JPL PUBLICATION 79-115

Electric and Hybrid Vehicle System Research and Development Project

An Assessment of Inductive Coupling Roadway Powered Vehicles

K. O. Leschly, et al.

April 15, 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. JPL Pub. 79-115	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN ASSESSMENT OF INDUCTIVE COUPLING ROADWAY POWERED VEHICLES		5. Report Date April 15, 1980
		6. Performing Organization Code
7. Author(s) K. O. Leschly, et al.		8. Performing Organization Report No.
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103		10. Work Unit No.
		11. Contract or Grant No. NAS 7-100
		13. Type of Report and Period Covered JPL Publication
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		
		14. Sponsoring Agency Code

15. Supplementary Notes

Also sponsored by U.S. Department of Energy under Interagency Agreement EM-78-I-01-4209

16. Abstract

The technical concept underlying the roadway powered vehicle system is the combination of an electrical power source embedded in the roadway and a vehicle-mounted power pickup that is inductively coupled to the roadway power source. The purpose of the study reflected in this final report was to investigate the feasibility of such a system, implemented on a large scale. Factors considered included current and potential transportation modes and requirements, economics, energy, technology, social and institutional issues.

These factors interrelate in highly complex ways, and firm understanding of each of them does not yet exist. The study therefore was structured to manipulate known data in equally complex ways to produce a schema of options and useful questions that can form a basis for further, "harder" research. A dialectical inquiry technique was used in which two adversary teams, mediated by a third-party team, debated each factor and its interrelationship with the whole of the known information on the topic.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Conversion Techniques Transportation Power Sources	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	262	

JPL PUBLICATION 79-115
Electric and Hybrid Vehicle System
Research and Development Project

An Assessment of Inductive Coupling Roadway Powered Vehicles

K. O. Leschly
A. Feinberg
R. Heft
G. Warren

April 15, 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration.

ABSTRACT

The technical concept underlying the roadway powered vehicle system is the combination of an electrical power source embedded in the roadway and a vehicle-mounted power pickup that is inductively coupled to the roadway power source. The purpose of the study reflected in this final report was to investigate the feasibility of such a system, implemented on a large scale. Factors considered included current and potential transportation modes and requirements, economics, energy, technology, social and institutional issues.

These factors interrelate in highly complex ways, and firm understanding of each of them does not yet exist. The study therefore was structured to manipulate known data in equally complex ways to produce a schema of options and useful questions that can form a basis for further, "harder" research. A dialectical inquiry technique was used in which two adversary teams, mediated by a third-party team, debated each factor and its interrelationship with the whole of the known information on the topic.

PREFACE

The automotive application of an inductive coupling roadway powered vehicle (RPV) system has been suggested as a subject for further research and development (R&D) within the U.S. Department of Energy (DOE) Electric and Hybrid Vehicle (EHV) Research and Development Program. Like EHVs, the principal merit of the RPV system is its potential for petroleum conservation and displacement, with electricity as a substitute. The technical concept behind the RPV system is the combination of an electrical power source embedded in the roadway and a vehicle-mounted power pickup, which is inductively coupled to the roadway power source.

An assessment of the potential benefits, constraints and impacts related to the possible implementation of the RPV system has been conducted by the Jet Propulsion Laboratory, California Institute of Technology, sponsored by DOE. The assessment was designed to help DOE decide on the issue of further funding to RPV research within the EHV R&D program. The results of the assessment are documented in this report.

The overall and relative (to EHVs) viability of the RPV system was evaluated in terms of a multitude of factors related to the possible implementation of such a system: transportation, economics, energy, technology, social, institutional, etc. The problem of evaluating these factors is dominated by their complexity and relatively high dependency on judgmental considerations and expectations about the future. A dialectical inquiry (structured debate) was therefore initiated to augment the more detailed and quantitative analysis of these elements (limited analysis). This approach seems to capture information and insight of particular importance to policy-making, beyond what is usually provided by other methods of inquiry. The structured debate was held between two parties with conflicting viewpoints and interests in the outcome of the R&D policy decision. A third party, which was neutral in these respects, was chartered to clarify the arguments during the debate and to summarize and analyze the structure of the arguments following the debate. A final round on detailed analysis (extended analysis) was then performed, focused on the more pivotal and weaker elements of the arguments presented as well as the assessment of the overall plausibility of the arguments.

The debate was centered around the following five issues, which for the most part were found to be unresolvable at the present:

- To what extent will the RPV system displace petroleum?
- Will the RPV system be prohibitively expensive?
- Will the RPV system benefit or restrict transportation, and how much?

- o Can rational implementation strategies be developed for the RPV system?

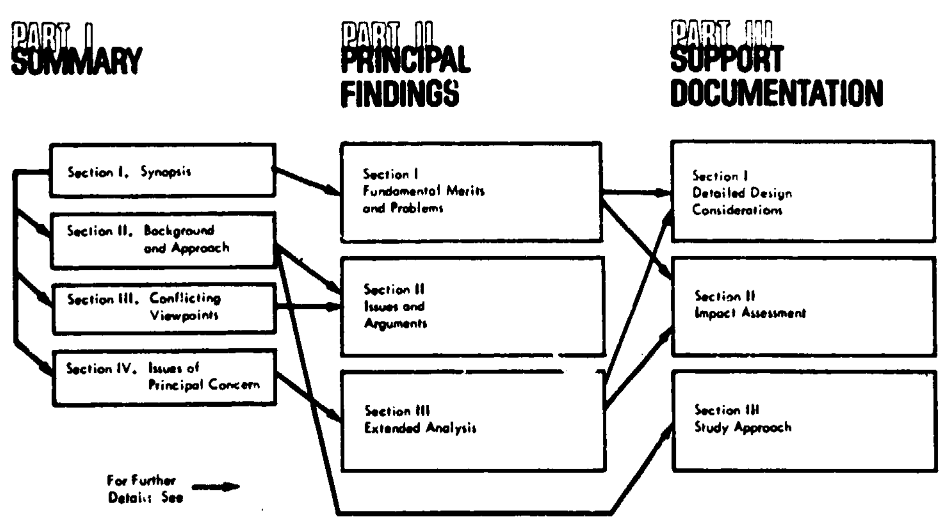
- o How acceptable/preferable will the RPV system be to the consumers?

