FUEL CELL ENVIRONMENTAL LIFE CYCLE ASSESSMENT: A PROGRESS REPORT

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Energy generation using fuel cells offers the possibility of high conversion efficiency and reduced pollution. Thus, in the future, conventional methods of energy generation using coal-fired power plants, natural gas turbines and internal combustion engines can potentially be replaced by fuel cells. The United States, Japan and several countries in Europe are currently developing fuel cells for transportation, distributed energy generation and portable electronics applications. On a system basis, the efficiency of chemical to electrical energy conversion in fuel cells can be as high as 45%. Also, because of the lower operating temperatures compared to turbines and internal combustion engines, emissions such as carbon monoxide and nitrogen oxides are extremely small. An assessment of the environmental impact of fuel cells over the entire lifecycle is needed to determine the specific benefits in various application scenarios. Such a comparative pollutants assessment must include a "cradle to grave" approach encompassing fuel production, fuel transportation, materials/manufacturing processes, waste management, and recycling. A comparative pollutant model would be a useful tool for industry and government in estimating energy savings and environmental credits, and providing a holistic understanding on regulatory needs. Another important benefit would be the ability to make appropriate comparisons with competitive energy generation technologies such as hybrids, turbines, and internal combustion engines, and to set up realistic targets. Also, exercising the model will assist in the initial screening for potential hot spots and showstoppers and focus on the right component technologies design for manufacturing, designs for input substitution and waste minimization, and prevent any unforeseen burdens.

In order to achieve the above goals EPA's National Risk Management Laboratory and the Jet Propulsion Laboratory (JPL) have initiated a program on "Model Development for Fuel Cell Environment Life Cycle Assessment(LCA)" through an Interagency Agreement between EPA and NASA laid out in October 2002. The near-term goal is to develop a comparative pollutants model (CPM) tool and a long-term goal of developing comparative risk assessment models (CRAMs).

The specific objectives of this initial phase effort are:

1. Review of state-of-art manufacturing technology for polymer electrolyte membrane fuel cells.
2. Develop a list of raw materials, process methods, recycling techniques along with specific energy requirements and emission characteristics
3. Adopt LCA methodology suitable for fuel cells and develop a portable model tool that will accept queries and access databases and generate emission output reports.
4. Exercise model to deliver query-based reports for a few case examples to validate the model.

The specific accomplishments of the initial efforts are summarized below:

1. A review of the state of art technology of polymer electrolyte membrane fuel cells and solid oxide fuel cells and a summary of environmental impact has been completed.
2. Background literature survey on LCA of fuel cells has been completed
3. LCA methodology applicable for fuel cells has been identified

4. Goal Definition for LCA has been completed
5. Definition of life cycle stage boundaries and components within boundaries have been identified
6. Inventory methodology based on energy inputs has been defined.
7. Key data sources data have been identified
8. Conceptual framework for model development has been completed

Preliminary overall assessment of environmental impact for all the life cycle stages has suggested the following:

Maintaining a high well-to-wheels efficiency of the PEM fuel cell based transportation applications is key to realizing reduced carbon dioxide emissions. The energy generation phase thus provides the opportunity for significant environmental benefit. If renewable fuels are used, the net carbon dioxide emissions can be reduced to a minimal value resulting in reduction of the greenhouse gas emissions. Fuels would need to be de-sulfurized and this adds substances such as zinc oxide, zinc sulfide to the processing and recovery steps. Choice of fuel type is key to maximizing benefits. It is therefore important to define the fuel and assess its impact from a well to wheels standpoint. Manufacturing processes for polymers, catalysts and inks must ensure that the use of volatile organics is minimal. Energy intensive processes such as that for the production of pure graphite must be minimized. The technology of PEM fuel cells requires noble metal catalysts in the fuel processor and the fuel cell stack. These materials will have to be recovered before disposal. Recycling and disposal of fluoropolymers in the membrane and bipolar plates would require precautions because of the release of hazardous fluorine containing substances.

Solid oxide fuel cells are anticipated to replace natural gas and coal power plants. The key benefit is the lower carbon dioxide emissions as a direct result of higher fuel to electric efficiency of the fuel cell systems. Also, the operating temperatures of the fuel cell are well below that required for producing NO_x. Hence considerable benefits will be realized in the energy generation phase of the life cycle. The fabrication of the fuel cells requires energy intensive high temperature processes. The fuel cell also uses heavy metals such as nickel, chromium, and manganese in the catalysts, electrodes and interconnects which are prepared in the appropriate pure chemical forms before use in the fuel cell and then recovered appropriately prior to disposal. The high temperature fuel cell system components bears significant resemblance to the combustion based power plants in their control and heat exchange equipment and hence the impact in this area is dependent on the amount of sub-system support required per kW of generating capacity. If natural gas continues to remain the preferred fuel, no additional impact is anticipated from fuel distribution.

The prior work on Life Cycle Assessment(LCA) of fuel cells is limited. Most of the literature on environmental benefits of fuel cells focuses on the cleanliness of the " use phase" of fuel cells. It is found that these type of assessments have received more attention in Europe than in the United States. The key available literature relating to LCA of fuel cells is identified in references 1-4. Brief summaries of these studies will be presented in the poster.

