Materials Of Concern For Gas Turbine Propulsion Systems

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Pratt & Whitney is being driven by market demands, federal regulations, and corporate policies to eliminate the use of hazardous materials in the design, manufacture, and refurbishment of gas turbine engine components. A list of hazardous materials has been identified, based on customer-driven requirements, as well as current and expected U.S. and foreign regulations. A data base has been created that links targeted materials to specifications called out in P&W engine designs. Target materials have been ranked according to relative toxicities that have been prioritized and published by the University of Tennessee and Purdue University. A Hazardous Materials Index has been developed as an important metric to track progress in the development of green components and products.

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Introduction

This paper describes a disciplined approach to identifying and quantifying risks associated with the use of hazardous materials in the design, manufacture and maintenance of gas turbine engines and space propulsion systems. Customer-driven concerns, as well as federal, state, local and foreign regulations form the basis and rationale for the establishment of a Pratt & Whitney materials of concern list. A data base has been established that contains hazardous material information for all of the material and process specifications called out on component drawings. The data base is populated with quantitative data measuring the relative toxicity or hazardous nature of these materials. A hazardous materials index is then defined which is the summation of the individual toxic or hazardous attributes for any engine part, assembly or module, or for the entire propulsion system. The data base and index values drive both component design and material & process development via standard work tools. Aggressive goals for hazardous material reduction are then tied directly to the index and are tracked on a continuing basis.

Background and Approach

Pratt & Whitney has invested significant resources over the past fifteen to twenty years in the development of new material and chemical process technologies. These materials and processes address customer and regulatory requirements by providing non-hazardous alternates for the design, manufacture and maintenance of engines. We have successfully reduced toxic air emissions from our facilities by 99% and hazardous waste by 83% from 1988 to 1999. Ozone Depleting Substances and NESHAP non-compliant handwipe solvents have been completely eliminated in our U.S. operations. Our Standard Practices Manual lists approved alternates for non-compliant materials and for many other hazardous substances.

More recently, Pratt & Whitney has initiated an aggressive Green Engine Program, Figure 1, a rigorous approach to minimizing environmental and health impacts associated with the design, manufacture, use, maintenance and ultimate disposal of our products. We have committed substantial additional resources to the creation of a highly disciplined approach to identifying, measuring and controlling key hazardous materials for propulsion systems. The objectives of this new approach include, first, the identification of a well defined list of targeted materials based on specific regulatory and customer-driven concerns; second, the creation of a data base that documents quantitatively the level of concern of each material and links these hazard values to the material specifications called out for our engine components; third, the definition of a hazardous materials index that clearly measures the environmental and human health impacts of our designs and readily permits tracking of product values on an ongoing basis; fourth, the development of standard work tools that guide the designer in the selection of non-hazardous materials; and, finally, the use of this information to drive the development of new technology to meet aggressive hazardous material reduction goals. An additional future objective is to refine a life cycle cost model that defines the economic value of new technologies.

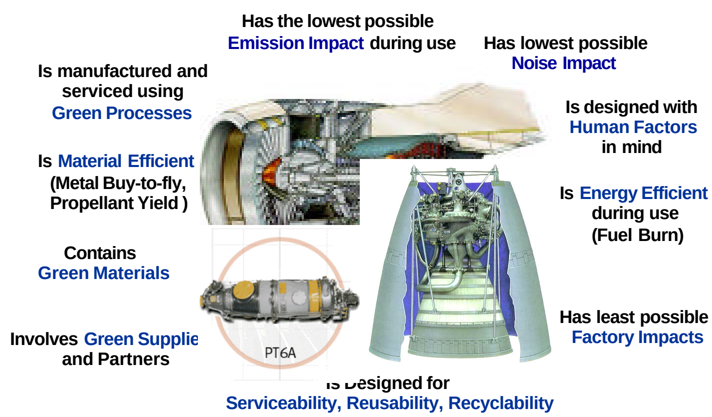


Figure 1. Scope of Green Engine Program

Materials of Concern

A list of materials that are of specific concern in the gas turbine and space propulsion business has been developed, based on both regulatory and customer input over many years. The U.S. Environmental Protection Agency, the European Union and other local, national and international regulatory agencies have targeted many hazardous materials for control or elimination. For many years, our military customers have required the identification and control of hazardous materials in products manufactured for their use. More recently, commercial customers are restricting or banning the use of certain materials in engines and airframes. The Pratt & Whitney materials of concern list includes the use of all chemicals identified by these bodies that are relevant to our products.

