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THE REMOTE AREA POWER PROGRAM (RAPP)

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Abstract

In this paper we discuss the motivation and program structure for the Remote Area Power Program for Alaskan Villages. Rural Alaskan Villages are typified by small populations (many of less than 100 people), no road access to places outside the village, no access to the national (or even an Alaskan) electrical grid. Most of the Villages have electrical power typically generated by diesel generators providing power to each dwelling by a small very local micro grid. This system is difficult to maintain, very inefficient, and subject to frequent outages. To protect against power outages due to mechanical breakdowns, redundant generators are frequently in place, resulting in higher capital costs. Maintenance work is most often done by skilled workers from outside the village. Fuel must also be transported to the village. All of this results in a very high cost of power (up to 80 cents a kilowatt hour), currently subsidized by the state government to about ten cents a kilowatt for residential users through "Power Cost Equalization".

Recent advances in Proton Exchange Membrane (PEM) fuel cell technology have created the hope that these devices can be used in reliable, affordable remote power applications. Higher electrical conversion efficiency and heat recovery for residential use results in higher fuel utilization, high reliability results in lower maintenance costs, and networking a small microgrid allows reduction in the redundancy necessary for reliable power, leading to lower capital costs. The long-term goal is to work towards a carbonless infrastructure based on renewable energy.

Goals and Basis for Goals

The goals of this program are to accelerate the development of PEM fuel cells for distributed power applications, significantly reduce the consumption of fossil fuels, begin development of a power generation system based on hydrogen as an energy carrier. The basis for this goal is to work towards a carbonless energy infrastructure based on renewable energy.

Summary of Approach and Rationale

The cost of generating electrical power in remote areas is much higher than in grid connected areas. In remote rural villages in Alaska, these costs can rise as high as $.80 per kilowatt-hour. Conservation does not reduce the fixed cost of operating a utility, and so other ways to reduce the cost of electricity are sought.

In order for a new technology to be successful in this market, it must reduce the total system cost of energy. The system must be highly reliable in order to reduce O&M expenses. The capital cost must be low. And the system should be efficient, so that less fuel needs to be transported to the remote location. In Alaska, there is an added criterion, the system must work in the severe arctic climate.

Based on these criteria, stationary distributed power systems based on PEM fuel cells are attractive. They provide distributed power generation capability, heat can be recovered to increase fuel utilization, system reliability can be provided by networking units together, and capital costs can be reduced due to the lower excess capacity needed to cover outages.

Economic Analysis

In thermodynamics, it is essential to define a system boundary in order to define system efficiency. In order to compare PEM Fuel Cell systems with conventional power systems in the 5kW range, we have selected for this work an overall system boundary that looks at hydrocarbon fuel into the system and the AC electricity out. This boundary includes the reformer, fuel cell, inverter, and any batteries that are part of the system, and all of the parasitics necessary to perform the internal functions necessary to keep the system working. Note that this is a significantly different definition of fuel cell efficiency than used by this program last year, when the system boundary was defined around the fuel cell system only, using pure hydrogen as the feed stock, and DC electricity as the output.

When this program began in 1998, the fuel cell industry was claiming that net electrical efficiencies of over 40% based on the lower heating value were possible in PEM fuel cell systems running on hydrocarbons. In order for this number to be true, efficiencies of individual components had to be high. A system with a reformer efficiency of 75%, a fuel cell efficiency of 58%, and an inverter efficiency of 94% meets this overall efficiency target. It should be noted that this efficiency value can still be found on the web sites of fuel cell companies.

An analysis of a PEM system specifically designed for the Alaskan Environment was done in the spring of 1998 by Phil DiPietro. This analysis used slightly more conservative estimates of efficiencies for the system: the reformer at 70%, the fuel cell at 55% (the DOE OTT target efficiency), the inverter at 90%, plus a reduction in power out due to load leveling using lead acid batteries at 80% for part of the electrical load. These assumptions give an overall electrical efficiency of 31.5%. This analysis also included a cost analysis, showing that given reductions in capital cost due to decreased redundancy in the system, credit for heat recovery, and some fairly optimistic projections about fuel cell system costs, the PEM fuel cell system would lead to lower energy costs in remote villages.