The results of the initial analysis, the structured debate, and the extended analysis indicates in summary that:

- o The full-scale automotive implementation of the inductive coupled RPV system is not an effective and efficient technology for meeting future transportation and energy conservation requirements. Electric, hybrid, and synfueled/internal combustion engine vehicles seem, at the present, to have a higher potential for meeting these needs.

- o The pursuit of small scale applications of the RPV system concept, such as mall buses and airport/in-plant shuttle services, could potentially provide a valuable and necessary (but not sufficient) R&D base. Such projects would have to be motivated by other purposes than strictly economic petroleum conservation.

This report is divided into three parts. The Summary (Part I) is mostly a summary of the Principal Findings (Part II), except for the synopsis, which in essence summarizes the rest of the sections in Part I. The Principal Findings (Part II) contains both summaries (of portions of Part III) and source material, whereas Part III (Support Documentation) is strictly source material. This concentric structure of the report resembles to a great extent the chronological sequence of the study in reverse. It should be noted that the report, and Part III, Sections I and II in particular, assume some familiarity with the Lawrence Berkeley Laboratory (LBL) Feasibility Study /1/, which is therefore recommended for further reading in parallel with this report. The following diagram displays the structure of the report as described above.



CONTENTS

PART I. SUMMARY

PART II. PRINCIPAL FINDINGS

SECTION

PART III. SUPPORT DOCUMENTATION

SECTION

Figures

Tables

PART I: SUMMARY

SECTION I

SYNOPSIS

The national energy policies are focused to reduce the costly and vulnerable dependency on imported petroleum. In the longer term they are aimed at the inevitable transition away from the strong reliance on this single nonrenewable souce of energy. A substantial reduction in the use of petroleum by passenger cars and trucks would be of prime importance, considering that these vehicle types together account for about 80% of all transportation fuels and almost half of the U.S. petroleum consumption. Several options for moving in this direction are presently being explored involving various time frames and prospects for success (e.g., promotion of the use of public transportation and car-pooling, improvements in vehicle fuel economy, development of advanced heat engines and synthetic fuels).

One of the more promising long-term options is centered around electrification in the transportation sector. This option is presently being pursued primarily in terms of research and development of electric and hybrid vehicles (EHVs). The purpose of the study reported here is to assess the viability of an alternative technology for automotive electrification, the inductive coupling technology (ICT), and the advisability of further pursuing this technology and its system application, the roadway powered vehicle (RPV) system.

A. BASIC QUESTIONS

The automotive (passenger car) application of the inductive coupling technology has more specifically been suggested as a subject for further research and development within the U.S. Department of Energy (DOE) Electric and Hybrid Vehicle Research and Development Program. Like EHVs, the principal merit of the RPV system is its potential for petroleum conservation and displacement, with electricity as a substitute. The present study is designed to help DOE decide on the level of funding for further research and development of the RPV system, at this time and as part of the EHV Program. On this background, answers have been sought to the following basic working questions:

(1) What are the significant constraints and impacts related to the possible implementation of the RPV system?

(2) How does the RPV system compare with other technologies for petroleum displacement through electrification in the transportation sector?

B. ROADWAY POWERED VEHICLE SYSTEM

The technical concept behind the RPV system is the combination of an electrical power source buried in the roadway and a vehicle-mounted power pickup, which is inductively coupled to the source with an air gap on the order of one inch between the two (see Figure 1-1). This concept is referred to as the Inductive Coupling Technology or ICT concept. In principle, the coupling works like a transformer. It could conceptually just as well be used for offroad and stationary applications.

As an RPV system, it will enable the vehicle, which must be equipped with an electric propulsion system, to maintain freeway speeds from roadway power alone. An additional onboard energy source and/or power plant is required to operate the vehicle when not on the powered roadway. In other words, apart from the power pickup, the vehicle design looks similar to that of electric or hybrid vehicles; or even conventional internal combustion engine (ICE) vehicles with the further addition of an electric motor.

Power conditioners, which convert the utility power to a higher frequency (180 Hz) required by the RPV system, would be installed adjacent to the roadway every 3 to 8 km. The increased peak load on the utility system would be of the order of 5 to 15%, assuming a full scale freeway implementation in a given area, and varying with the time of the day depending on the particular traffic conditions of the area.

Initial investigations of the conceptual design and feasibility of the RPV system were performed by the Lawrence Berkeley Laboratory (LBL), University of California, sponsored by DOE. In addition to the extensive design study of the power system, this work included analysis of the potential impact, and comparisons with alternative nonpetroleum-based automotive technologies. In essence, it was concluded that:

> "Analyses and modeling indicated that adequate power can be efficiently coupled by the system. The economics of the system appear to be favorable, and no implementational problems were identified that would make the system impractical. In addition to the engineering development of the power system, including performance verification with prototype hardware, continuing efforts should further address the effects of stray magnetic fields, the compatibility of the system with existing automobiles, electrical safety, and the process of transition from the use of existing automobiles" /1/.

Based on the findings of this study, a static prototype of the inductive coupling was built and tested at LBL, under the continued sponsorship of DOE. These tests resulted in a number of technical measurements concerning electrical characteristics, magnetic forces, power transfer capabilities, thermal effects, and noise effects /2/ /3/.

The focus of the studies performed at LBL was upon the technology itself (the ICT concept) with the application and impacts receiving a more limited examination. This study accepts the technological feasibility and focuses on the system applications (the RPV system).

