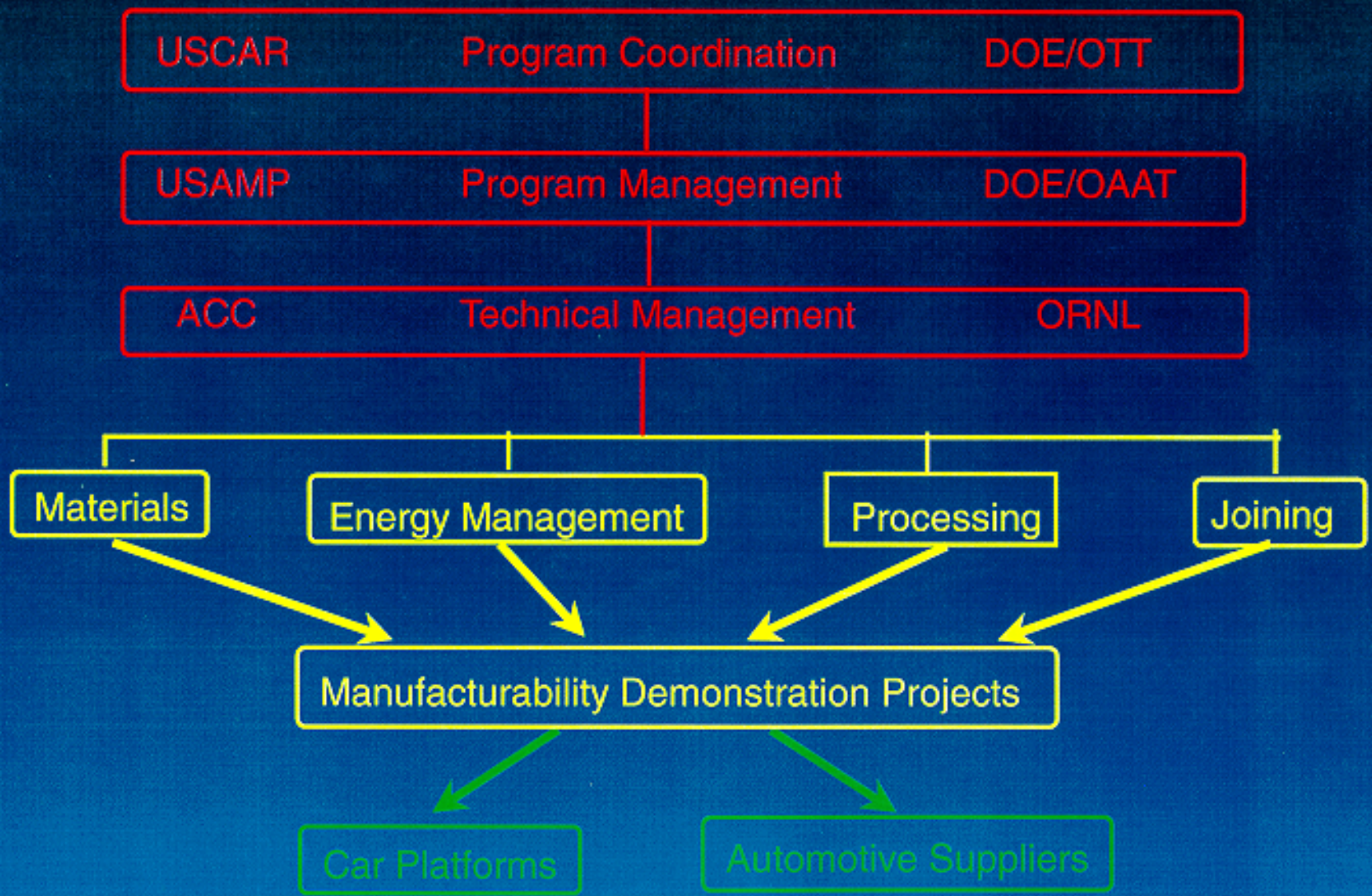
Advantages

- Less Expensive Tooling
- Parts Integration
- Net Shape Forming
- No Corrosion
- Energy Absorption

