POLICY facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Fuel Cells

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Health and Environmental Impacts of SOFC Fuel Cells in the Transportation Sector

Background

Auxiliary power units (APUs) are used to provide all or part of the non-propulsion power for vehicles—space conditioning/heating, refrigeration, lighting. They do not replace the internal combustion engine, but complement it. Solid oxide fuel cell technology is considered a good fit for APUs. Mainly because of cost limitations, fuel cell based APUs are predicted to penetrate the market of heavy duty trucks and luxury vehicles (recreational vehicles and limos) first. For trucks, fuel cell APUs can provide the essential auxiliary power needed while also reducing the amount of time the truck engine idles. Heavy duty truck idling contributes significantly to energy consumption and diesel engine emissions in the U. S. Fuel cell APUs in heavy duty trucks would offer high efficiency, low emissions, and a low noise alternative.

Introduction

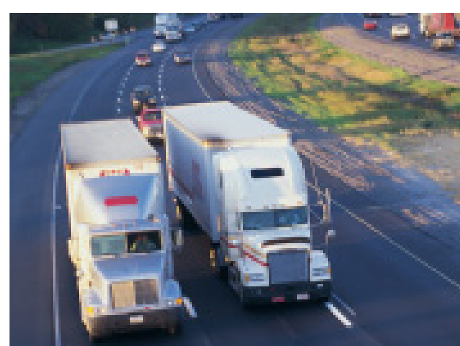
The purpose of this study was to identify the environmental and health impacts of using a SOFC based APU in the transportation sector. This study used an integrated framework that can systematically identify and quantify the tradeoffs between cost effectiveness, efficiency, and environmental and health impacts of fuel cell systems.

Health and Environmental Impacts Model Results

An integrated framework, a multi-objective optimization model, was developed to model the health and environmental impacts of a SOFC APU. The base case was developed based on emissions and vehicle data from the South California Air Basin and the Los Angeles area. The efficiencies and fuel cell performance of the base case follows in Table 1.

Table 1. Base Case

Overall efficiency	37.4 %
Fuel cell efficiency	47.4 %
Reformer efficiency	90.5 %
Cell power output (kW)	5.7
Voltage (V)	0.687
Current density (A/m^2)	6103.8
Cell area (m^2)	1.3678



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Given this base case data, and using the multi-objective optimization model, health and environmental impacts were identified for the base case. This data, shown in Table 2, is given in Potential Environmental Impact (PEI) per second. PEI of any given material is defined as the expected effect that the material would have on the environment if it was emitted. Table 2 gives the generation rate of the PEI for the base case. Note that some values are negative. That means that the PEI emitted from the fuel cell APU in the base case is actually less than what was inputted into the fuel cell APU, from diesel fuel.

Table 2. Generation Rate of PEI for the Base Case

	(PEI/s)
Human Toxicity Potential by Ingestion	-0.096955
Human Toxicity Potential by Inhalation or Dermal Exposure	-0.000018
Ozone Depletion Potential	0.000000
Global Warming Potential	0.000841
Photochemical Oxidation Potential	-0.132937
Acidification Potential	0.000684
Aquatic Toxicity Potential	-1.620944
Terrestrial Toxicity Potential	-0.096955
Total rate of PEI	**-1.946284**

A pay off table (Table 3) was created that compares the efficiency, cost, total PEI out, carcinogenic risk, chronic hazard quotient, and acute hazard index of the base case against six optimization scenarios. Carcinogenic risk, chronic hazard quotient, and acute hazard index gets to the "health risk" of a particular material. The six optimization scenarios include maximizing efficiency, minimizing cost, minimizing total PEI emitted, minimizing the cancer risk, minimizing the chronic hazard quotient and minimizing the acute hazard index.