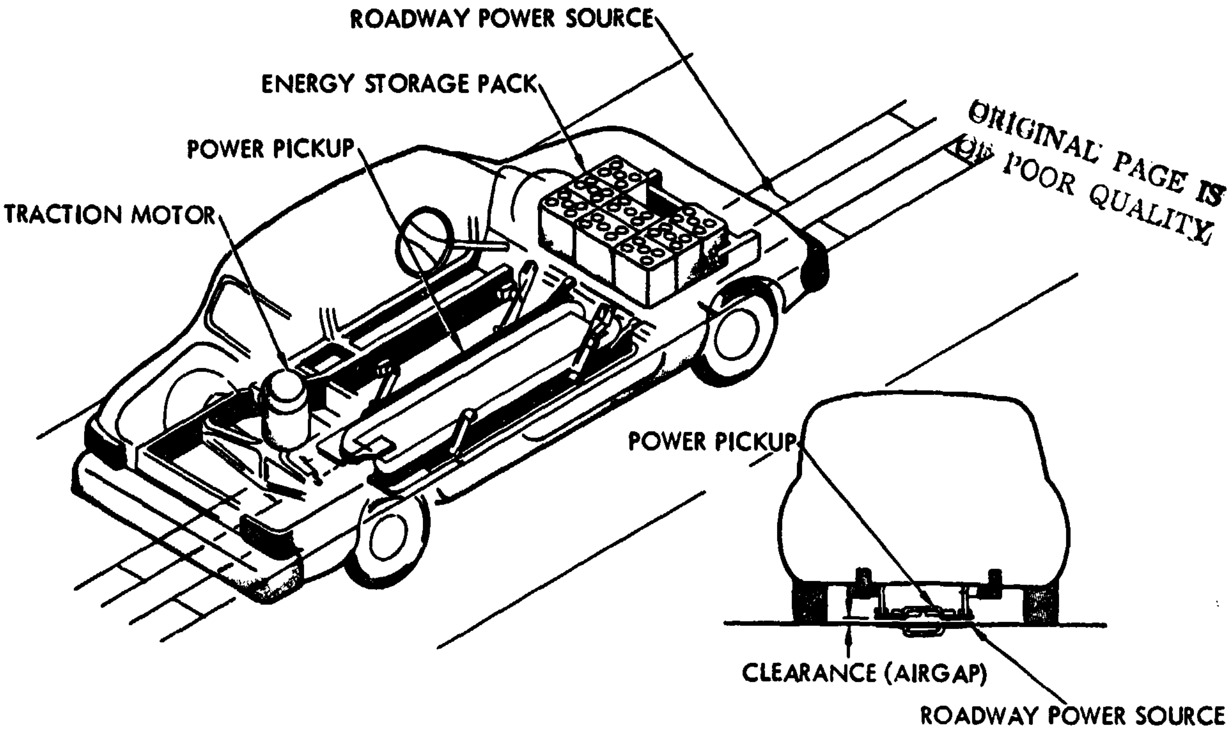


Figure 1-1. Roadway Powered Vehicle System Concept

C. NATURE OF THE PROBLEM

The present effort is concerned with the overall viability of the RPV system concept, and hence an attempt to assess the multitude of factors related to a possible implementation of such system: transportation, economics, energy, technology, social, institutional, etc. The problem of assessing these factors is dominated by their complexity and the relatively high dependency of the assessment on judgmental considerations and expectations about the future. It has therefore been a primary concern to focus the attention on the unknown and uncertain elements as well as the known ones; and not to lose sight of their relative importance (to the overall viability).

This concern for the analysis of the important unknown (i.e., the key issues) is judged to be of particular interest to policymaking (e.g., R&D funding decisions) because of the pivotal nature of such information with respect to the final decision. The art of merging the key issues in the framework of a limited and often fragmented scientific data base, is the principal task of the policy-maker (e.g., DOE). The assumed ideal of the advisor (e.g., JPL) is to provide both a relevant database (what we know) and a relevant insight into the issues of concern (what we do not know), in the most efficient way.

A central element of the method used for studying the question concerning the funding level of future RPV research is an application of what is known as dialectical inquiry /21/ /22/ /23/ /24/. It proceeds from the assumption that policy-making is ultimately based on the weight of arguments presented for and against a policy option. Dialectical inquiry augments detailed scientific analysis by showing where this analysis fits into the structure of the arguments. It captures and provides information and insight of particular importance to policy-making, beyond what is usually provided by other methods of inquiry.

The specific procedure for the dialectical inquiry employed by JPL was to conduct a structured debate between two parties with conflicting viewpoints and interests in the outcome of the R&D policy decision. A third party, which was neutral in this respect, was chartered to clarify the arguments during the debate and to summarize and analyze the structure of the arguments following the debate.

The overall study results of the structured debate and the supporting technical analysis is summarized in the following in terms of the most important conclusive findings (what we know) as well as the remaining pivotal issues (what we do not know).

D. CONCLUSIVE FINDINGS (WHAT WE KNOW)

The following summarized results have been generated with a high degree of certainty. They constitute the essence of what is believed to be known about the RPV system, and at the same time important to the overall viability.

- o There are no identified inherent technical problems with the RPV system concept from an electrical viewpoint. It should be conceptually feasible to build and operate an RPV system, as suggested in the LBL Feasibility Study /1/, even though many engineering design problems are still to be solved.

- o The life cycle cost comparison with electric, hybrid, and advanced ICE vehicles shows that the RPV vehicle is competitive, if the captial cost of the powered roadway system is not allocated to the vehicle use. This would occur at gasoline prices of $1.50 to $2.50/gal in 1978 dollars.

- The roadway installation of an RPV system is technically feasible but would most likely be more costly than estimated in the LBL feasibility study. However, the relative importance of this cost increase is small, when assessing the overall economic viability of the RPV.

- Any extensive roadway installation of the RPV system on arterials and other surface streets would be more problematic than on freeways. This is primarily because of interference with the need for underground access and future resurfacing and rerouting of lanes, which is typically expected of such roadways.

- The RPV system in itself would not place unreasonable or unreachable demands on the electric generation and distribution system.

- The Los Angeles region in specific, with its present petroleum dominated generation mix, is a poor choice for the RPV system, in spite of the attractiveness stemming from the extensive freeway network of this region.

- In particular, and as highlighted in the following, the questions on petroleum displacement and economic viability are a lot more serious than originally assumed or recently indicated in the GAO report on the DOE EHV Program /4/. While these questions <u>are</u> significantly more complex than originally assumed, the difficulties result from answers being derived from unverifiable and unrefutable assumptions.

E. PIVOTAL ISSUES (WHAT WE DO NOT KNOW)

The following five key issues were identified as the most important (pivotal) with respect to the DOE R&D decision concerning future RPV research, and hence furthermore the focus of the final round of technical analysis. It is concluded that these issues for the most part are unresolvable at the present, since they ultimately reflect diverging assumptions about the future and some of the more intangible aspects of the RPV system. While there exists other issues which are important, the five outlined below were deemed by the study team to be the five most important issues.

- To what extent will the RPV system displace petroleum?

