The Hydrogen Fuel Cell Locomotives As National Energy Policy Insurance

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1.0 Abstract

Debates rage over fossil fuel availability during the coming two decades. Through renewable sunlight, electricity generation, and electrolysis, hydrogen fuel cells offer an alternative energy collection and distribution option which is sustainable and non-polluting. Equipping locomotives with fuel cells has received considerable attention, although most conclusions indicate rail-owners cannot justify the associated re-engineering costs. However, from a national policy perspective, there are three reasons full federal funding for this re-engineering could be demanded.

First, the hydrogen fuel cell has the near-term potential to double locomotive operating efficiencies, quite similar to the sweeping advantage of diesel over steam. Second, installing a hydrogen distribution network for the railroad would be as trivial as it is pioneering, because locomotives travel thousands of kilometers between fueling stops. Third, and most important, the rail sector is insignificant relative to other fossil fuel demands, yet capable of meeting most all national transportation needs if called upon. For the smallest investment, the federal government could purchase insurance against changes to world energy supply or policy. What is necessary is federal subsidy of the 1-5 MWe fuel cell for locomotive purposes, perhaps nothing greater then the money spent on diesel development during the two world wars. Given a united rail fuel cell commitment, the entire railroad sector could reap greater profits and national stature given any world energy scenario or crisis.

2.0 Introduction

Powering railway locomotives with fuel cells has been studied by several research teams (Liddle et al 1981; Huff and Murray 1982; End Users 1992; Sobey, Wedaa, and Ditmeyer 1992; Gavalas et al 1995; and, Scott, Rogner, and Scott 1993). Although all parties agree fuel cells and rail locomotives offer an excellent marriage, opinion on approach and state of development differ widely. The author's key argument is not what the fuel cell can do for the rail, but what rail can do for non-polluting, high-efficiency, alternative energies. Adopting a positive and proactive attitude at this point in national energy policy could secure government financial support similar to the Federal Highway Act as an insurance policy against foreign intervention in local energy policy. Further, it would put in place a fully autonomous energy and transportation network beyond the reproach of any change in foreign energy supply.

Previous research into locomotive fuel cell research has fallen short in terms of these kinds of policy issues. Comparisons have always been made back to competing diesel systems, with no attention drawn to a national transportation network fully free of foreign markets. True to form, the dinosaur is more powerful than the horse, but most scenarios tell us only the horse will survive the approaching twenty years. Second, although it is known rail contributions to pollution are trivial, much research has centered on this issue. Primary arguments against fuel cell adaptation include:

- Current fuel cell technology is too bulky, or just within, the available locomotive limits of size, weight, and volume.
- Developmental costs are too great for railways to sponsor.
- The lack of hydrogen support infrastructure and external economies of scale.
- Although these are all important decisions within the microscopic view of individual firms, the macroscopic market approach yields opportunities as decisive as diesel's victory over steam. The authors stand by three hypotheses:
- From an engineering perspective, hydrogen fuel cells will double train efficiency within 5-10 years at the very minimum.
- From an economic perspective, developing a hydrogen distribution network for rail applications is a simplistic solution. Because low-cost, low-demand, hydrogen is currently available, rail applications are an ideal spearhead to usher in a global hydrogen fuel cycle.
- There is enough uncertainty in global fuel supplies to warrant the federal government to pre-equip one transportation sector with energy sustainability and autonomy as an insurance against foreign policy energy blackmail.

3.0 Doubling Net Engineering Efficiency

Carnot efficiency is a ratio of net work output divided by work input, and is constrained to a value less than one by the Second Law of Thermodynamics. One the other hand, the First Law of Thermodynamics states energy can neither be created nor destroyed; therefore efficiency losses occur during conversion from one energy form to another. The diesel-electric locomotive is a splendid example: through chemical combustion, the prime mover extract 39% of the fuel's chemical energy, while the alternator and rectifier generally transform 93% of that torque into electrical current (given a DC rather than AC system). Traction motors and reduction gearing then transfer 89% of the remaining work to the rail less any slippage. The net system efficiency is therefore approximately 32%. In comparison, stationary coal power plants are 38%, nuclear plants 33%, and automobiles, 20%.

Fuel cells are electrochemical devices with no moving parts that react complementary fuels across a membrane in a liquid environment similar to car battery. A stream of electrons with a predictable electromotive force is the result. Typically 40-60% of the chemical energy is converted to electricity with no moving parts, the remaining percentage discharged as heat. Cells operating in excess of 80% are technically feasible. Although a multitude of fuels are available, hydrogen is the only sustainable candidate: sustainable autonomy is the goal, and like the horse that leads the carriage, lower pollution and operating costs follow suit.

If the prime mover, alternator, rectifier, and turbocharger were replaced with a 45% efficient fuel cell; net locomotive efficiency would immediately jump to 41%—a 28% increase. Given a 60% fuel cell, net efficiency would leap 63% to 52%. And given a technically feasible 80% cell, a 117% jump to 69%. The efficiency argument does not stop here:

- Each time net efficiency increases, the size of the on-board cooling plant decreases.
- Because no emissions result, tunnel crossing restrictions would be removed, simplifying routing and scheduling (e.g. the Cascade and Moffet tunnels).

- Because fuel cells are not combustion cycles, power efficiency drop along trailing locomotives due to leading locomotive cooling plants will be eliminated.
- As efficiency increases, the same work may be accomplished with smaller engines. For example a 27% efficient 3500 HP engine may be replaced with a 2000 HP fuel cell locomotive, or a 6000 HP diesel unit with a 3300 HP fuel cell engine.