Disadvantages

- Cost
- Repair Processes
- Processing Methodologies
- Recyclability
- Design Databases

DOE/PNGV COMPOSITE MATERIALS RESEARCH
Research Program Organization



DOE/PNGV COMPOSITE MATERIALS RESEARCH
Glass Fiber Composites

Technical Management
ORNL/ACC

Current Efforts
Proposed Efforts
Completed Efforts

Processing
- Slurry Modeling (INEEL)
- Slurry Processing (Budd, ACC)
- P4 Preforming (Aplicator, OCF, ACC, NCCST)

Materials
- Durability (ORNL)
- Deformation & Degradation (Univ of Tulsa)
- Materials Screening (ACC)

Energy Management
- SCAAP (LLNL, ORNL, SNL ANL, LANL, ACC)
- NHTSA Modeling (ORNL)
- Energy Management (ACC)

Joining
- Adhesive Bonding (ORNL
- Adhesive Modeling (Univ of Texas, Univ of Missouri)
- NDT Laser Shearography (Oakland Univ.)
- NDT Rapid Testing (LBNL)
- Test Method Analysis (Tenn. St. Univ.)

Focal Project II

PNGV and Beyond Goals

Why Composites for Cars?

Glass Fiber Composites can reduce weight by 20 -30%

- Data Bases
- Design Methodologies
- Processing Technologies
- Material Crash Models
- Rapid Cure Technologies
- Joining Methods
- NDT
- Recycling

Carbon Fiber Composites can reduce weight by 40-60%

- All of the above
- Fiber Cost

Weight Reduction = Fuel Economy & Emission Reductions

DOE/PNGV COMPOSITE MATERIALS RESEARCH
Glass and Carbon Fiber Composites

Technical Management
ORNL/ACC

Fiber Processing
- Microwave Graphatization (ORNL, ACC)
- Advanced Processing Methods (Hexcel)

Materials
- Carbon Fiber Composite Dev. (ORNL, ACC)
- Rapid Testing (Univ of Tulsa)
- Materials Screening (ACC)
- Recycling (ANL)

Joining
- Adhesive Bonding (ORNL)
- Adhesive Modeling (U of TX, ACC)
- NDT (LBNL)

Implementation
Technology Deployment Line

Processing
- P4 Development (ACC, NCCST)
- Thermoplastic Comp Forming (Pending)
- P4A Development for Carbon Fiber (ACC, NCCST, Air Force, Boeing, Northrop, Lockheed)

Focal Project II
Focal Project III

Low Cost Precursors
- Advanced Polymer Precursors (VA Tech/Clemson)
- Non-Thermally Stabilized Precursors (Hexcel)
- Coal Base Precursors (MSU/Impact)
- Organic/Recycled Precursors (ORNL/AKZO)

Energy Management
- Computational Crashworthiness (LLNL, ORNL, ACC)
- Crash Energy Management (ACC, Nottingham Univ, Univ of Mich, MSU, Stanford, Univ of Cal - SB, Univ of Cincinnati)

PNGV & Year 2011 Goals

Program Funded

Non-Program Funded

#1 PRIORITY

Low Cost Carbon Fiber

$3 - $5 Per Pound

Carbon Fiber - Production

Carbon Fiber Production

Historically: Thermal reduction of a precursor by pyrolysis of all but the carbon followed by heat treatment of the carbon to obtain desired structure.

Precursor (PAN, Pitch, Rayon)	$1.60/lb - 50% loss ---> $3.20 investment	(50 - 60%)
↓		
Stabilization/ Oxidation	200 - 220°C +O_2	(25 - 40%)
↓		
Carbonization	1000 -1500°C in Ar; -O, H, N	
↓		
Graphitization	> 1800°C; heat treatment	
↓		
Chopping/ Spooling	$8 - 100 / lb	

Carbon Fiber Production

Thermal reduction of a limited number precursor by pyrolysis of all but the carbon followed by heat treatment of the carbon to obtain desired structure.