Table I is a list of these materials, divided into three categories, indicating levels of restrictions for use in new designs. The first column contains a list of materials that are prohibited from use, as valid alternates have been approved. The second column lists high-risk materials that are restricted for use, requiring management approval according to a standard work protocol that will be described later. As alternate materials are developed and validated, restricted materials become prohibited for use in new designs. Finally, the third column lists materials that have some negative environmental or health impact and which may be replaced in the future.

Prior to 1994, workers at the University of Tennessee developed an algorithm to quantify and rank the relative hazards of more than one thousand hazardous chemicals. Environmental and health impacts were based primarily on aquatic toxicity factors. From July, 1994 through August 1997, workers at Purdue University modified this approach to include impacts of these chemicals on air quality, potential for soil and groundwater contamination, and stratospheric ozone depletion. They also considered impacts on human health, considering factors such as toxicity, both chronic and acute, and carcinogenicity. The hazard values calculated using the Purdue University rankings were used at Pratt & Whitney to populate a data base linked to gas turbine material specifications as described below.

Materials Of Concern Data Base

The "Bills of Material" (BOM) for Pratt & Whitney engines are controlled by over 2000 industry and internal specifications. A data base was created by surveying (visually inspecting) these documents and recording the "callouts" of prohibited and restricted materials of concern from the list in Table I. The data base was then populated with relative hazard values from the Purdue University study. Since some documents specify the use of multiple hazardous materials, the total hazard value for each specification was determined by summing the individual values for all materials of concern used. In this way, we were able to quantify the environmental and human health risks associated with every specification used in our product designs. This powerful data base could then be used to query bills of material for component, assembly, module and engine designs as described below.

Hazardous Materials Index

The data base described above linked the relative hazard values for materials of concern to the specifications called out on component and assembly drawings. The purpose was to create a tool for quantifying the relative environmental and human health impacts that resulted from our product designs. A metric rigorously determined in this way would provide a highly credible driver for technology development.

A hazardous materials index was defined based on an algorithm used at Pratt & Whitney Canada:

$$I_h = \sum_{n=1}^{N} T_n * P_n / D$$

where: I_h = Hazardous Material Index
N = number of specifications in design
T_n = hazard value of n^{th} specification
P_n = number of part numbers that call out specification n
D = total number of part numbers in the design

For any component, assembly, module or engine, the Hazardous Materials Index, I_h, is defined as the summation over all the specifications in the design of all the specification hazard values, multiplied by the total number of specified parts used and normalized to the total number of parts in the design. By normalizing the total hazard value, products of different size and complexity can be compared to identify the biggest impacts and opportunities for improvement. The hazardous materials index can be used to set quantifiable goals and track progress in attaining them.

Table I
Materials of Concern

Prohibited	Restricted	To Be Reduced
Arsenic & compounds	Chromium, hexavalent	Acetone
Asbestos	Class II ODS	Ammonia
Benzene	Cyanides	Butyl alcohol
Beryllium	Dimethylformamide	Ethyl benzene
Cadmium & compounds	HCFC-14 lb & HCFC-22	n-Hexane
Chlorinated solvents	Hydrazine	Hydrochloric acid
Ethyl alcohol	Hydrofluoric acid	Isocyanates
Ethylene glycol ether compounds	Hydrogen fluoride gas	n-methyl-2- pyrrolidone
Formaldehyde	Lead & compounds	Isopropyl alcohol
Mercury & compounds	Manmade fibers, e.g., cristobalite , fiberfrax	Nickel plate
Methanol (methyl alcohol)	MDA (4’, 4’-Methylenedianiline)	Nitric acid
Methylene chloride	Methyl alcohol (methanol)	Petroleum distillates (e.g., Naptha, Mineral Spirits, Stoddard Solvent, Varsol, evaporative lubricants)
Class I ozone depleting substances	Methyl ethyl ketone (MEK, 2-butanone)	Phosphoric acid
Radioactive materials, Including thoriated (TD) nickel	Methyl iso-butyl ketone (MIBK, 4-methyl-2- pentanone)	Sec-butyl alcohol
Toluene diisocyanate	Phenol	Sulfuric acid
	Styrene	1, 2, 4-Trimethylbenzene
	Toluene	
	Xylene	