These are simplifying changes resulting from a fundamental change in engineering. Just like the steam locomotive of the 1940's, the diesel engine has reached an efficiency plateau. For example, the period between 1900 and the Great Depression saw a doubling of steam locomotive efficiencies, from below eight to about fifteen. Design innovations included:

- Accommodating higher operating pressures in steal boilers in place of cast iron.
- Increasing fuel flow with mechanical stokers rather than human labor.
- Articulation of drive wheels to accommodate heavier power plants within the constraints of established track radii.
- Super heaters and the compound steam cylinder.
- Replacing frame assemblies with single piece cast steel chassis.

Because most heat energy was dumped overboard in the form of water's heat of vaporization, steam engine efficiency could only plateau with no hopes of improvement. Conversely, diesel engines could extract fuel energies with four times the efficiency, offering an overwhelming economic lever. Diesel engines have reached their plateau, and fuel cells are the best option to doubling working efficiency fully independent of foreign fossil fuel supplies.

4.0 How Railroads Can Insure National Energy Policy

The advantages of hydrogen fuel cells do not end with engineering simplification or efficiency enhancement—it also offers a sustainable alternative fuel for a variety of other modes: automobiles, utility power generation, and marine propulsion. However, because these other applications represent a much larger market demand with supply lines bordering on the ubiquitous, developing a production and allocation system from a dead stop is prohibitive except in times of crises.

The rail network offers three unique levers to build a hydrogen allocation system without national economic hardship.

- Trains travel several thousand miles between fuel stops. Tenders add additional range without degrading field performance. The demands of these characteristics may be satisfied through a very simple allocation network.
- There are existing supplies of low-cost hydrogen that could meet the discrete and limited needs of rail transportation during its development towards autonomy. These sources include refinery venting and chemical industry byproducts. There is also a great potential to weave together utility off-peak load-leveling schemes. Given new Federal Energy Regulation Commission (FERC) deregulation, energy may be purchased anywhere in the nation and transported to the best place for rail application electrolysis.
- The rail industry is a small part of the national transportation system, yet could assume the lion's share of duty if necessary. A small national investment could have major benefits in terms of policy flexibility.

Diesel technologies came into their own right following the First World War, with substantial research centering on marine applications. During the Second World War, locomotive manufacturers were restricted by the crisis to produce standard steam designs, while the diesel enjoyed another round of government subsidy. In order to harvest the efficiency benefits of fuel cells, a similar externalization of development funds is necessary. The fundamental question the railroads and its suppliers must ask, is whether their simplified distribution and immediate engineering benefits would interest the current government enough to off-set development and deployment costs should the railroads agree to commit to hydrogen technology. In return, the government would receive:

- A complete and fully functional alternative fuel cycle.
- An avenue to establish a fuel cell operating history for further policy development.
- The creation of a manageable and supportable demand for a new energy industry.
- A no-impact economic demonstration for established energy firms to evaluate.
- An insured ability to meet national transportation needs in the event fossil fuel supplies are lost.

Rail's greatest advantage is its small representation within the entire fossil fuel picture, while also representing a discrete, yet complete, national transportation segment. Levering this position as a federal insurance policy could help shift fuel cell development onto federal ledgers, setting the stage to make rail the first autonomous energy sector.

5.0 Conclusions And Recommended Action

United States' energy policy has centered on no policy, allowing the free market to care for itself. Following the Second War, the federal government made a commitment to the national highway system as an insurance policy for wartime transportation needs. Heavy transportation is crucial to US economic potency: we can survive without the personal transportation of the automobile, but not without industrial transportation.

Matching sustainable hydrogen with locomotives through fuel cells is no longer a question of technical feasibility, but rather one of refinement, kick-off economics, and implementation. When long-term rail operators, equipment providers, and federal goals are examined, many commonalties are found: low operating cost and an ability to meet transportation needs during times of international energy instability. Many transportation and stationary energy users can benefit from hydrogen technology, but only rail offers simplified distribution opportunities together with an excellent fuel cell marriage in terms of scale in a near-term, achievable, environment.

Although rail fuel cell research is not new, building a low-cost, high-payoff national transportation insurance policy is. Like ITS America, a rail consortium should be formed with the common goal of an autonomous railway system built from sustainable hydrogen technologies. Specific points and research agendas should include:

- The economic benefits of the simplified rail energy distribution network.
- The identity of achievable engineering milestones and a deployment timeline.
- The identity and magnitude of existing hydrogen sources, utility load-leveling strategies, and solar hydrogen options.
- The types of government assurances and price controls the rail sector requires to fully contemplate a hydrogen transition.
- A transition and deployment plan for submission to the government for a funding program similar to ITS America.

There are few analysts who believe fossil fuel supplies will remain stable over the next twenty years. Even a doubling of oil prices would significantly harm industrial transportation capabilities: a quadrupling could be catastrophic. Line equipment is currently under design and purchase whose lifetime exceeds the projected duration of affordable fuel to run them. Investment in current technology is therefore at risk: its not even a question of which risk is greater, because fossil fuel supplies will slip towards unavailability. If railroads and their suppliers were inclined to become the nation's energy insurance policy, they would be the leaders in developing a new energy infrastructure, once again pioneers across the frontier.

6.0 References

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