Are these the only materials and the only way?

Current Carbon Fiber Research

Microwave Carbonization and Graphatization (ORNL, Akzo)

Develop a variable frequency microwave carbon fiber manufacturing process that will produce large volumes at $3-5 per pound for 30 million modulus fibers. Produce a pilot production set-up that goes from PAN or PITCH fiber to fully carbonized and possibly partially graphatized fiber to demonstrate technology.

Advanced Polymer Precursors (Va Tech/Clemson)

Advanced Processing and Precursors (Hexcel)

Coal Based Precursors (MSU/Impact)

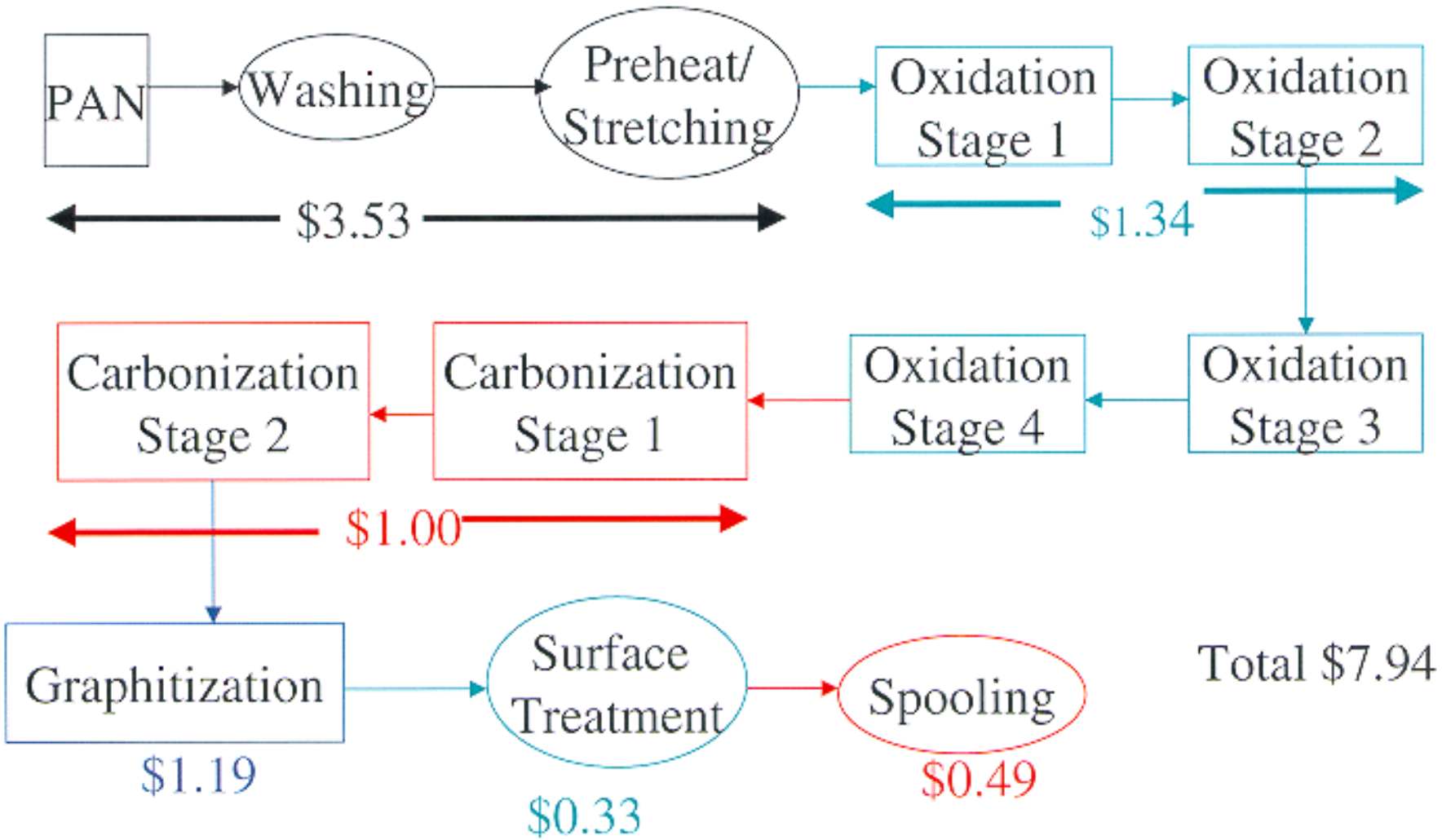
Organic/Recycled Precursors (ORNL)