  The magnitude of such benefits depends on the future expected utility load profile and the type of source fuel used to generate the marginal increase in required electricity. Projections of fuel types for meeting such future peak loads vary considerably between regions and between utilities with the only uniform trend being towards decreased use of petroleum. Assumptions about future load-leveling strategies to offset the need for conventional peaking plants, such as east-west interchange* and storage of baseload production, are critical. The system energy efficiency and its sensitivity to variations in the ratio between coupled and uncoupled vehicles on the system is another critical factor.

- Will the RPV system be prohibitively expensive?

  The effect of the impact on petroleum consumption, and hence the cost per barrel of displacing petroleum, is of course important. The economic viability is found to be much more sensitive to the way in which the costs are allocated than the unitized cost elements themselves (i.e., market penetration, implementation rate, discount rates). This leads to the more fundamental question of choosing an appropriate model for the economic assessment in the first place. Would a capital cost comparison be sufficient? Would a life cycle cost analysis be too arbitrary, considering the imperative multitude of implicit assumptions?

- Will the RPV system benefit or restrict transportation, and how much?

  The beneficial aspects are primarily related to the potential for automation of the RPV system, and hence potentially an increase in traffic capacity and safety. The restrictions are envisioned as a result of inclement weather situations and the prospects of failure to fully develop and automate the system.

- Can rational implementation strategies be developed for the RPV system?

  A commitment to a full-scale implementation (which at the present looks very risky) of the RPV system seems to be required to yield any significant impacts with respect to private automobiles, and avoid the potential degradation in

*The concept of sending excess base capacity of one region to another, several time zones distant, to meet peak demands.

urban transportation which is linked to small scale implementation plans. The initial pursuit of a less aggressive implementation strategy might, on the other hand, be preferred to secure a more definite understanding of the risks and promises of the RPV system concept, before any final commitment to a go-ahead decision. Any implementation strategy poses furthermore the critical question of market penetration and consumer acceptance (see next).

The last pivotal issue seems to underlie all of the previous issues, and be particularly important and uncertain:

- o How acceptable/preferable will the RPV system be to the consumers?

  On the one side it is postulated that virtually all of the potential consumers will buy RPVs on the basis of a number of attractive features: more convenient, simple and safe technology and mode of transportation, no gasoline lines or fuel supply problems, no range problems or performance degradation, and an equivalent price. On the other side it is postulated that 20 to 50% market penetration of EVs (including RPVs) is an absolute maximum if, in fact, the RPV system adds significant benefits to EVs. At the same time it is felt that the implementation of an RPV system would be too risky, because breakthroughs in battery and other EV technologies would make EVs more attractive, and hence make RPVs obsolete.

F. REFLECTIONS AND RECOMMENDATIONS

The basic issue explored in this study has been: Is the inductive coupling RPV system a promising technology for meeting the U.S. transportation and energy conservation needs?

The existence of two conflicting sets of answers and supporting viewpoints concerning this question was realized from the very beginning of this study. While the reasons behind these viewpoints initially were thought to be disputable primarily on the grounds of verifiable scientific data, it was found that the discrepancies were much more dependent on unverifiable judgments and assumptions about the future. In the reporting of the study results, a major attempt has therefore been made to present the two conflicting viewpoints in parallel.

In summary, the one viewpoint is warranted by a rather deeply held belief that the nation's need to displace petroleum and the citizens' recognition of this (and hence their willingness to accept the RPV technology) will dominate the policy arena during the next few decades. The other viewpoint differs markedly in these beliefs. Its claims are warranted by the basic belief that market economics will be the dominant factor in the policy arena during the next few decades, and that as an energy saving transportation alternative, the RPV system does not possess economic viability.

One fundamental difference between these viewpoints involves their concept of the role of government and large institutions. The one looks to government and other large institutions to set social goals and to take a strong, active role in achieving them. The large scale systems characteristics of the RPV system partly necessitate this belief. The other favors a strong reliance on free market economics with minimal direct government intervention.

With these fundamental disagreements in mind, the following principal conclusions have been reached:

- The full scale automotive implementation of the inductively coupled RPV system is not an effective and efficient technology for meeting future transportation and energy conservation requirements. Electric, hybrid, and synfueled-ICE vehicles seem, at the present, to have a higher potential for meeting these needs.

- The pursuit of small scale applications of the RPV system concept, such as mall buses and airport and in-plant shuttle services, could potentially provide a valuable and necessary (but not sufficient) R&D base. Such projects would have to be motivated by other purposes than strictly economic petroleum conservation.

It is at the same time recognized that the usefulness of continued government funding of RPV system research depends on factors in addition to the RPV system viability, such as answers to the following questions (not addressed in this study):

- Should less restrictive research and development funding criteria be applied to RPV systems since such systems produce principally a nationwide positive externality (i.e., less petroleum use), not a private benefit and hence do not attract significant numbers of strong advocates?

- Should DOE concentrate its funding on a few of the most viable options or should it distribute its funding among many options?

- Will small increments in R&D funding yield relatively high returns in new knowledge, considering the present relatively low level of knowledge about the RPV system?

All in all, it is recommended, that:

- Since the conclusion of many pivotal issues depends on subjective assumptions on the nature of future institutions and technologies, DOE should weight the assumptions and arguments (assess their plausibility), presented by the RPV system advocates and skeptics in this report, against those which they believe to be most consistent with the DOE EHV program.

- The possibility of initiating a DOE/DOT joint research program focused on smaller scale public transit applications of the RPV system concept should be explored.

- Any near-term R&D funding of the RPV system technology should at least include the most uncertain aspects of the technology: the RPV system pickup/suspension design, roadway design, and system automation (in particular in terms of installation, reliability, maintenance, safety, cost, and energy efficiency).

SECTION II

BACKGROUND AND APPROACH

This section deals first with the background, purpose, and scope of the study. Secondly, a brief description is given of the overall study process.

A. BACKGROUND PURPOSE AND SCOPE

As a result of the encouraging technical findings of an "Investigation of the Feasibility of the Dual Mode Electric Transportation System" /1/, i.e., the RPV system, conducted in 1976 and 1977 at LBL, a static prototype of the inductive coupling was built and tested during 1977 and 1978.* The test results were documented in a separate report /2/, and an IEEE conference paper /3/. The question was then raised by the DOE, which had been sponsoring these activities, whether this technology and its automotive (passenger car) application, as described conceptually in the LBL reports, should be pursued more vigorously in parallel with DOE's ongoing electric and hybrid vehicle R&D activities.