Table 3. Payoff Table

	Base case	**Max Efficiency**	**Min Cost**	**Min PEI**	**Min Cancer Risk**	**Min Chronic Hazard Quotient**	**Min Acute Hazard Index**
Efficiency	0.37	0.65	0.47	0.65	0.63	0.52	0.59
Cost ($)	13919	22336	12038	22323	20579	24744	18109
Total PEI out (1/s)	0.0102	0.0585	0.0790	0.0585	0.0602	0.0720	0.0636
Carcinogenic Risk	6.65E-12	2.73E-11	4.43E-12	2.22E-12	2.22E-12	4.43E-12	4.43E-12
Chronic Hazard Quotient	1.33E-05	3.39E-06	3.76E-06	3.63E-06	4.84E-06	3.34E-06	3.79E-06
Acute Hazard Index	1.16E-04	5.87E-05	6.95E-05	6.01E-05	7.09E-05	4.27E-05	3.83E-05
System pressure (bar)	1.29	1.20	1.20	1.20	1.20	1.20	1.20
Reformer temperature (°C)	800	788.34	821.82	773.68	743.60	899.78	900.00
Fuel utilization	0.9	0.89	0.79	0.88	0.90	0.77	0.90
Air preheating (°C)	650	900.00	626.61	890.73	896.82	887.02	829.84
Diesel intake (kmol/hr)	0.00621	0.00358	0.00484	0.00358	0.00368	0.00443	0.00391
SOFC air stoichiometric ratio	7.6	3.11	3.01	3.03	4.49	3.00	3.41
Cell voltage (V)	0.69	1.03	0.9	1.03	1.01	1.02	1.00
Cell current density (A/m^2)	6103.8	216.5	1967.7	216.5	264.1	200.2	339.5

From the Table 3, one can see that the design that minimizes PEI and health impacts have a high efficiency, but note that the opposite is not true. The design that maximizes efficiency minimizes PEI but not health impacts. The design that minimizes cost has a tradeoff in environmental and health impacts. The design that minimizes PEI does not minimize all health impacts.

Comparison with Idling Diesel Engines

Previously, the model was focused on optimizing health and environmental impacts of a SOFC APU compared to the health and environmental impacts of a base case. As stated in the introduction, diesel trucks are a reasonable first application for SOFC APUs so it is also desirable to identify the health and environmental impacts of these APUs (optimized for minimum cost) compared to idling diesel truck engines.

The output rates of PEI for SOFC based APUs and idling diesel engines is shown in the Table 4. Note that the total output of PEI for idling diesel engines is three orders of magnitude greater than the case of SOFC APUs. Figure 1 charts that same data shown in Table 4.

Table 4. Output Rates of PEI for SOFC Based APUs and Idling Diesel Engines

	SOFC Based APU (PEI/s)	Idling of Diesel Engines (PEI/s)
Human Toxicity Potential by Ingestion	1.134E-05	21.1950
Human Toxicity Potential by Inhalation or Dermal Exposure	0.000094	5.4810
Ozone Depletion Potential	0	0
Global Warming Potential	0.000656	2.0142
Photochemical Oxidation Potential	2.049E-07	6.7500
Acidification Potential	0.000452	73.7100
Aquatic Toxicity Potential	0.077801	283.500
Terrestrial Toxicity Potential	1.134E-05	21.1950
Total rate of PEI	**0.079026**	**413.1000**