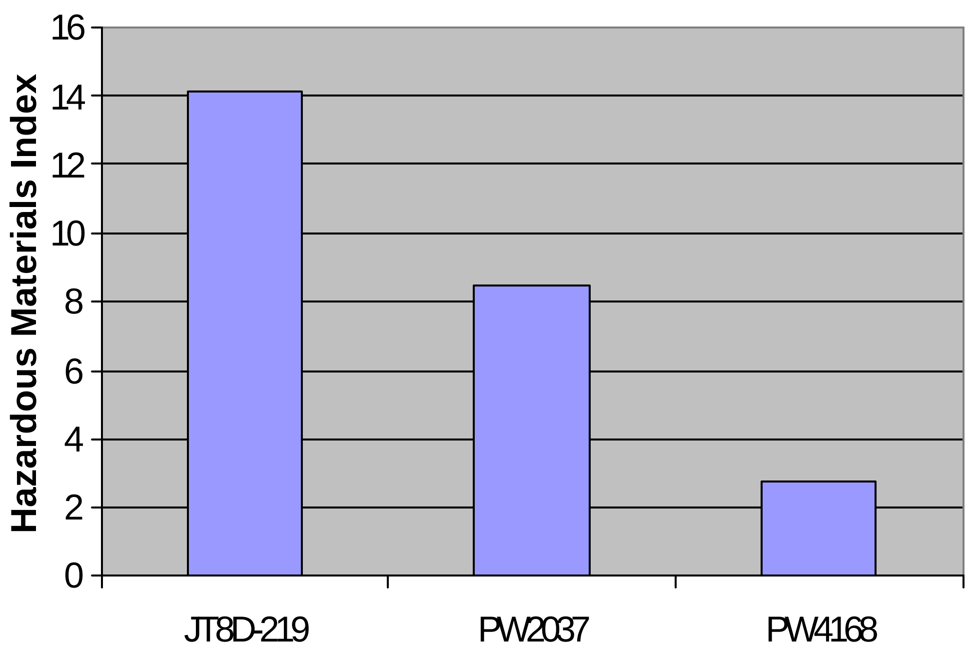


Figure 2. Prohibited Materials Of Concern – Legacy Engines

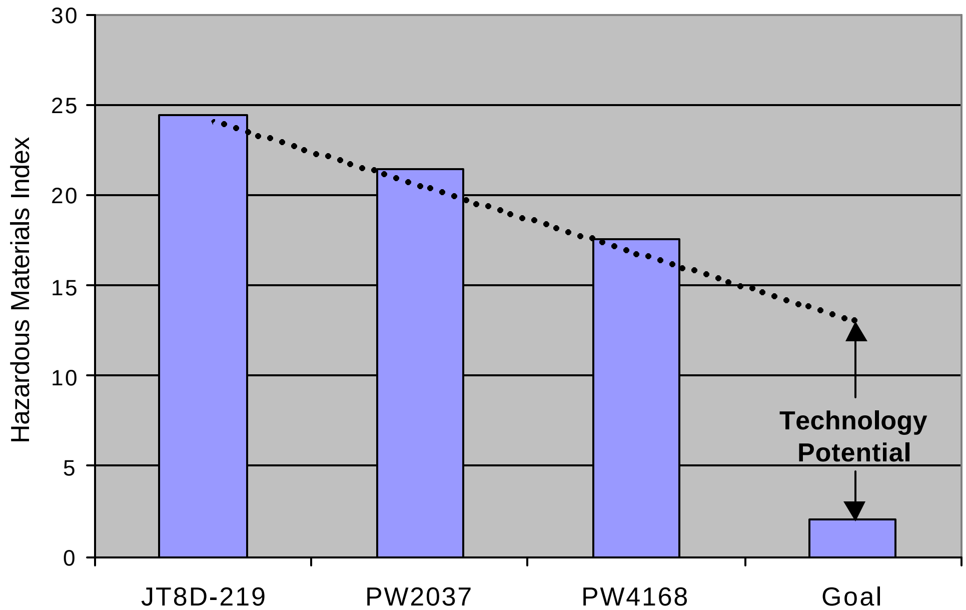


Figure 3. Restricted Materials Of Concern – Legacy Engines

A hazardous materials index can be easily calculated for prohibited and restricted materials of concern, separately. Figure 2 illustrates how the use of prohibited materials of concern has decreased substantially in newer engines, compared to legacy designs. Figure 3 illustrates that although some progress has been made in the elimination of restricted materials, the opportunity to improve is substantial. Considering the trends in these two figures, it is obvious that the index for prohibited materials is driving technology development needs for mature engines, while the index for restricted materials is driving technology for new designs. The latter technology then flows down through our legacy products via the specification change process.

Figures 4 and 5 illustrate how technology links directly to the hazardous materials index for a current generation engine. The percent contribution to the total index by any specific material of concern can be easily extracted from the data base for any particular engine. For instance, eliminating leaded dry film lubricants and silver plated fasteners from the PW6000, currently being developed, will result in a reduction of the restricted materials index by 26.6 %. Eliminating chromates in the form of chromic acid anodize, conversion coatings, primers and chrome plate will reduce the index by another 33.8%. The estimated life cycle cost savings is also shown in these figures. Our life cycle cost model is currently being refined and will be the subject of a future paper. While technology is being developed to replace other materials shown in the figures, clearly our greatest focus is on the big hitters.

Design Standard Work

The materials of concern data base is linked to drawing specifications and has enabled the creation of a standard work tool for designers. A standard work protocol facilitates the selection of "green" materials and processes for new designs. Figure 6 shows schematically the materials design and approval process. The tool contains background information, technical contacts and protocols. It references a list of material and process specifications that contain materials of concern. The designer can also link to the data base containing materials of concern and hazard rating detail. Finally, it links to a menu for selection of alternate materials and processes, cross-referenced by specification.