Details Proprietary

Technology Deployment Line (TBD)

Develop a user facility to investigate the use of alternate precursors, alternate energy deposition methods or improvements in production line components.line components

Carbon Fiber Production Flow (Price)



DOE COMPOSITE MATERIALS RESEARCH
Carbon Fiber Production User's Facility

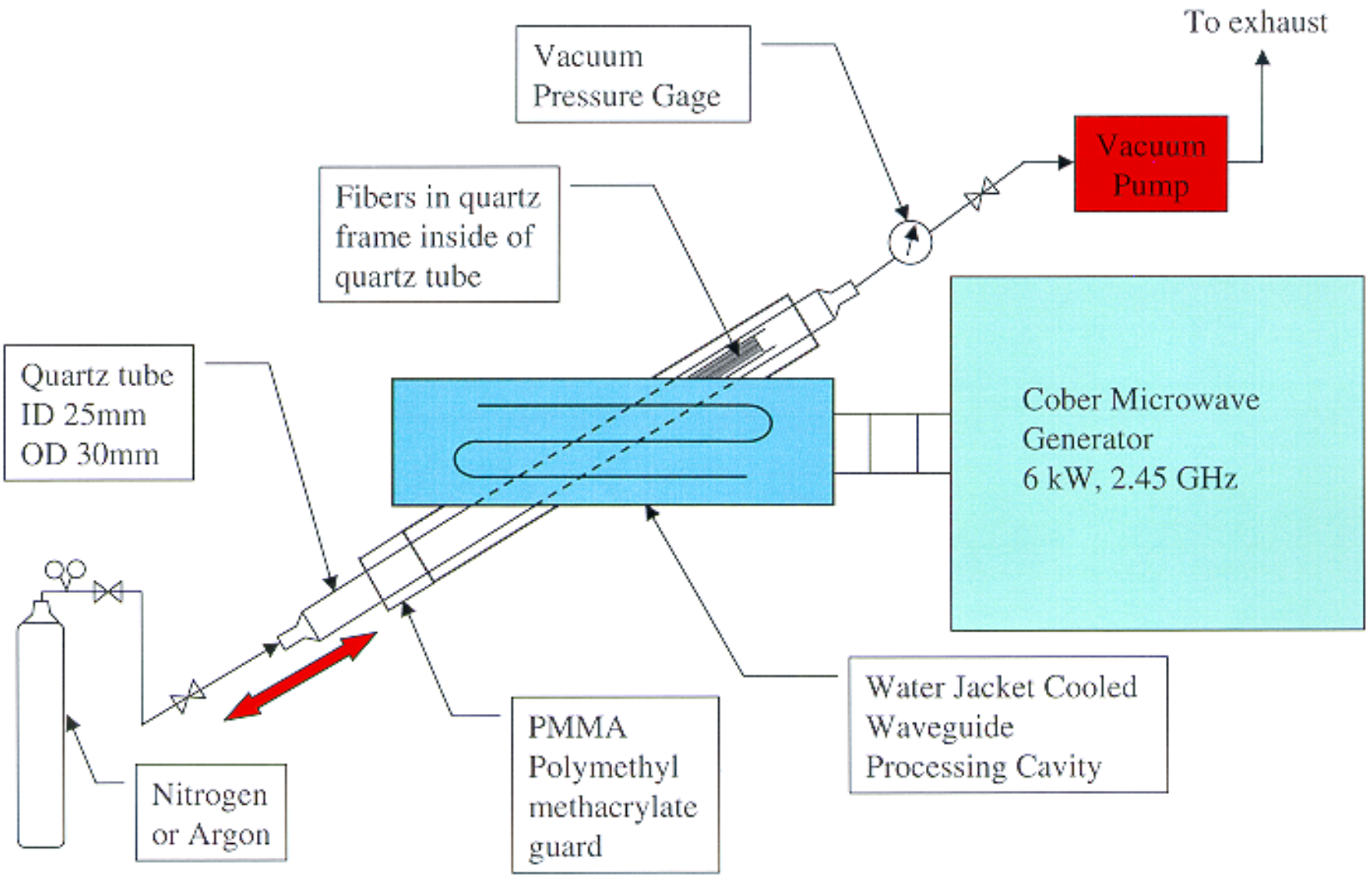
ISSUE: If lower cost precursors, new processing equipment, alternate manufacturing methods or domestic sources of precursor were available today, current manufacturers would be unable to incorporate the technology. Manufacturers do not have a system that can be shut down for trying new technologies or precursors due to the rapidly increasing demand for carbon fiber and inflexible design of current systems.

