OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Aerospace Workshop Planning Session

SUMMARY REPORT

Department of Energy/Energy Efficiency and Renewable Energy

Industrial Technologies Program

September, 2010

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

OAK RIDGE National Laboratory

1.0 Introduction ____ *2*

1.1 Purpose ____ **2**

1.2 Key Findings and Recommendations ____ **2**

1.3 Dates, Location, Attendees ____ **5**

1.4 Agenda: (8 AM through 2 PM, WEDS, 2 JUN 10) ____ **6**

2.0 Presentations ____ *7*

2.1 Pratt & Whitney (Frank Preli) ____ **7**

2.2 Lockheed Martin (John Barnes) ____ **8**

2.3 Boeing (Brian Smith) ____ **9**

2.4 General Electric (Eric Huron) ____ **10**

4.0 Attachments ____ *12*

Acronyms: ____ **13**

DOE/ITP/ORNL Aerospace Workshop Planning Session

Summary Report

August 2010

1.0 Introduction

The Department of Energy (DOE) is developing new initiatives to establish energy efficient manufacturing methods and materials technologies that will enable the U.S. industrial base to maintain and expand their competitive posture in the decades ahead. DOE recognizes the time critical nature of the challenges that exist and asked Oak Ridge National Laboratory to convene an Aerospace Manufacturing Workshop comprised of strategic planners from industry and government to address the challenges and opportunities that lie ahead. The DOE Aerospace Manufacturing Workshop will help guide the future of our Nation's manufacturing competiveness and future DOE materials and manufacturing R&D initiatives focused directly in the aerospace manufacturing sector. As a precursor to this workshop, a one-day planning session with key U.S. Aerospace manufacturers was conducted in the Washington, D.C. area on June 2, 2010 to establish the agenda and basic structure of the DOE workshop. This report summarizes the discussions held during the one-day planning session and makes recommendations for further activities with emphasis on the implementation of an Aerospace Industry Workshop to address key thrusts identified during the planning session. The planning session was the first step in a process to obtain industry insights that will be of significant value in focusing the subsequent workshop on specific technology areas and DOE-relevant metrics.

1.1 Purpose

As a precursor to this workshop, Dr. Jim Williams, Honda Chair at Ohio State University, was tasked by Dr. Craig Blue, Director, Energy Materials, ORNL, to identify key participants from industry that would be invited to participate in a planning session to establish the agenda and structure of the subsequent DOE workshop. The results of the planning session will aid DOE in defining technology areas of interest and a workshop structure that will facilitate a more in-depth understanding of the Aerospace industry's energy efficiency awareness and initiatives. These results will be essential for focusing industry representatives on the most effective approaches and metrics to generate energy savings in the research, manufacturing and operational phases of the Aerospace industry.

1.2 Key Findings and Recommendations

During the planning session aerospace industry management representatives identified key thrusts that need to be addressed by the Aerospace Workshop participants to define where the greatest potential exists for energy savings in materials, process and manufacturing technology research and development. The three principal recommended thrust areas to be addressed and the supporting technology areas where research investments need to be focused are shown in the table below:

DOE/ITP Aerospace Workshop

Planning Session Summary

(Key Thrust Areas Needing to be Addressed)

Industry Drivers: a) Performance b) Weight c) Cost

Principal Thrusts		
Composites • Out of Autoclave Cure • High Strength Fibers • Advanced Resins • Process Modeling • Joining	**Low Cost Titanium** • Near Net Shape • Direct/Additive Manufacturing • Powder Metallurgy • Precision Forging • Process Modeling • Joining	**High Temperature Materials** • Hybrid Materials/Structures • Advanced Alloys • Precision Forgings • Castings vs. Forgings • Coatings • Joining

Metrics: (Note: ITP Goal is 100 Trillion BTUs/year savings)

- Specific Fuel Consumption
- Buy to Fly Ratio
- Elevated Operating Temperatures
- Re-Use/Recycle Strategy

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These three principal thrusts include:

- Composites
- Low Cost Titanium and
- High Temperature Materials

These three thrusts were based on their potential for the highest payoff in terms of energy savings for the near term. These thrusts also have the potential to have a significant impact on the Aerospace Industry's research investment drivers which include:

- Increasing system performance
- Decreasing system weight
- Reductions in system cost

An unexpected finding from the planning session is the fact that the aerospace industry does not focus on energy savings by itself as a key factor in determining their design and development process. They focus primarily on cost, weight and performance and rely heavily on the "Buy to Fly" ratio (the ratio of materials weight procured to the weight of the finished product) as a principal metric. Energy savings are only an embedded factor in their current practices of evaluating program performance. The workshop agenda will need to focus the aerospace industry attendees on the need for energy consumption as a metric in their design and development processes. Workshop participants will be tasked prior to the workshop to identify specific R&D activities within the three thrust areas that can result in significant quantifiable energy savings.

It is recommended that the follow-on Aerospace Workshop be conducted in the near future with broader industry participation to focus on the three thrust areas as summarized in more detail on attachment 4.1. At the workshop the industry experts will be able to bring their collective expertise together in a collaborative environment to quantify and further define the program thrusts that have the potential for significant energy savings in the near and far term. The results of the workshop will directly support DOE in developing a suite of competitive R&D programs to establish energy efficient manufacturing methods and materials technologies.

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1.3 Dates, Location, Attendees

The Planning Session was held in Arlington, V.A. on Wednesday, June 2, 2010, at the Strategic Analysis Conference facilities in Arlington, V.A. The session consisted of a pre-discussion event the evening before followed by working panel sessions the day of the meeting. Participants included:

DOE:	Dr. Chien-Wei-Li, Technology Manager, DOE/ITP
ORNL:	Dr. Craig Blue, Director, Energy Materials, ORNL
	Dr. Ron Ott, ORNL representative to DOE/ITP
	Dr. Jim Williams, Professor and Honda Chair, Ohio State University
	Dr. Bill Peter, Group Leader Materials Processing, ORNL
	Mr. Art Clemons, Consultant to ORNL
	Mr. Brian Horais, Consultant to ORNL
Pratt and Whitney:	Dr. Frank Preli, Chief MPE
Lockheed Martin:	Mr. John Barnes, Manager, Manufacturing Exploration and Development
Boeing:	Dr. Brian Smith, Director of Composites
General Electric:	Mr. Eric Huron, Manager of Structural Metals Development

1.4 Agenda: (8 AM through 2 PM, WEDS, 2 JUN 10)

Times	Activity	Presenter/Moderator
0730-0800	Coffee and Pastries	
0800-0820	1. Introduction	Dr. Jim Williams
0820-0840	2. Background & Expectations	Dr. Craig Blue (ORNL)
0840-0850	3. Structure of the Planning Session	Brian Horais (ORNL Consultant)
0850-0900	Coffee Break	
0900-1000	4. Industry Presentations and feedback on Energy Efficient Approaches: - Pratt and Whitney (15 Minutes per presentation) - Lockheed Martin " " - Boeing " " - General Electric " "	
1000-1130	5. Planning Session Activities: - Develop Aerospace Workshop Approach: What are the key elements for a successful workshop - Identify highest "payoff" manufacturing technologies and their applications - Define the metrics for return on investment - Identify desired workshop participants and number of participants - Suggest location and time for workshop - Develop Workshop Agenda	Jim Williams/Brian Horais
1130-1300	LUNCH (in the Ballston Area)	
1300-1400	6. Action Items and Wrap-up	Jim Williams/Brian Horais

2.0 Presentations

Dr. Craig Blue provided background information on the DOE Industrial Technologies Program and set the DOE expectations for the planning session in his opening comments which are included as attachment 4.2. A brief group discussion was conducted prior to the individual industry presentations. Summary comments from the group discussion are provided followed by specific comments from each of the four industry presentations.