Green Materials And Processes For The PW6000

Figure 7 summarizes our technology development program to replace materials of concern in the PW6000 engine. It is anticipated that lead, cadmium and chromate alternates, in addition to elimination of xylene and toluene in manufacturing processes, will result in a dramatic reduction of the hazardous materials index compared to recent generations of engines.

Summary and Conclusions

The vision of green gas turbine and space propulsion systems is rapidly becoming a reality at Pratt & Whitney. Hazardous materials in our products and processes throughout the life cycle are aspects of the green engine that are receiving high priority. The disciplined approach described in this paper has helped to create a technology development roadmap based on credible and accurate data. Materials of concern have been identified based on customer- and regulation-driven requirements. Relative environmental and human health impacts have been documented using a credible academic study. A powerful data base has been constructed that has been linked to design specifications and is used to query product bills of material for hazardous material content. Accurate documentation and mapping of hazardous materials applications throughout the product design can be accomplished. A hazardous materials index has been defined to accurately characterize environmental and human health impacts and is used to compare products of different size and complexity. It is also used to accurately gauge progress toward attainment of quantifiable goals. Most importantly, the index identifies areas of greatest toxicity and associated life cycle costs and drives development of technology. A standard work tool has been created to guide designers in the selection of materials and processes. Finally, the development of a new generation of "green" engines, starting with the PW6000, can be credibly documented and publicized.