While the LCA studies identified above do provide some perspective on the environmental issues with fuel cells, a comparative pollutants and risk assessment model was not found to exist. Further, no detailed description of any of the models and their assumptions is available. The reports suggest that inventory gathering would have to be initially based on pre-commercial processes and will need to be updated periodically as commercial processes are developed. The

focus of these assessments have been the "use phase" and the importance of the fuel type in determining emission impacts has been proven by the fuel cycle based calculations. Assessment of the impact of the manufacturing and disposal phases has been ignored.

By examining the LCA efforts for various technologies, it has been found that methodology identified in International Standards Organization documents : ISO 14040 /41/42/43, form the basis of many of the LCA studies and is clearly applicable for the fuel cell effort. The Society for Environmental Toxicology and Chemistry (SETAC) has also similar guidelines. JPL has

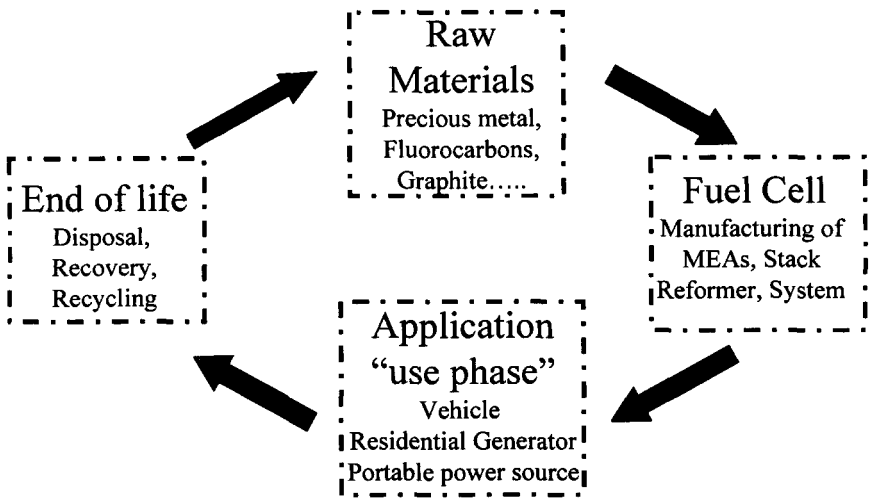

Figure 1. Life cycle stages of fuel cell

identified some of the background issues with the LCA technique and have tentatively defined approaches deal with these issues:

- Some of the manufacturing models are not fully developed at this time and there may be competing methods of fabrication. In order to address this problem JPL's technical experience in the area of fuel cells will be used to determine the most applicable technology.
- Variability and uncertainty exists in data that is obtained from the field. For this we will examine variability and uncertainty in the context of the impact and quantitatively reflect it in the final analysis with statistical error bars.
- To compare fuel cell technology with competing technologies, LCAs for all the competing technologies would be needed. For this it is proposed to seek EPA assistance in identifying appropriate documents. The comparisons will obviously be restricted to cases where useful LCA information is available.
- One of the chief criticisms of static LCA approach is that it does not include any temporal changes, and societal responses to the technology. For this we propose to include some of the typical temporal and societal factors that may affect LCA conclusions and include possible future scenarios in the model.
- Depending on the quality of the data available the LCA can become qualitative, semi-quantitative or completely quantitative. While every attempt will be made within the

scope of the program to seek quantitative information we are convinced that in some cases semi-quantitative LCA conclusions can still satisfy the objectives of EPA.

The specific LCA goal for the first phase will be to determine the impact of polymer electrolyte fuel cells for transportation, distributed generation and portable applications. The fuels have been identified to be natural gas, methanol and hydrogen. The various life cycle boundaries are defined in Figure 1. The various life cycle stage boundaries and components within boundaries have been identified. Inventory gathering will focus on obtaining data on energy inputs in each of the lifecycle stages. Key data sources data include information provided by manufacturers, the GREET model, the Economic-Input model from Carnegie Mellon University and the other specific LCAs wherever available. Examples of such data are presented at the poster. It is anticipated that inventory development will be a significant part of the LCA effort, as gathering reliable and useful data can be a slow process.

The conceptual framework and flow control diagram of the CPM software tool has been developed. In this tool, queries are generated for the specific application. Based on the queries the relevant inventory databases are accessed and a comparative pollutant report is generated. The outputs will display criteria pollutants and greenhouse gases at a regional and local level.

Future efforts will be directed at completing the inventory of energy requirements and emissions for various life cycle stages, organizing available pollutant inventory into database format, applying statistical criteria to deal with data uncertainty, and developing user queries and output formats in consultation with EPA/NRML . A Graphical User Interface program based on Labview™ or Microsoft Access™ Platform for posing of query and generation of reports using CPM would be developed. Such a program would be web-accessible or portable as required. Specific case studies for validation of the results will also be conducted.

Acknowledgement

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