Group Comments:

- GE does not focus on the energy efficient manufacturing investment - energy is an afterthought
- Emphasis for industry is weight reduction for energy savings down stream
- Need industry re-education in the ranks on the emphasis for energy savings
- Components of cost not always understood - but DOE may have already done some cost modeling that addresses energy costs
- "Buy to Fly" (the ratio of materials weight procured to the weight of the finished product) is a major cost metric
- Needs lots of convincing before large investments will be made by industry (primes and vendors) in new processes, materials, etc. - Titanium is a prime example
- Total costs consist of Cost to Make + Operational Cost
- Issues for implementing new energy efficient manufacturing approaches include: what does it cost, how does it impact the supplier's pocket book, and what new capital investment must be made
- Adoption issues exist other than just new process or material - these include qualification, certification costs - which impact the OEM's investments that must be made up front
- Industry has different business models (than DOE) that do not include manufacturing energy costs as an identifiable factor- need to be sensitive to these

2.1 Pratt & Whitney (Frank Preli)

- IR&D decisions are made on cost and performance - fuel efficiency and cost to manufacture
- "Buy to Fly" is a key metric and a direct indicator of waste
- Subcontractors are risk averse and will need to be incentivized to change their processes (this may take a disruptive shift in vendor approaches)
- Near Net Shape manufacturing may be such a disruptive shift
- Additive manufacturing (make a few versus making many) is not well developed in the US
- Life cycle cost drivers include new materials (save weight), qualification costs, fuel efficiency (787 is an example of significant life cycle fuel savings - 20 % fuel savings versus similar size jetliners)

- Multiple business models exist in industry - the challenge will be how to incentivize and how to leverage government investments
- Need to cast a broad net (10 year vision), not a narrow focus (3 year vision) to get the attention of industry that typically has ROI periods of more than 10 years on innovation investments
- Aerospace Industry is a high energy input but low volume (~10,000 aircraft) when compared to the transportation/automotive industry (50 million + vehicles)
- Aircraft have very high duty cycles and high energy consumption compared to vehicles
- The majority of aerospace industry investment dollars go to research for weight reduction and performance improvements (~75%)
- Light-weight metals and matrix composites are used in engine inlets and fan blades, while high temperature metals and materials are used in the core of the turbofan engines
- Key questions are: which Materials and which Processes to invest in
    - Titanium, steel, nickel alloys are critical - and composites are finding their way into engine applications (casings, fan blades, etc.)
- Need to move manufacturing technology research from reactive (present position) to before you need it (proactive) and not just focus on solving problems (reactive)
- Most of the manufacturing energy input is made before the "billet" is machined
- Near net shape and reuse/recycle strategies can reduce waste and manufacturing energy requirements
- Die-cast versus investment casting approaches need to be studied
- Additive manufacturing can be an area with potential large gains
- Overall recommendations for aircraft turbofan engine development: reduce buy to fly, develop lower energy use technologies, improve energy efficiency (high temperature core and lightweight fan and low pressure core)
- a 1/4 to 1/2% increase in energy efficiency is substantial (in life cycle costs/energy usage)
- Paybacks on new investments usually take up to 30 years

2.2 Lockheed Martin (John Barnes)

- Lockheed Martin's research focus on materials R&D is - 1/3 on high performance (gee whiz) and 2/3 on final product development for lower cost
- Military/Government Aerospace does not invest as much as commercial industry (Government profits limited to12%)
- F-22 buy-to-fly ratio is 110K lbs buy to 9K lbs fly (12.2:1), 101k lbs machined away
- Near net shape manufacturing can have a high payoff, but little US investment
- Additive manufacturing has high potential, but most of the innovation is occurring offshore
- Need to look at new technologies such as powder metallurgy and validate its usefulness - otherwise, scrap it

- NDE (non destructive evaluation) technologies need to be further developed to reduce the time for machining/qualification of parts
- Supply chain is the weak link in energy efficiency innovation - they look at the cost of materials in balance with machining costs
- There is opposition on the machining side for new ideas (vendors happy with status quo)
- Question: can high strength polymers eliminate aluminum? - The buy-to-fly ratio of aluminum is worse than titanium but the material costs of aluminum are so low, vendors don't care
- Can new manufacturing technologies reduce the buy-to-fly ratios (example, use pellets instead of plates for raw materials)
- Life cycle costs are driven by: fuel, corrosion and repair costs - corrosion costs are high for aluminum
- The digital factory (model then fabricate) is of interest because of the reduction in tooling costs
- Corporate R&D activities can be long-range but must include results off-ramps to continuously provide funding justifications (little steps, not big ones)