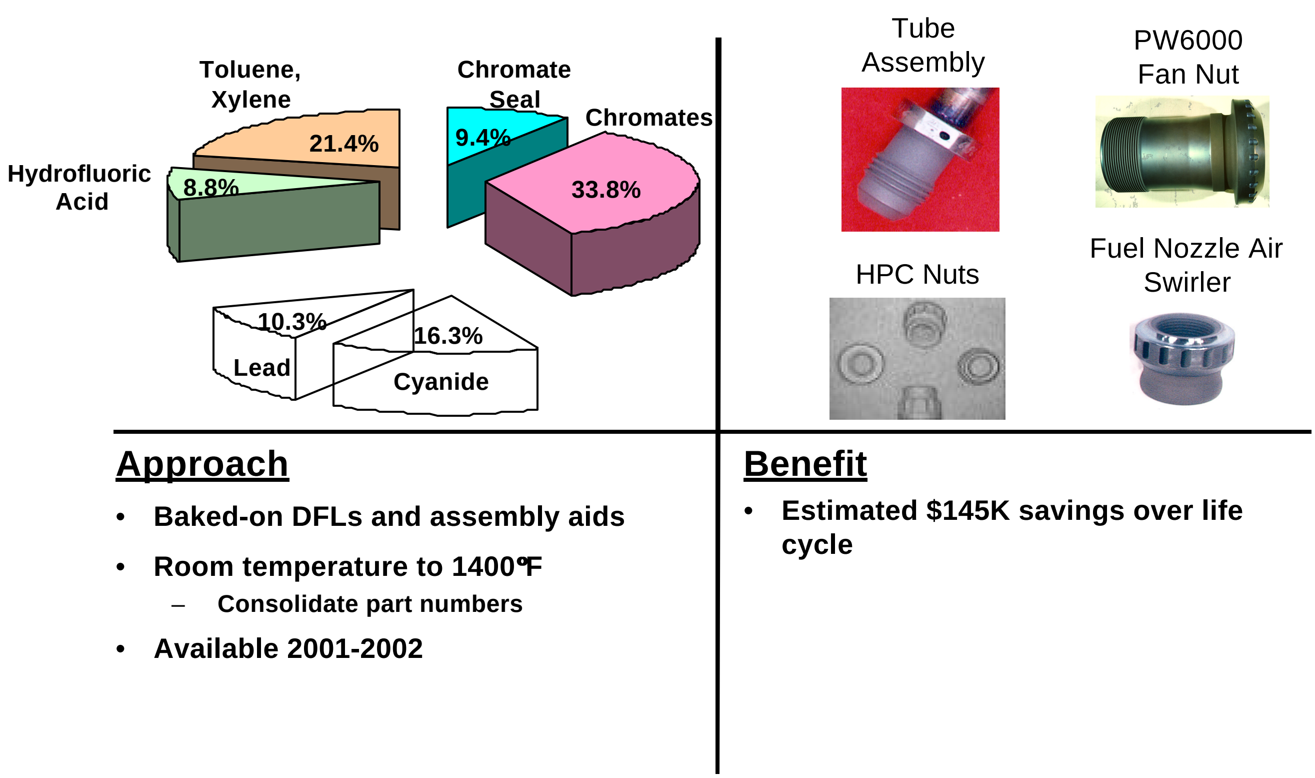
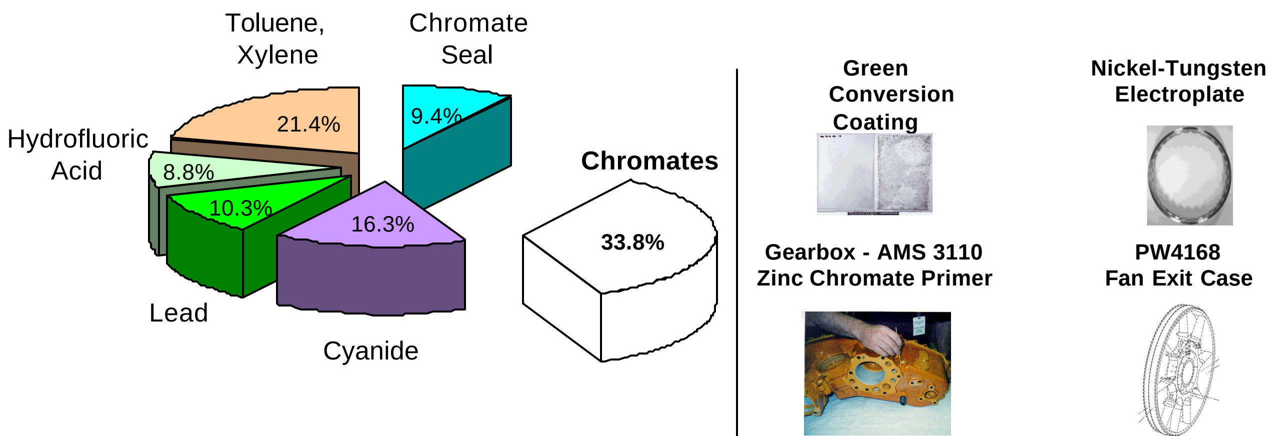


