2006-1091: A WELL TO WHEELS APPROACH TO THE DEVELOPMENT OF AUTOMOTIVE CURRICULA IN APPLIED ENGINEERING PROGRAMS

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A Well-to-Wheels Approach to the Development of Automotive Curricula in Applied Engineering Programs

Introduction

Historically, many seemingly promising alternative energy technologies have failed to significantly penetrate the market, often because of economic realities or the difficulty of integrating these technologies into the existing worldwide energy infrastructure. When developing courses and course sequences in energy systems in engineering technology programs, the applied nature of the programs make it especially important that the students be educated in both traditional and emerging technologies, and that the technologies be viewed from as realistic a viewpoint as possible. This requires that the students develop a systems point of view, in which the potential effectiveness of the technology is quantified not in terms of peak efficiency measured in a laboratory, but rather how the technology penetrates and affects the global energy infrastructure.

At Arizona State University, an automotive option within Mechanical Engineering Technology is under development, a particular focus of which will be highly efficient vehicles. Power plant technologies that are emerging in this field include electric vehicles utilizing batteries, hybrid internal combustion engine/electric systems, and fuel cell systems, and students need to be educated in all of these technologies from a systematic, "well-to-wheels" viewpoint. For example, fuel cells for transportation have received a great deal of attention because of the potential for zero emissions if a hydrogen infrastructure can be developed and if that infrastructure is independent of fossil fuels. However, this infrastructure is not in place at the present time, and hydrogen is being produced primarily from reforming of hydrocarbons, resulting in pollution at the hydrogen production stage. Therefore, the real environmental impact of an automotive fuel cell transportation system must account for these effects.

At ASU, while all technologies will be a part of the curricula, the decision has been made to focus resources on the technologies that the students are most likely to be exposed to early in their careers. As a consequence, there is a need to develop case studies, ultimately to be used in the classroom, which compare both the economic and technical realities of the competing technologies from a systems viewpoint. In this paper, well-to-wheels comparison of diesel electric hybrid systems with fuel cell systems are discussed. Conclusions from this study are being used to guide the course and curriculum development.

Engineering Systems Overview

The potential long term market penetration of emerging technologies, such as fuel cell systems for transportation applications, is difficult to forecast for several reasons, including the fact that this development will depend strongly on breakthroughs in research. On the other hand in the short term it is possible to quantify the performance in comparison to existing systems assuming that they are to be initially based on proven technology. However, as will be discussed in this section, even in the short term a valid comparison of the technologies requires that the global system, from well-to-wheels, be considered since comparison of the performance of independent subsystems can be misleading. This is especially important in educational program development for applied programs, since the constraints of a finite curriculum require that topics be prioritized carefully.

A system is composed of components and/or processes linked together in such a manner as to achieve a desired outcome. The simplest system consists of one input and one output with the process being enclosed in the "black box" of the system. The input and output of the system can be measured and "intimate knowledge" of what occurs within the black box may or may not be necessary to understand the system. This is an important concept for the student since they do not always need to know the intimate details of how the system is operating to judge its effectiveness.

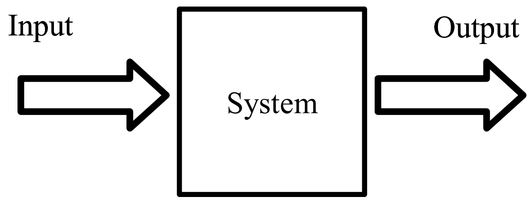

Figure 1 – Simple model of a System

Multiple systems may be assembled together to create complex systems. This is the type of system that is encountered when considering the entire infrastructure necessary to support transportation technologies. The "well-to-wheels" system goes from production of the energy supply to operating the vehicle.