2.3 Boeing (Brian Smith)

- The Boeing 787 is all about fuel efficiency - this is what airlines base buy decisions on
- Typical buy-to-fly ratio is 12:1 (engine manufactures may be a little better)
- Assembly costs are very high in aerospace, therefore key metric is performance at an affordable or reduced cost - example is a reduction in fasteners (composites) versus traditional aluminum aircraft skins resulting in reduced assembly costs
- Over the last few years Boeing claims a 32 to 33% overall energy reduction but 60% of the parts are built outside of the company (not included in this energy reduction)
- Cost drives vendors - but the prime contractor defines the parts specifications, especially in titanium
- Innovation in composites should address higher modulus and improved toughness
- 787 - 850 planes sold: 50% carbon fiber, 25% titanium
- 737 - 25 to 35 planes produced per month: principal content is aluminum - but trades need to be conducted for aluminum versus fiber and titanium
- What is the long term "story" for aluminum as an aerospace material?
- There are four "streams" in materials and process innovation:
    - New materials (focused on supply base and partners)
    - Substitutional materials - equivalent properties at lower energy costs
    - Process improvements - such as out of autoclave curing and reduction of certification steps/barriers
    - Buy-to-fly ratio: need to reduce waste (and associated cost/energy consumption)
- Weight reduction areas are one of the highest leverage factors

- R&D investments are divided: 50% on carbon fiber, 20% on titanium, 10% on aluminum and the rest on finishes and materials
- Current R&D is balanced (new versus existing) due to the 787 and 737 productions existing simultaneously
- Highest overall leverage is performance versus cost
- Digital manufacturing in titanium is of interest: linear friction welding, reduced machining costs, powders (with minimal defects)
- Challenge in supply chain is "how to bring in new technologies?"
- Drivers for carbon fiber are: buy-to-fly, out of autoclave cure, joining parts together
- What about aircraft seats? The airlines buy these and there is little R&D on efficiency
- Need to expand the analysis tools for fiber materials to expand the solution set (beyond the typical 0/45/90 degree analysis criteria)
- Bring supply chain along to help pick up new technologies

2.4 General Electric (Eric Huron)

- Materials science R&D is not "energy aware" (i.e. energy consumption is not explicitly considered as a metric)
    - Principal metrics are dollars per pound, specific fuel consumption, and repair ability
- Industry will pay more in manufacturing to save weight
- High temperature materials research is always worthwhile - reduces specific fuel consumption in life cycle costs
- Low energy manufacturing is of interest, for example: melt-less titanium, powder, consolidation, and the associated defect inspection/NDE
- Nickel based processes need to be improved - raise yields of current alloys, and expand use of new alloys
- Smaller furnaces should be introduced to reduce energy costs (already being done in Europe)
- Modeling should be improved to include hybrid materials (and their properties), not just monolithic materials properties
- How to encourage capital investments within industry (primes and vendors)?
- Additive manufacturing should be investigated for manufacturing as well as repairing benefits
- Near net shape manufacturing - in rolling fabrication applications - should be investigated
- The fragmented aerospace industry needs to develop a means to share certification costs
- Overall, additive manufacturing, hybrid structures and near-net-shape approaches are of high importance
- New materials and coatings that would allow more crude alternative fuels/blends – materials that would eliminate corrosion or contamination
- Thermal management a concern
- Alternative materials – getting away from rare earths

3.0 Planning Session Brainstorming

After the industry presentations a brainstorming session was held, lead by Brian Horais and Jim Williams, to capture the key comments and inputs from the industry representatives. The results of this brainstorming session, included in attachment 4.3, are summarized in the following paragraphs.