In order to address this question, concerning the broader set of promises and problems related to the RPV system concept, JPL was asked by DOE to conduct an "assessment of the roadway powered vehicle system." The results of this work, which took place during 1979, are documented in this report.

At the beginning of 1979, the Lawrence Livermore Laboratory (LLL) assumed responsibility for the hardware development of a test vehicle, and is now installing a 50-m RPV system road segment for dynamic testing.

Meanwhile the U.S. Government Accounting Office (GAO) came out with a report, entitled "The Congress Needs to Redirect the Federal Electric Vehicle Program" /4/. While the dominant parts of this report are concerned with the demonstration project of DOE's EHV Program, some questions are also raised with respect to the further pursuit of RPV research by DOE. The GAO report recommends in essence to "reexamine the potential of electrified roadway systems in relation to other competing EV R&D efforts"(/4/, p. 41).

---

*The principal investigator, John G. Bolger, has been working with the design and development of RPV system technology for about 10 years prior to the LBL investigation and prototype testing.

The present JPL study could also be seen as a response to this GAO suggestion, even though there is some disagreement with the supporting GAO analysis and arguments. The GAO work can be viewed as a rough-cut critique, without sufficient insight and understanding of the important issues to serve as a basis for sound R&D decision-making with regard the RPV system.

The JPL study is designed directly to help DOE decide on the level of funding for further R&D of the RPV system at this time and as part of the EHV Program. Initially this led to the formulation of the following basic working questions:

(1) What are the significant constraints and impacts related to the possible implementation of the RPV system?

(2) How does the RPV system compare with other technologies for petroleum displacement through electrification in the transportation sector?

Taken together, these questions have been recast into one basic issue concerning the overall viability of the RPV system concept:

- Is the RPV system a promising technology for meeting the U.S. transportation and energy conservation issues?

The JPL study is scoped to address this issue and its related sub-issues only. Other issues (unrelated to the overall viability of the RPV system, but of potential importance to a DOE R&D decision) have been identified, but not pursued any further, such as:

- Should less restrictive research and development funding criteria be applied to RPV systems since such systems produce principally a nationwide positive externality (i.e., less petroleum use), not a private benefit and hence do not attract significant numbers of strong advocates?

- Should DOE concentrate its funding on a few of the most viable options or should it distribute its funding among many options?

- Will small increments in R&D funding yield relatively high returns in new knowledge, considering the present relatively low level of knowledge about the RPV system?

In summary, the JPL study can be viewed as a limited technology assessment. It is limited in the sense of only looking at what were found to be the most important consequences/requirements of a possible implementation of the technology, and how this technology compares to other competing technologies. It is also limited in the sense that it is designed with only one purpose in mind: to provide supporting analysis for the DOE funding decision with respect to continued RPV system research.

B. STUDY PROCESS

The initial evaluation of the RPV system was concentrated on six topical areas: coupling, roadway, power generation and distribution, comparison with alternative technologies, transportation, and economics. While this evaluation generated answers on many of the subquestions regarding various detailed aspects of the RPV system, it also brought up new and more fundamental questions with respect to the underlying assumptions of the overall analysis. The results of this initial evaluation are documented in Part II, Section I (summarized), and Part III, Sections I and II. At this point, the lack of general consensus between the results of the tentative JPL analysis and the LBL Feasibility Study /1/ became clearer, while the reasons and assumptions behind them became more complex and uncertain. This should be expected when dealing with ill-structured problems which include missing data points and strong elements of judgmental considerations).

In order to expose underlying assumptions and challenge their validity and importance with respect to the DOE R&D decision on the RPV system, a three-day workshop was held as a structured debate between the two competing viewpoints. This particular approach (dialectic inquiry) has successfully been applied in parallel cases of corporate strategic planning and decision-making.

A more detailed account of the merits and assumptions related to this approach is given in Part III, Section III. In essence, it is warranted by an item of common sense from the business planning arena, as in the words of W. W. Simmons, a former director of Exploratory Planning at IBM: "When opinions are spread out, ... (you) can ask for comments from persons holding the most extreme positons first, because they generally can contribute more toward clarifying the issues than can persons with moderate opinions" /31/.

The workshop was very successful in pointing to a number of pivotal assumptions about the RPV system and the future. The results, in the eyes of a third (observing) party, are documented in Part II, Section II, of this report. It led to an extension of the analysis in three key areas of concern: Transportation impacts, economic parameters, and petroleum displacement. It furthermore indicated the need for a general plausibility analysis of the arguments. The results of these four items of extended analysis are documented in Part II, Section III.

While the participants in this study generally favored the dialectical inquiry method used and the conclusions reached, they also voiced a few caveats and made some suggestions for improvement. Their feedback is contained in Appendix C of this report.

SECTION III

CONFLICTING VIEWPOINTS

This section deals with the analysis of the structured debate. A more detailed documentation of this analysis, performed by the third party, which witnessed the debate and interrogated the debaters, can be found in Part II, Section II of this report.

The debate was centered around the question of R&D funding for the RPV system. While the one point of view strongly favors continued support of RPV system research, the other is less focused in terms of what is favored. This viewpoint is more focused at the negative aspects of the RPV system than to demonstrate a strong case for either of the debated alternatives: electric, hybrid and synfuel ICE vehicles (see Figure 1-2).

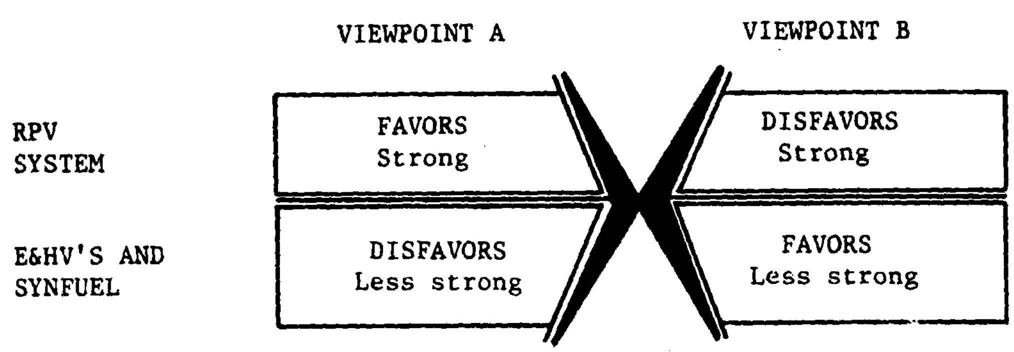


Figure 1-2. Focus of the Two Conflicting Viewpoints

The method of inquiry (dialectic inquiry) was to bring together representatives of these two viewpoints, to present the facts, assumptions, and modes of reasoning which led them to their differing conclusions.