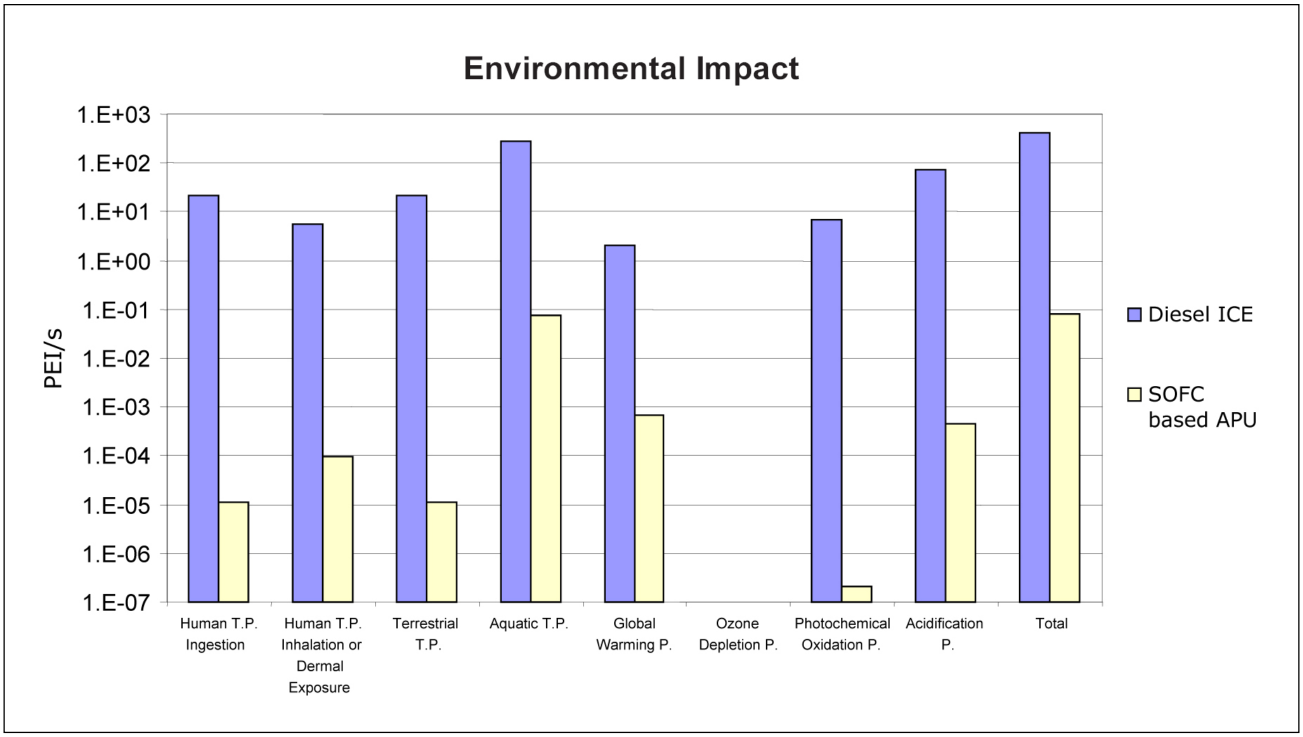

Figure 1: Comparison of PEI for Each Health and Environmental Impact Category

The results of the health risk assessment are shown in Figure 2. In all the health categories there are several orders of magnitude difference between idling diesel engines and SOFC based APUs. As shown in Figure 2, idling diesel engines do not meet the acceptable limits for most of these categories.

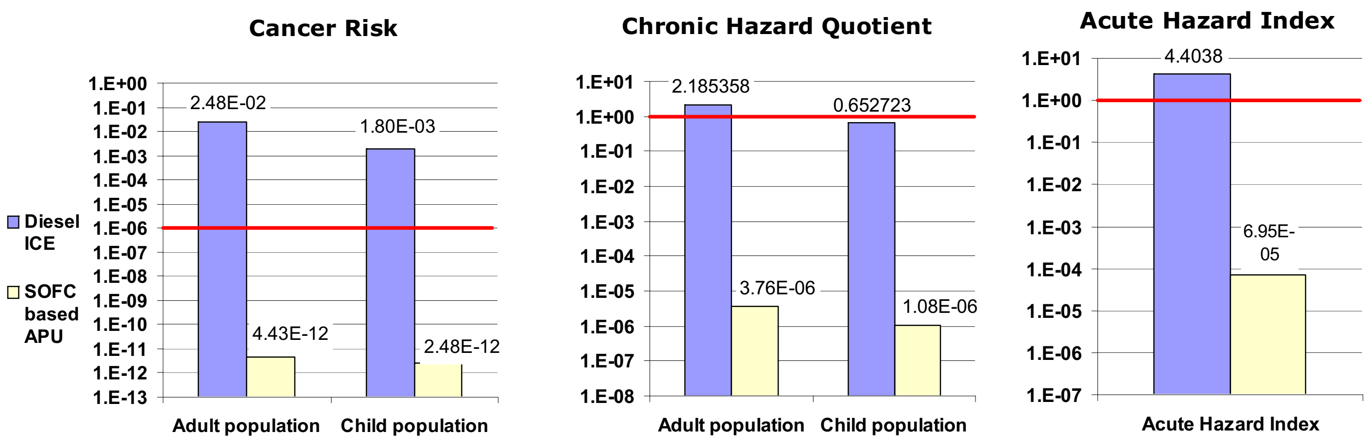

Figure 2: Results of the health risk assessment.

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Conclusion

The modeled developed for this study can identify the health and environmental impacts of SOFC based APUs. A multi-objective optimization of the model identified the tradeoffs that occur when maximizing or minimizing particular objectives. The payoff table showed that minimizing PEI and health impacts have a high efficiency, and the design that maximizes efficiency minimizes PEI but not health impacts. The design that minimizes cost has a tradeoff in environmental and health impacts. The design that minimizes PEI does not minimize all health impacts.

A comparison of health and environmental impacts of SOFC based APUs and idling diesel engines was also made. Not surprising, the health and environmental impacts from SOFC based APUs were orders of magnitude lower than idling diesel engines. This makes the environmental and health benefit case for SOFC based APUs in heavy duty trucks and recreational vehicles.