Initial discussions focused on First Costs (manufacturing) versus Ownership Costs (life cycle). The First Costs discussions were further divided into categories for metals, composites, and enabling processes/technologies. Each of these subcategories was then divided into their relevant categories (such as castings, joining, curing, heat treating, etc.)

The discussion then shifted to a free-form panel on the "low hanging fruit" or to state it in a different way, which technologies and processes offer the most near term and most productive means to improve manufacturing and operational energy efficiency. Included in this discussion were:

- Near net shape methods/technologies
- Modeling
- NDE
- New materials/architectures for product improvement
- Substitutional materials
- Manage/utilize revert (scrap)
- Adoption incentives by suppliers and OEMs
- Metrics for success and ROI calculations
- Composites
- Ti production and processing
- Heat treating
- Joining
- Machining
- Castings
- Standardization of specifications

Subsequent to the planning session several of the participants provided feedback on the content and planned workshop. A suggested structure for the workshop was submitted by Jim Preli of Pratt & Whitney and is included as attachment 4.4.

4.0 Attachments

4.1 Background Information and Expectations for Planning Session

4.2 Workshop Organizational Format (suggested by Jim Preli, P&W)

4.3 Planning Session/Brainstorming Charts Prepared by Dr. Jim Williams

4.4 Planning Session Summary Chart of Key Thrust Areas

Acronyms:

DOE – Department of Energy

ORNL – Oak Ridge National Laboratory

ITP – Industrial Technologies Program

IR&D – Internal Research and Development

OEM – Original Equipment Manufacturers

R&D – Research and Development

NDE –Non Destructive Evaluation

ROI – Return on Investment

Background Information and Expectations for Planning Session

- **Why are We Here?**
  - **To develop the structure of a Workshop that will provide a basis for future DOE/ITP investments in energy efficient manufacturing and materials research**
  - **To help identify the potential areas of "high payoff" investments**
- **How can Industry Help?**
  - **Provide Industry Perspectives on IR&D Investment Decisions**
  - **Help understand the overall life cycle contributions**
  - **Help sell the program**
- **What does this Planning Group Need to Do?**
  - **Define the metrics to evaluate future programs**
  - **Develop the Workshop Approach**
  - **Help understand opportunities for leveraging**
- **Other Thoughts**
  - **DOE/DOD/NASA Program Phases**
  - **Which combinations of R&D and life cycle processes are best?**

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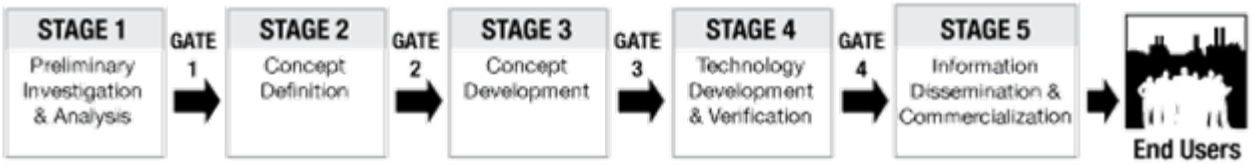
Opportunity Evaluation Criteria

DOE Opportunity Award Criteria	Potential ITP Evaluation Criteria
Criterion 1: Technical Merits of the Proposed Technology, Weight: [25%]	**Criterion A:** Total Process Energy Efficiency: [TBD%]
Criterion 2: Potential Energy, Economic, Environmental, and Market Benefits, Weight: [40%]	**Criterion B:** Emissions Reduction [TBD%]
Criterion 3: Technical Approach and Project Management Plan, Weight: [25%]	**Criterion C:** Leveraging Industry Investment: [TBD%]
Criterion 4: Qualifications and Resources, Weight: [10%] *Applicants with non-federal cost-share above the minimum may be given preferential consideration.*	**Criterion D:** Technical Merit [TBD%]
	Criterion E: Maintaining & Increasing U.S. Capabilities [TBD%]

Evaluation Criteria need to be developed that will support the ITP objectives and priorities