The following subsections describe in summary the basic positions and world views of the two competing viewpoints, the selected issues for debate, and as an example, the structure of the arguments present on issue No. 1 concerning petroleum displacement.

A. BASIC POSITIONS AND WORLD VIEWS

The basic positions of the two conflicting viewpoints identified and argued are summarized in Table 1-1.

Table 1-1. Summary of the Two Basic Positions

Viewpoint A	Viewpoint B
1. The RPV system will displace a significant amount of petroleum.	1. The RPV system will not displace a significant amount of petroleum.
Because:	Because:
o RPV vehicles will be much more efficient and acceptable to the consumer than the alternatives (EHVs and synfuel ICE vehicles). o The system will be able to serve highway (electric) transit and trucks much better than EHVs. o The system need not use petroleum for power generation. The small increase in utility load during peak hours could be offset by adding nonpetroleum baseload capacity.	o Cost and technology barriers are too substantial to overcome. o The system creates additional peak-load demand for electric generation capacity and no nonpetroleum alternative has been convincingly argued.
2. The RPV system is economical.	2. The RPV system is uneconomical.
Because:	Because:
o Capital costs are comparable or lower than the other alternatives and the operating costs are lower.	o Present-value life cycle costs are higher, in terms of levelized required revenue or dollars per barrel of oil displaced.

Table 1-1. (contd)

Viewpoint A	Viewpoint B
3. The RPV system enhances mobility.	3. The RPV system reduces mobility.
Because:	Because:
o The addition of automation to the system will increase highway capacity and decrease accident rates.	o The barriers to implement automation and fully develop the system are insurmountable.
o The problems of inclement weather will be minor.	o Inclement weather will interfere with efficient system operation.
4. There are several implementation strategies available for bringing the RPV system into widespread use.	4. The RPV system will not be successfully implemented.
Such as:	Because:
o Early implementation of self-contained transit system (malls, people movers), as precursors to highway use.	o The system will fail to achieve economies of scale for private auto manufacturers.
o Midterm implementation on interstate truck routes as precursors to automobile use.	o Consumer acceptance will be too low to warrant the large scale implementation project required to gain any market penetration in the first place.

Viewpoint A appears to be warranted by a rather deeply held belief (world view), that the nation's need to displace petroleum and the citizens' recognition of this and their willingness to accept the RPV technology will dominate the policy arena during the next few decades.

Viewpoint B differs markedly in these beliefs. Its claims are warranted by the basic belief that market economics will be the dominant factor in the policy arena during the next few decades. This leads to the conclusion that, as an energy saving transportation alternative, the RPV system does not possess economic viability.

One fundamental difference between the world views of the two basic positions involves their concept of the role of government and large institutions. Viewpoint A looks to government and other large institutions to set social goals and to take a strong, active role in achieving them. The large-scale systems characteristics of the RPVs partly necessitate this belief. Viewpoint B favors a strong reliance on free market economics with minimal direct government intervention. This viewpoint advocates battery operated electric and hybrid automobiles and synthetic fuels.

B. ISSUES FOR DEBATE

As an agenda for the debate, the following issues were jointly (by the two debating teams) selected and prioritized in terms of importance with respect to the overall viability of the RPV system.

o I.	Petroleum Displacement	o System Energy Efficiency o Source Fuel o Peak Demand
o II.	Cost Elements	Economics o Cost Allocation o Comparison
o III.	Automation	Transportation o Modes o Availability o Safety o Capacity
o IV.	Institutional	Implementation Process o Infrastructure o Social and Environmental o Scenarios and Timeframe
o V.	Comparison with Alternatives	o Electric, Hybrid, and ICE Vehicles o Synfuels

It should be noted that the order of Issue No. 1 and No. 2 was determined by the flip of a coin. While the team in favor of RPV system research and development (the Blue Team) held that the issue of petroleum displacement was more important for a determination of the RPV system viability than the economics issue, the opposite was argued by the opposing team (the Red Team), in concurrence with the viewpoints of the two teams, as outlined in the previous subsection. It should also be noted that only the first four issues were debated directly (because of time constraint), while the last issue was brought up only indirectly during the debate of the other issues.

C. THE STRUCTURE OF THE ARGUMENTS

Following the debate, the third party analyzed the outcome of the debate and placed it into a structure patterned after a model developed by Steven Toulmin /29/. The elements of this structure and their functional role in an argument on a particular issue is outlined in Figure 1-3. The petroleum displacement issue and the related principal claim of the Blue Team is used as an example for clarification.

The definitions of terms used for the argumentation analysis are as follows:

Claim	An assertion which is the conclusion of the argument presented.
Data	Facts (or that taken to be fact by at least one party to the argument).
Warrant	Principles, rules, inference--licenses which entitle the claim to be made from the data presented.
Rebuttal	Conditions under which the authority of the warrant need be set aside and/or conditions which diminish the strength of the claim.
Backing	The set of categorical statements which form the foundation of a warrant.