Program Plan

The RAPP program began in July of 1998, and was divided into three phases. Phase I involved delivery and verification of system components, and was successfully completed, with fuel cells delivered and operating in September of 1998, and a reformer delivering fuel cell quality hydrogen. Phase II was intended to result in a laboratory integrated system capable of converting diesel to grid quality AC power. Phase III was intended to result in a fully automated system suitable for field demonstration of the technology in a remote arctic site, but this phase is currently on hold.

Past Results

The past results in this program have been encouraging, as Phase I and Phase II goals have been met. Three hydrogen PEM fuel cells were delivered to the program and made operational by September 30, 1998. Two additional fuel cells have been tested since then. A steam reformer operating on kerosene was delivered by December 30, 1998, and a POX reformer was delivered on April 5, 1999. Three fuel cell benches were constructed and made operational by February 15, 1999. Systems efficiency data was collected on three PEM FC systems, and a paper was presented at the 10th Annual NHA meeting in April 1999.

Current Year Effort

During the past year, much of the effort of this program has been transferred to the University of Alaska Fairbanks, with completion of a new laboratory facility there in the summer of 1999. The dedication of this laboratory occurred in August, and was attended by DOE Assistant Secretary Dan Reicher. As part of this dedication, a demonstration of the technology being tested was given. Kerosene was fed into the Northwest Power reformer (with a paladium membrane), fuel cell quality hydrogen (less than 1 PPM CO) was produced and fed to the Schatz Energy Research Center fuel cell, DC electricity was fed into an inverter, and AC electricity was produced to run the lights in the lab for two hours. It was a fine demonstration, but it should be noted that the fuel used was a desulfurized bio diesel, the reformer burner was operating on propane, and the reformer required the attention of an experienced operator.

The UAF Energy Center has developed an automated control system for the diesel reformer. This control system requires maintaining accurate control over two independent low flow liquid streams, and requires numerous decision points for start up, steady state operation, and shut down procedures. UAF is currently working with Sandia Livermore and NPS to further develop this control system.

Much of the work in the past year has focused on the performance of the diesel reformer. The first diesel unit delivered to the program and use for the demo in August, but had some materials problems in the burner area due to the high temperatures required for diesel reforming, and failed after about 50 hours on the bench. A second diesel reformer was delivered in late December 1999, with different materials, and is currently providing clean data on the laboratory bench.

The test bench at UAF was designed to provide a mass and energy balance for the reformer. Inputs of air, water, diesel fuel, electrical power (for pumps, blowers, and control solenoids), propane (sometimes used to supplement the burner) were measured, as well as hydrogen flow and heat in the combustion exhaust. In most cases at least two independent measurements were made to assure the accuracy of the data set.

In order to assess the performance of the reformer, measurements were made of the composition of the raffinate gas. These measurements were then compared to equilibrium thermodynamic calculations done by Andy Lutz at SNL. Results showed significant departure from equilibrium conditions.

Results

The most significant result to date has been the encouraging demonstration that it is possible to run a pure hydrogen PEM fuel cell on hydrogen produced from a heavy hydrocarbon fuel. The reformer has been operated in a self-sustained mode (diesel fuel only) using a control algorithm developed at UAF. Energy Balance data and reformer gas composition measurements have been made.

However, system efficiency measurements have not been encouraging to date. The energy balance data collected show that the overall efficiency of the reformer is less than expected, in the range of 36% (LHV) of the energy leaving the system in the hydrogen stream. Much of the energy leaves the system in the combustion exhaust (about 43%), and additional losses occur due to radiation and convection from the reformer surfaces.

Using the experimentally obtained values for reformer (36%), fuel cell (49%), and power conditioning (80% with inverter and batteries) and subtracting off the electrical parasitic losses for the reformer yields an overall systems efficiency of 12.8%. This is not a very satisfactory result, being considerably lower than what can be obtained by conventional technology.