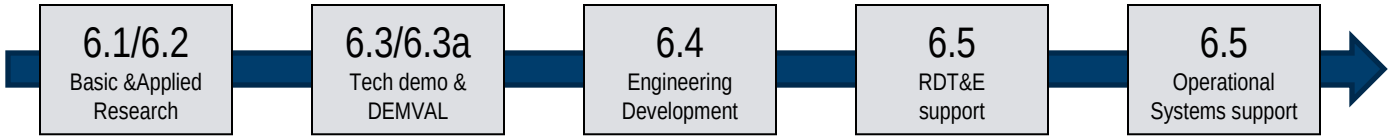
Developmental Process Comparisons

DOE / ITP



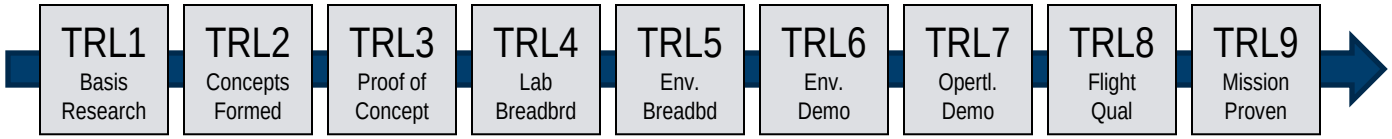
Stage Gate Process Management

DOD



Research, Development, Test and Evaluation Program Elements

NASA



Technology Readiness Levels

DOE, DOD and NASA all have their own process descriptions for the development life cycle

Sample Program Category Groupings

Total Program Energy Efficiency can be derived through a number of combinations of R&D versus life cycle investments

- ***This Workshop needs to decide the best programs to promote***

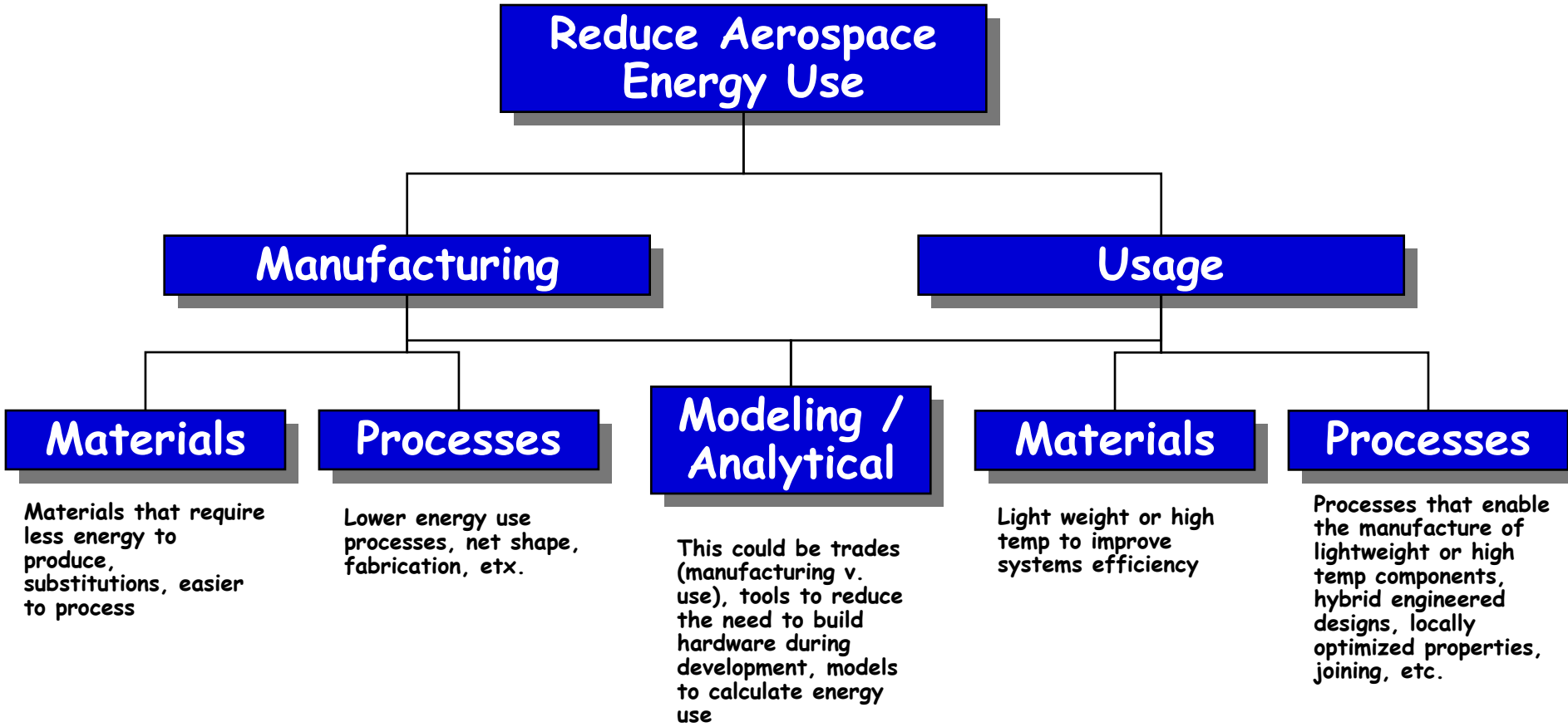
Pro-gram	Manufacturing & Materials R&D	Life Cycle Process Development	Overall Process Energy Demands	Should this be Funded?	Should DOE/ITP Fund ?	Should Industry Fund or co-fund?
A				YES	?	?
B				YES	?	?
C				YES	?	?
D				YES	?	?
E				NO	?	?