PROPOSAL: Develop a user facility to investigate the use of alternate precursors, alternate energy deposition methods or improvements in production line components.line components

FACILITY:
- Complete line (small number of tows)
- Modular Design for ease of incorporating new technologies
- All Controls with Widest Possible ranges
- Complete Fiber Characterization support equipment
- Well instrumented for process control and equipment status verification
- Focus on commercially available equipment

PRECURSOR $1.60/lb → STABILIZATION /OXIDATION 200 - 220C → CARBONIZATION 1000 - 1500 C → GRAPHATIZATION >1800 C → SIZING → FIINISHED FIBER

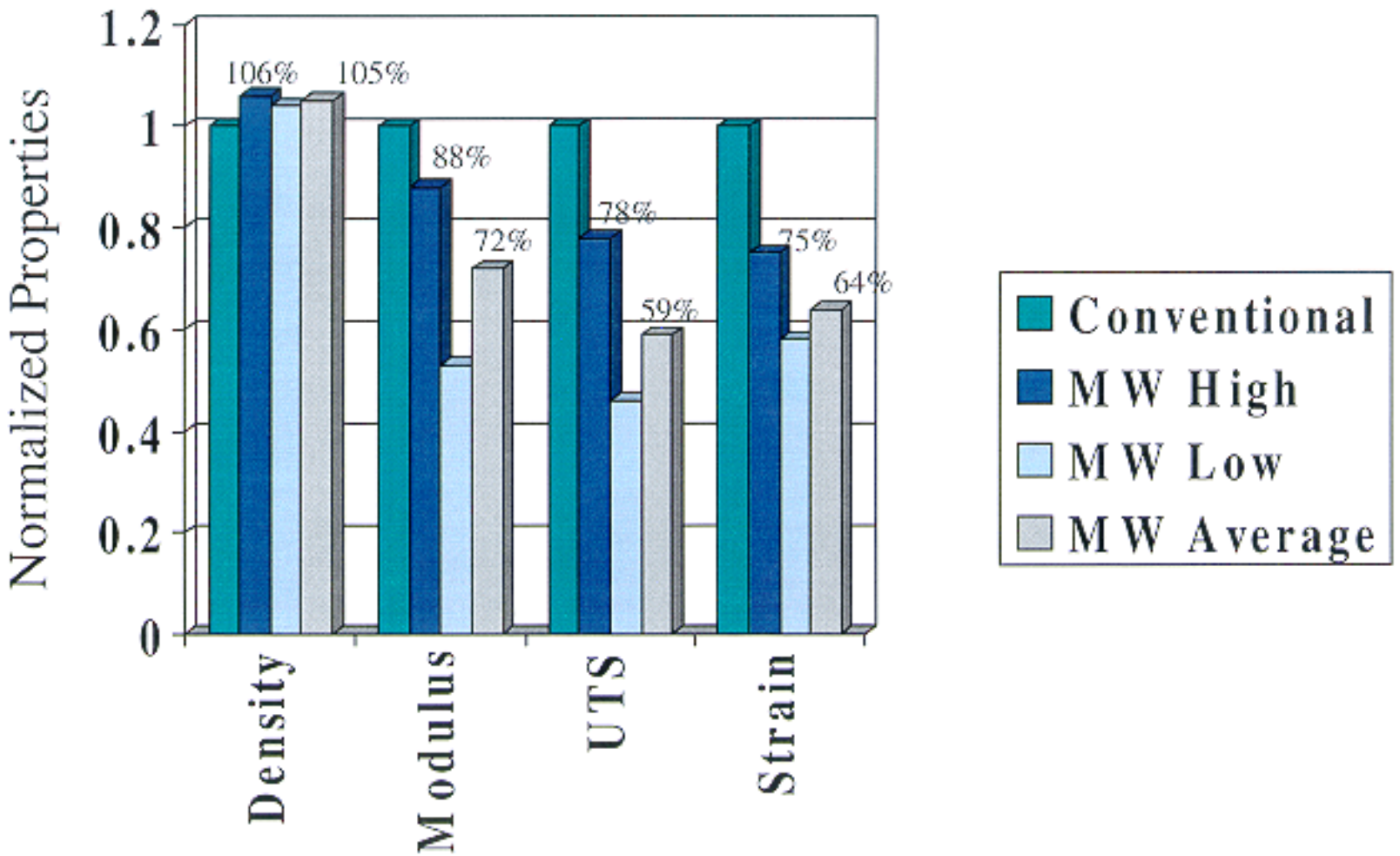
Fiber Processing via Microwave / Plasma
-Schematic-



Carbon Fiber Finger Print Properties Summary

Density (g/cm^3)	
Conventional:	1.78 - 1.84
Microwave:	1.77 - 1.88
Electrical Resistivity (ohms-cm)	
Conventional:	0.003
Microwave:	0.005 - 0.017
Tow Area (x 10^{-4} sq in)	
Conventional:	34.07
Microwave:	24.9 - 36.06
Fiber Diameter: (um)	
Conventional:	7.4
Microwave:	6.2 - 7.5

Finger Print Properties (Mechanical)



Carbon Fiber Cost By Cost Category ($/lb)

Cost Category	Conventional	Microwave	% Change
Raw Materials	3.35	3.35	0
Process Materials	0.51	0.45	-11.8
Energy (Electricity)	0.39	0.32	-18.0
Labor Expense	0.71	0.66	-7.0
Capital (+ Bldg.)	1.77	1.00	-43.5
Other Expenses	1.21	0.61	-50.0
Total	**7.94**	**6.40**	-19.4

Future Materials Research

Thermoplastic Resin System Development

Develop a structural thermoplastic system with properties equivalent or greater than thermoset systems at equal or lower cost. Such a system would be melt recyclable, hot formable and more repairable.

Rapid Cure Technologies

Investigate rapid cure technologies. May include UV, IR, E-Beam, Acoustic, etc. Several proof-of-concept projects could be used as the first phase.

Recycling Technologies

Develop methods for recycling thermoset and thermoplastic composites. These methods may include using the recycled material in less demanding but economically advantageous applications. May include the recovery of carbon fiber.

Advanced Design Concepts

Develop advanced design concepts that take in account significant parts consolidation, lower cost tooling and the use of multiple materials.

Thermoset Resin Selection

Assist in screening currently available resins and fibers. Identify appropriate carbon/resin systems and processing parameters.