Figure 4. Percentage Contributions From Lead And Cyanide To The Hazardous Materials Index For A Legacy Engine



Approach

- Sulfuric acid to replace chromic
- Chromate-free conversion coatings
- New primers and sealants
- Controlled nickel-tungsten process to replace chrome
- Available 2001-2003

Benefit

- Estimated $180K savings over life cycle

Figure 5. Percentage Contributions From Chromates To The Hazardous Materials Index For A Legacy Engine

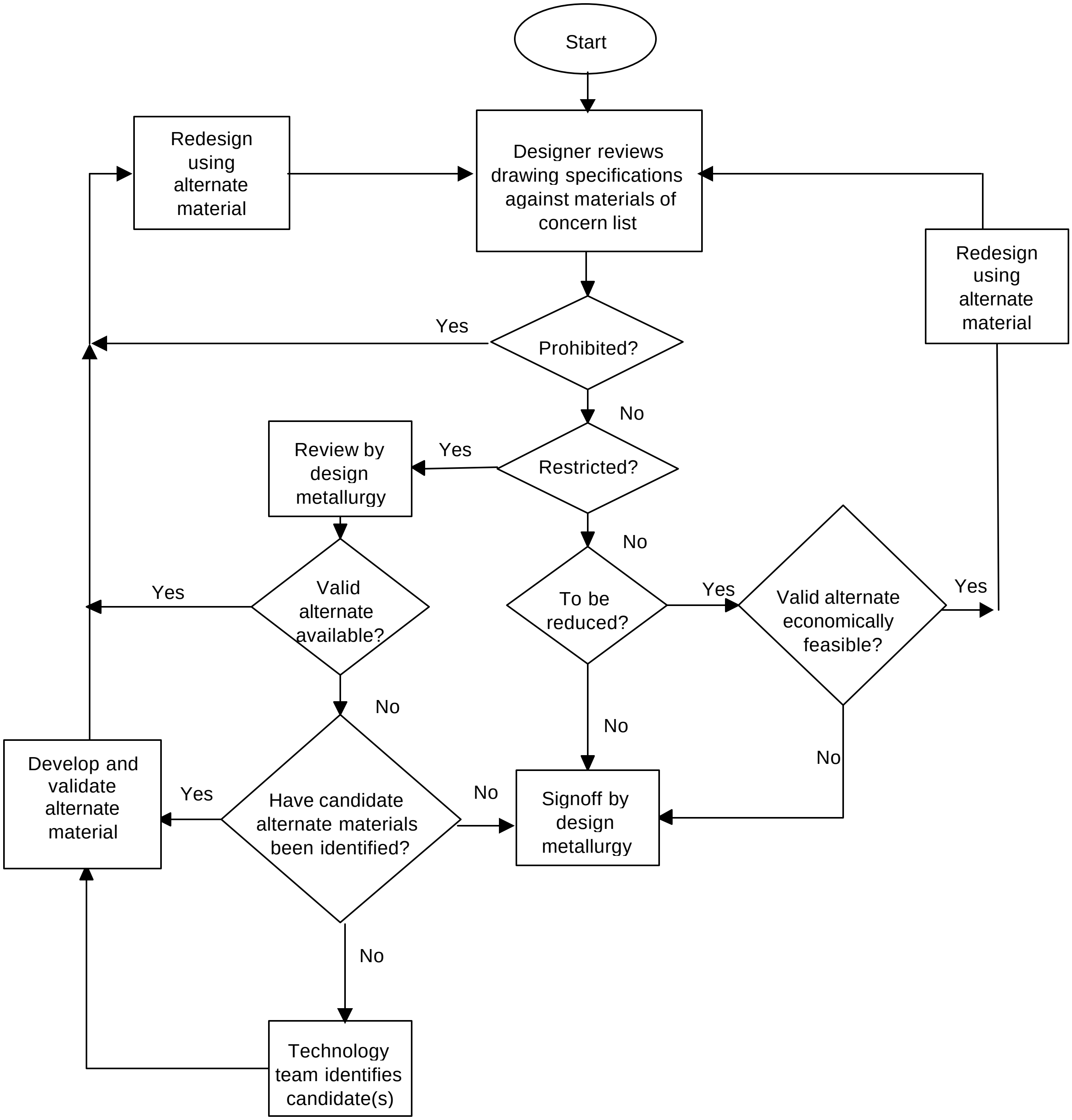


Figure 6. Schematic – Standard Work Protocol

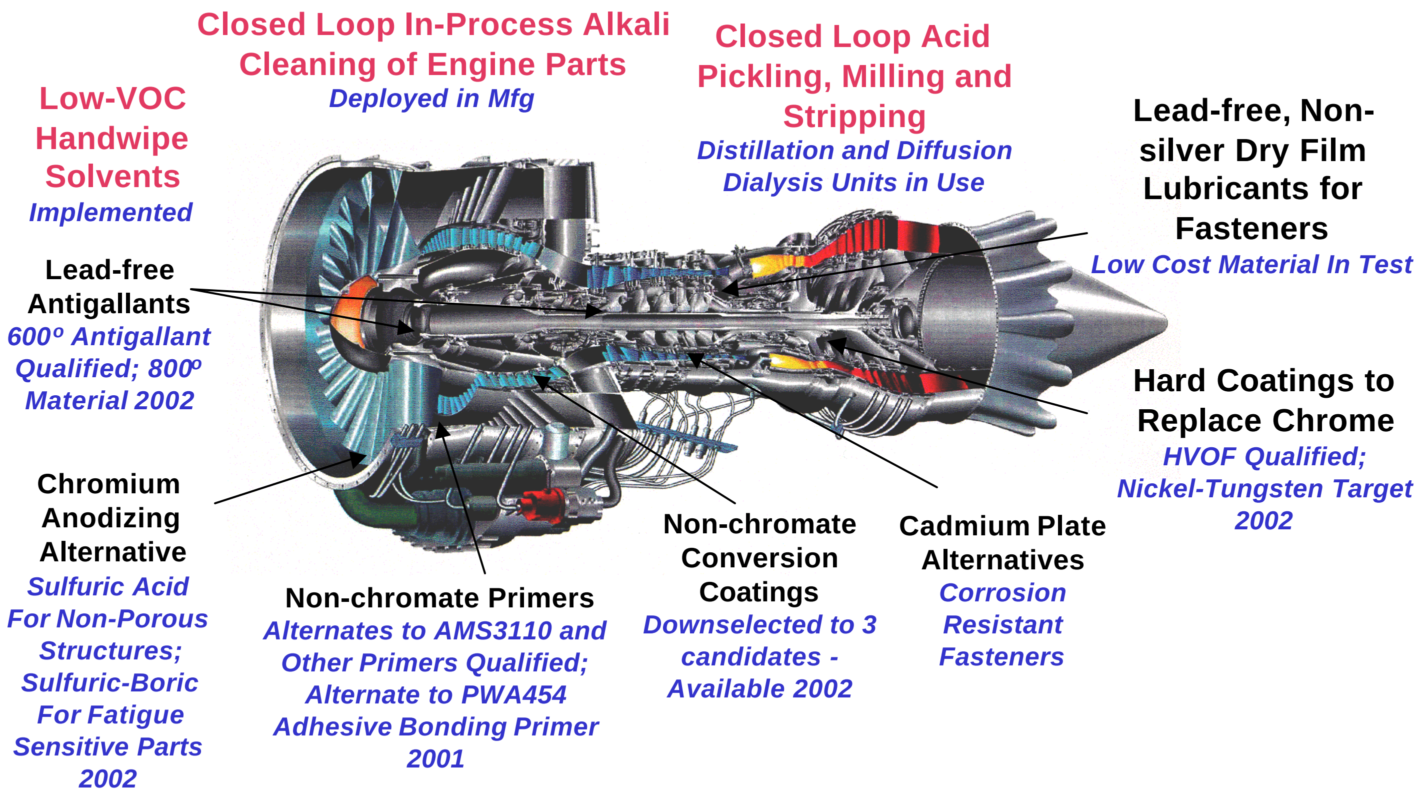


Figure 7. Green Materials and Processes For The PW6000

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