Color Key

Program /Process with Reduced Energy Demands

Program /Process with Increased Energy Demands

Workshop Organizational Format



Much of the material on the preceding pages could be categorized into these boxes to help guide the group's thinking. Each of the boxes above could be further subdivided by type of material or type of process

Outline of Workshop Topics/Thrusts

- First Costs
  - Metals Processes
    - Forgings including billet
    - Castings including re-melt stock
    - Machining
    - Heat Treat
    - Coating
  - Composites
    - Fiber Manufacturing
    - Weaving
    - Impregnation
    - Curing
  - Enabling processes/technologies
    - Joining
    - NDE
    - Tooling
- Ownership costs (excluding purchase cost)
  - Fuel consumption
  - Life
  - MRO (Maintenance, Repair and Overhaul)
  - Availability

Low Hanging Fruit

- **Near net shape methods/technologies**
  - Additive manufacturing
  - Precision forging
  - Powder metallurgy
- **Modeling**
  - Process modeling including defects and their sources
  - Performance modeling including minimum property values
  - Cost modeling which includes energy
  - Design tools for inhomogeneous mat'ls
- **NDE**
  - Near net shape
  - Real time
- **New materials/architectures for product improvement**
  - Light weight
  - Better SFC (higher operating T)
  - Hybrids materials and structures
- **Substitutional materials**

Low Hanging Fruit (cont'd)

- Manage/utilize revert (scrap)
- Adoption incentives by suppliers and OEMs
- Metrics for success and ROI calculations
  - Energy savings
  - Jobs
  - Green House gas reductions
- Participants
  - OEMs
- Constraints
  - ITAR
  - Offset agreements
- Composites
  - SFC improvements
  - Higher performance
  - Lower cost fiber
  - Out of autoclave and novel curing
  - Discontinuous reinforcements

Low Hanging Fruit (cont'd)

- Ti production and processing
- Heat treating
  - Rapid/energy efficient heating
- Joining
  - Solid state processes
    - Friction stir methods
  - Drill and fill
- Machining
  - High speed
  - Alternate methods
- Castings
  - Permanent mold
- Standarization of specifications

Workshop Structure & Schedule

- 1-1/2 days overall
  - ½ Day: Introduction/scope definition presentations
  - ½ Day: Sub-group meetings
  - Sub-group report outs
- Timing and potential days for workshop
  - The workshop must be completed by mid-August for 2 reasons:
    1. Summer vacations will make scheduling problematic after mid-August
    2. The intended work-product is a DoE Program Plan which must be ready by September 30 to get funding consideration
  - Potential dates are:
    - August 4&5
    - August 11&12 or August 12&13