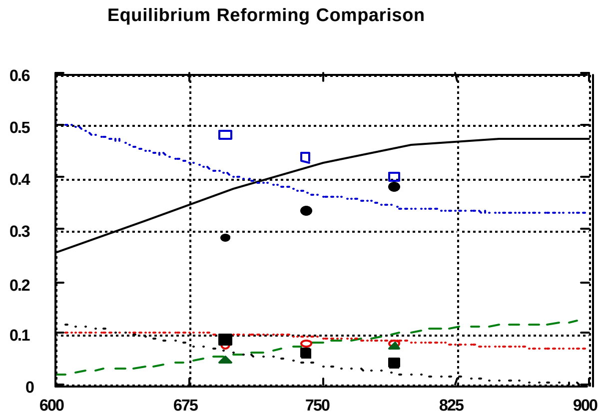
It must be noted that the reformer is still in the prototype stage, and that the experience to date with the reformer does suggest possible improvements in the reformer design. In particular, the deviation from thermodynamic equilibrium suggests that reducing the space velocity in the catalyst area is necessary to improve performance. Heat recovery from the combustion exhaust is also necessary. While it is hard to predict exactly how much improvement can be made in the performance, of the unit, the improvements should be considerable. However, the smaller the reformer, the greater the surface to volume ratio, and the greater the relative heat loss.

As part of our evaluation of reformer efficiency, we also calculated efficiencies based on various system boundaries, as well as attempting to differentiate between efficiency and hydrogen yield. In tests designed to evaluate catalyst performance, hydrogen yield is often the parameter given, but these measurements are often done at a constant temperature without regard for the heat losses in the system. Since the purpose of this work is to evaluate total system efficiency, these heat losses become an important energy flux, and cannot be ignored. Results of this analysis are show in the figure below.

Based on the results to date, it is apparent that the current level of performance of the reformer is significantly lower than had been hoped at the beginning of the program. Therefore the decision has been made to delay phase III of the program until this issue can be resolved.

The issue of reformation is an important one for the fuel cell industry. Small-scale reformation allows use of conventional hydrocarbon fuels in widely distributed power generation systems, but forces the development of small-scale reformers. This technology requires careful attention to heat management, fuel vaporization, catalysts, and combustion technology, and represents a difficult problem. Diesel reforming is a problem that has a long history, and will likely require significant additional effort and resources to solve.

It is widely recognized that, due to the long hydrocarbon chains and the sulfur content, diesel represents one of the hardest fuels to reform. It may be that the only logical way to progress with the rural power program at this point is to switch fuel feedstocks to a fuel easier to reform, such as propane or methanol, and continue development of the integrated system with one of these fuels. Development of the small-scale diesel reformer could continue on a parallel track, and be introduced into the field when ready.



- Equilibrium reforming of heptane at 1100 K, including solid carbon.
- $C_7H_{16} + 14\,H_2O \rightarrow 7\,CO_2 + 22\,H_2$
- Vary steam/carbon ratio; stoichiometric is 2.
- C(s) appears below steam/carbon ratio of 1.
- The cycle efficiency computations neglect C(s), for a minimum steam/carbon ratio of 1.5.

Comparison of Thermal Efficiencies for Reformer Systems

Reaction Balance	Energy Balance	Thermal Efficiency	Hydrogen Yield
Complete reaction:	Balance Energy using H2 at HHV	100	78
CH4 + 2H2O -> CO2 + 4 H2	Balance Energy using H2 at LHV	90	74
Chemical equilibrium at 900 C	Adibatic System; Balance Energy using reformate at LHV Exhaust products at 100 C (liquid)	88	73
Chemical equilibrium at 700 C	Adibatic System; Balance Energy using reformate at LHV Exhaust products at 100 C (liquid)	56	47
Equilibruim at 900 C for Heptane	Adibatic System; Balance Energy using reformate at LHV Exhaust products at 100 C (liquid)	81	68
Experimental on Kerosene 800C	Heat provided by suplimental fuel	65	52
Self Sustained on Kerosene	Energy Loss in Combustion Exhaust and Radiation and Convection	40	33