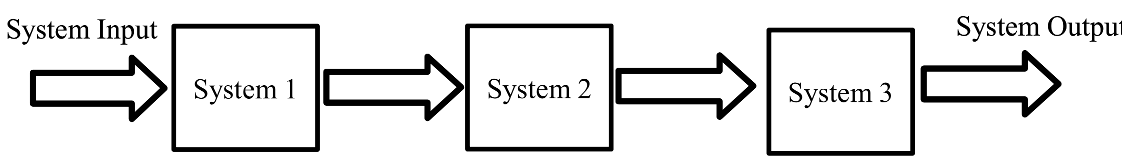

Figure 2 – Model for Assembled System

The efficiency of a cascaded system is simply the efficiency of each system multiplied together. For instance consider the system shown above and assume the following efficiencies for each system:

System 1 = 0.90
System 2 = 0.75
System 3 = 0.57

The overall system efficiency would be equal to 0.38 which is considerably less than any single component of the system. In the automotive field, the concept of efficiency of an assembled system, the well-to-wheels model, is very important for students in an applied program to understand since future technology will be driven by the overall system performance. A highly efficient subsystem which requires an inefficient infrastructure support to operate is not likely to reach the marketplace.

An important measure of an energy systems performance is the emissions output of the system. This is not always straightforward because a power providing device may have very low or no emissions during operation, but considerable emissions may be produced during the fuel production and transportation phases of the overall system. For example, in an attempt to control the development of automotive technology the state of California has developed the following criteria to determine the allowable emissions for low emissions vehicles (LEV), ultra low emissions vehicles (ULEV) and super ultra low emissions vehicles (SULEV)[1]. However, these requirements are only for the vehicle and not for the whole system.

Category	NMOG	CO	NOx	PM	HCHO
LEV	0.090	4.2	0.07	0.01	0.018
ULEV	0.055	2.1	0.07	0.01	0.011
SULEV	0.010	1.0	0.02	0.01	0.004

Table 1. California Standards for Low Emission Vehicles

A vehicle powered by a hydrogen proton exchange membrane (PEM) fuel cell is a SULEV by these standards since the only emission from these fuel cells is water. But once again it needs to be emphasized to students that the focus is on the fuel cell and not the whole system.

In a more pragmatic scenario, consider two hypothetical "well-to-wheels" systems to evaluate the system efficiency:

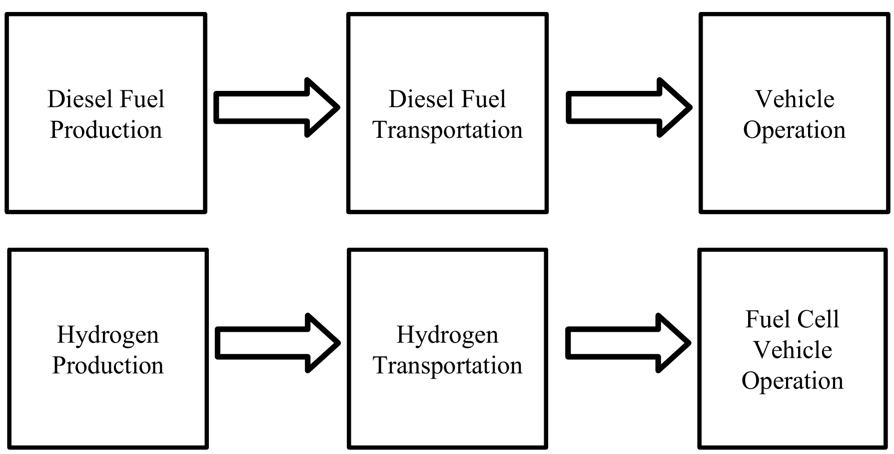

Figure 3 Hypothetical Well-to-Wheels Systems

The efficiencies of these two scenarios would simply be:

Diesel Fuel Production efficiency	D_1
Diesel Fuel Transportation	D_2
Vehicle Operation	D_3

Overall System Efficiency: $D_1 * D_2 * D_3$

Hydrogen Production efficiency	H_1
Hydrogen Transportation	H_2
Fuel Cell Vehicle	H_3

Overall System Efficiency: $H_1 * H_2 * H_3$

A realistic comparison of vehicles powered by fuel cells as opposed to diesel engines requires that all of these efficiencies be accounted. As will be discussed below, when this is done, fuel cell vehicles do not compare as well as is popularly believed, and it is not at all clear that they will be making significant inroads into the automotive market in the near future. As a consequence, while fuel cell technology is very important for students to understand because of its long term potential, the portion of an applied automotive engineering curriculum that is dedicated to this topic must be prioritized carefully.