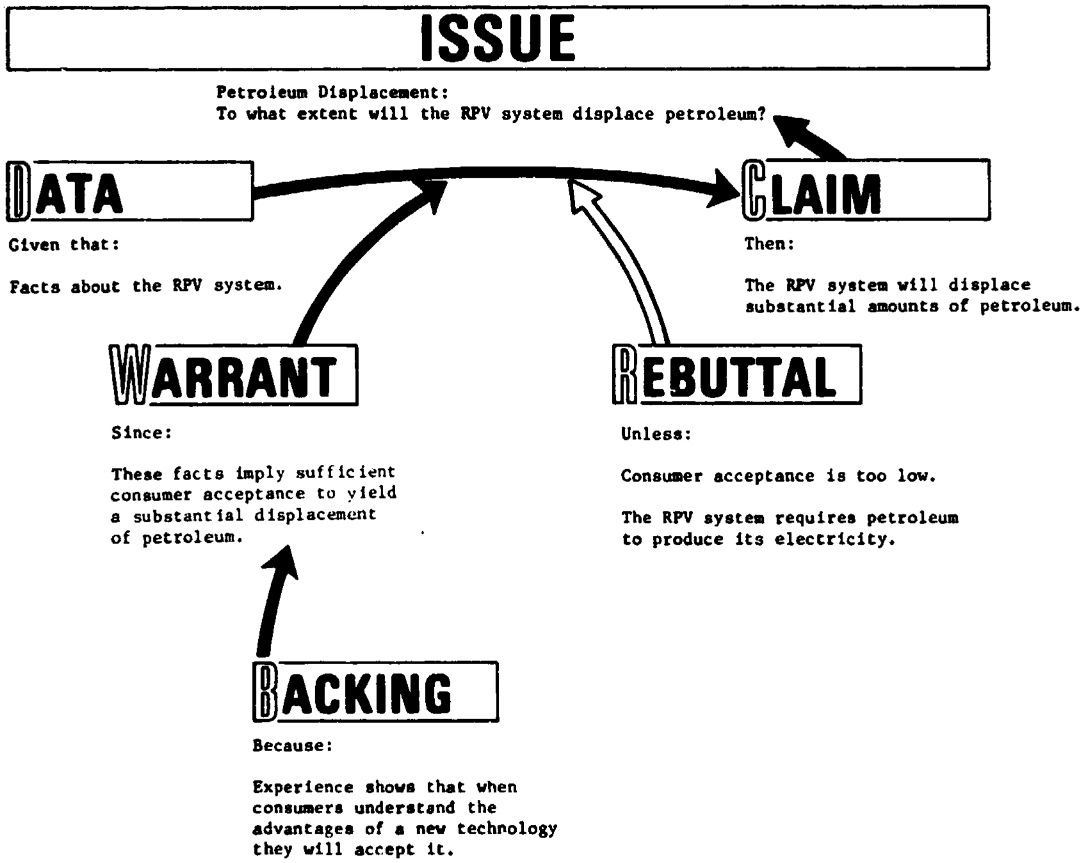


Figure 1-3. Model of an Argument (Blue Team Issue No. 1 Claim)

After a principal claim is identified in terms of data, warrant, backing, and rebuttal, the most critical elements of the argument are analyzed in further detail. This identification of sub-arguments also applies to the Toulmin model. Two forms of sub-arguments are utilized in this study. One is to choose a critical data item and treat it as a claim. The other is to refute a rebuttal by using a counterclaim. The purpose is to lay out the hierarchical structure of the arguments pertaining to the policy issue in question. The arguments analyzed in this study are carried as deep as three levels, as illustrated in Figure 1-4.

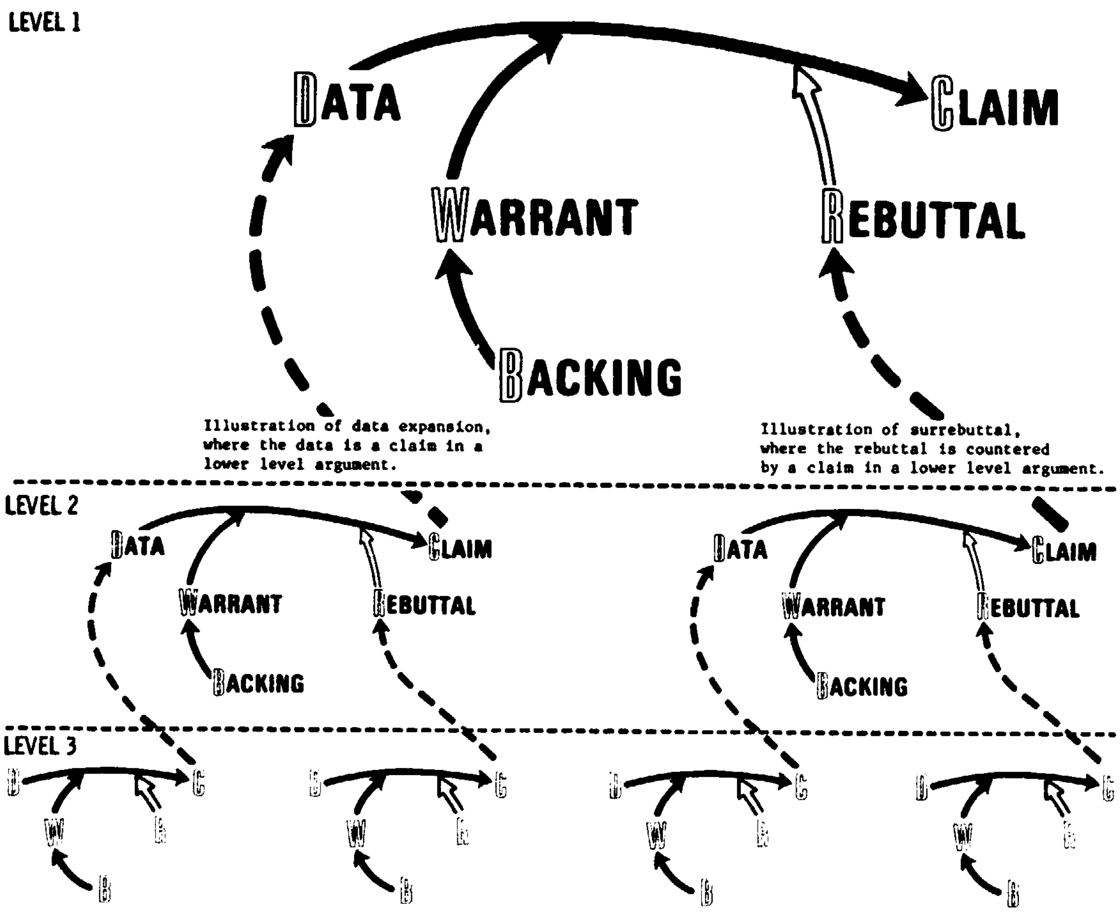


Figure 1-4. Hierarchy of Arguments

The structure of all of the four issues debated directly is outlined in detail in the body of this report, together with the outline of a fifth issue on consumer acceptance (see Part II, Section II). Although this last issue was never discussed separately, it was found to be of equivalent importance since it frequently surfaced in the debate of the other issues. Figures 1-5 and 1-6 show (in summary and as an example) the structure of the arguments presented or the petroleum displacement issue (No. 1) with emphasis on the critical paths in the arguments.