Nanocomposite Tech

Develop nanocomposite reinforcing additives in the 20% to 40% range to stiffen and strengthen the resin matrix, especially thermoplastic resin systems.

DOE COMPOSITE MATERIALS RESEARCH

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PRECURSOR → **STABILIZATION /OXIDATION** → **CARBONIZATION** → **GRAPHATIZATION** → **SIZING** → **FINISHED FIBER**

$1.60/lb — **200-220C** — **1000 - 1500 C** — **>1800 C**

Future Joining Research

Non-Adhesive Joint Modeling

Develop predictive modeling and design methodologies for non-adhesive joining activities.

Rapid Cure Technologies

Investigate rapid cure technologies and adhesive systems. May include UV, IR, E-Beam, Acoustic, etc. Several proof-of-concept projects could be used as the first phase.

Advanced NDE Techniques

Fully develop non-acoustic NDE techniques for joints put together with and without adhesives.

Reversible Bonding

Develop adhesive bonding technologies that are reversible for repairability and recyclability.

Thermoplastic or Thermoset Welding - Adhesiveless Bonding

Develop methods for joining thermosets and thermoplastics without the use of adhesives or fasteners and without the introduction of a non-adherend material.

Alternate Material Joining Technologies

Investigate joining carbon fiber based composites to a variety of materials using non-adhesive techniques. Investigate surface preparation, adhesive screening and thermal expansion differences. Develop methods for mechanically fastening automotive composites. May include bolting, snap-fit joints, riveting and design methodologies that incorporate several different methods.

Future Energy Management Research

Crashworthiness Design Methodologies

Develop design methodologies for incorporating energy absorbing zones and materials into primary automotive structures.

Develop joint design criteria and methodologies for crashworthiness. Include pre-damaged joints from fatigue, environmental effects, cumulative damage. Include the use of snap fit joints for processing.

Bonded and Mechanically Fastened Structures

Conduct experimental arid analytical studies to develop methods that predict the crash performance of bonded and mechanically fastened structures. To be conducted for composite, metallic and hybrid structures.

Future Processing Research

Rapid Curing Technology

Investigate rapid cure technologies and resin systems for SRIM and RTM. May include UV, IR, E-Beam, Acoustic, etc. Several proof-of-concept projects could be used as the first phase.

Hermetic Slurry Processing

Investigate using air as the medium for depositing fibers into a preform. Would eliminate the use of water and the need for drying. May also be faster due to the flow characteristics of air as opposed to water.

Thermoplastic Forming

Investigate high rate forming of fiber reinforced thermoplastics for use as structural automotive members. May include the development of production technologies where composites are molded to a rough shape and then forming completed by thermally assisted mechanical forming.

Thermoplastic Crosslinking

Develop advanced energy methods for crosslinking thermoplastic composites. Allows components to be formed by stamping type operations and then crosslinked providing higher temperature tolerance and structural stability.

Alternate Processing Technologies

Develop non-liquid molding technologies for continuous and discontinuous carbon fibers including pultrusion, extrusion, etc.

Future Carbon Fiber Research

Low Cost Precursor

Investigate methods for producing current precursors at significantly reduced cost. Precursors account for more than half the manufacturing costs of carbon fiber. Significant reduction of precursor boost would have a large effect on the cost of carbon fiber.

Precursor Selection and Screening

Investigate the use of precursors other than PAN and Pitch for producing carbon fibers. Also investigate slightly different versions of currently available PAN and Pitch. Develop facilities for evaluating alternate precursors on a trial level and for evaluating the effects of changing stabilization/oxidation and carbonization conditions.

Non-Conventional Carbon Fiber Production

Investigate methods of producing carbon fiber without thermal pyrolysis of conventionally used precursors.

Carbon Fiber Production User's Facility

Develop a user facility to investigate the use of alternate technologies. It will be a complete line, modularly designed for ease of incorporating new technologies. It will have broad control ranges, be highly instrumented for scientific development and be constructed from commercially available equipment.