Overall Fuel Cell System Efficiencies

Using the values provided by Bossel's study an analysis of overall system efficiencies can be made for the hydrogen fuel cell vehicle[2]. For example, the following data illustrates the efficiencies of a hypothetical fuel cell vehicle using water electrolysis to produce hydrogen. It is worthwhile to point out that this technology is on the horizon – currently almost all hydrogen is produced by the steam reforming process, which emits significant amounts of pollutants and greenhouse gases (GHG).

Water Electrolysis	0.70
Compression of H_2	0.90
Distribution Energy	0.90
Transfer to Tank	0.97
Fuel Cell Efficiency	0.50
Parasitic Accessories FC	0.90
Drivetrain	0.90
Power Plant to Wheels Efficiency	0.22

These numbers represent very optimistic estimates of component performances as well as assuming wide availability of highly efficient water electrolysis.

Sharer et. al. have conducted a comparison of hybrid gasoline and diesel systems with that of a PEM fuel cell system[3]. It can be seen from their study that the forecasted system efficiency is slightly better for the fuel cell hybrid than for the diesel hybrid. However, the fuel cell hybrid produces more greenhouse gas (GHG) emissions than the diesel hybrid. It is worthwhile to note that the cost of the diesel hybrid system is a great deal less than that of the fuel cell system. Since diesel hybrid systems utilize existing technologies they provide a realistic and timely option for large scale reduction of pollutants and GHG.

Moghbelli et. al. compared six different vehicle types with the direct hydrogen fuel cell vehicle efficiency only being only 2.2 greater than the worst case ICEV vehicle[1]. However, the direct hydrogen fuel cell did produce less carbon dioxide when compared to the other vehicles. The efficiencies are shown in the following table.

	ICEV	Hybrid EV series	CNG	FCV w/ Reformer	Battery EV	Direct H2 FC
Well-to-Tank	.86	.86	.86	.86	.36	.65
Tank-to-Wheels	.16	.27	.27	.32	.80	.47
Well-to-Wheels	.137	.232	.232	.275	.288	.305

Table 2. Comparison of Well-to-Wheels Efficiencies

The GHG emissions for each of these systems are shown in the following table:

Vehicle Type	CO_2 g/per mile
Direct Hydrogen FC	200
Indirect Methanol FC	240
Gasoline ICE	450
Compressed Natural Gas ICE	340
Reformulated Gas ICE	240

Table 3. Comparison of Greenhouse Gas Emissions.

These studies are representative of many comparisons of existing hybrid technologies with hypothetical fuel cell transportation systems[4,5,6]. The conclusions from these studies would indicate that the most realistic methods for reducing pollutant production and GHG emissions in the transportation sector involve the use of gasoline and diesel hybrid systems. While it is certainly important to continue intensive research into fuel cell systems for transportation, from an industry standpoint, it is likely that the near future of highly efficient vehicles will be dominated by gasoline and diesel hybrid vehicles. Consequently, from a curriculum development standpoint, it is important that students develop the knowledge necessary to support these technologies.

Implementation Throughout the Curriculum

In addition to prioritizing the development of new courses for an automotive program, the systems viewpoint can be emphasized in numerous existing courses in the engineering technology programs. A few examples of courses in which these concepts are currently emphasized include:

AET 210 ***Instrumentation*** – The accuracy of a measurement depends not only on the accuracy of the sensor, but also the performance of the complete data acquisition system.

MET 331 ***Machine Design 1*** – Efficiencies associated within coupled systems of mechanical components.

MET 435 ***Alternative Energy Systems*** **–** Realistic comparisons of different energy systems for applications other than transportation.

Summary

In the development of curricula for applied engineering programs it is important to take a systems viewpoint of technologies so that realistic comparisons can be made. For example, in the development of automotive curricula, the concept of a zero emissions vehicle can be very misleading, since pollution and GHG can be produced throughout the entire system, from the well to the wheels. Furthermore, the risk for the automotive industry in the development of gasoline and diesel hybrid technologies is small in comparison to hydrogen fuel cell vehicles since the existing infrastructure and technologies are already in place. Consequently, in an applied automotive engineering program, these topics should be emphasized. At the same time, it is important to continually update studies such as discussed in this paper so that the curriculum may rapidly evolve as technological breakthroughs occur that improve the competitiveness of new technologies.

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