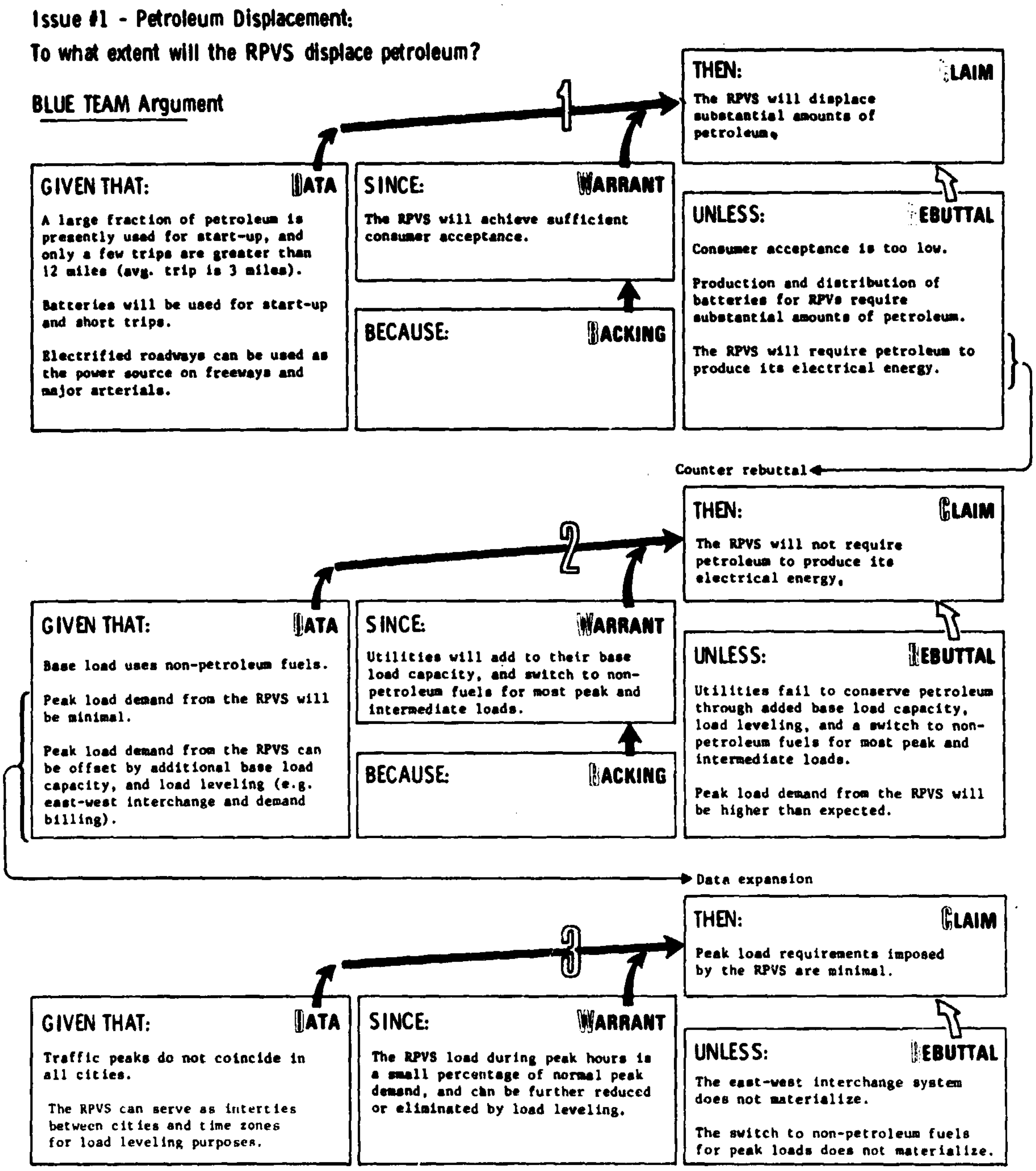


Figure 1-5. Blue Team Arguments Concerning Petroleum Displacement

Issue #1 - Petroleum Displacement:
To what extent will the RPVS displace petroleum?

RED TEAM Argument

THEN: CLAIM

The RPVS is not the most efficient system for achieving the highest amount of petroleum displacement.

GIVEN THAT: DATA

1. Costs are prohibitively high.
2. No gain in roadway capacity.
3. No gain in petro displacement.
4. Massive public investment & consumer acceptance are nexessary for the RPVS to be efficient.
5. Depends on successful development of other technologies:
   - Battery technology
   - Peak/off-peak power generation
   - Design of electric vehicles
6. Depends on public policy decisions in its favor:
   - Centralized/decentralized power distribution & urban development
   - Electric power/other fuels
   - Automobiles/public transit
7. East-west interchange not feasible.
8. More peak capacity required than stated in the LBL report.
9. RPVS efficiency is overstated compared to ICE or E&HV.
10. E&HVs will not add to peak load.
11. Minimal cold start losses with E&HVs.

SINCE: WARRANT

The barriers indicated by the data are insurmountable and supports the inefficiency of the RPVS.

BECAUSE: BACKING

1. Based on Red Team cost projections.
2. No new roads and no capacity increase of current system.
3. Petroleum used to build & power the system offset any petroleum displacement gained from having non-petro fueled vehicles.
4. The system is costly, it will not be developed by private industry, and consumers will not readily accept this new technology.

5&6. The RPVS will function at or above a minimally acceptable level, only if a particular scenario (within certain parameters) proves true.

7. Red Team's assessment, and research done by power companies substantiates this data.
8. Based on Red Team calculations.

9-11. Based on Red Team findings.

UNLESS: REBUTTAL

Blue Team arguments are correct and the major barriers can be overcome.

The data are refuted as follows:

a. Capital costs are similar to or lower than for the alternatives, and operating costs are lower.

b. Automation of the RPVS will smooth traffic flow and allow vehicles to travel closer together; and hence reduce energy consumption and increase roadway capacity.

c. RPVs are lighter than EVs and use less battery energy; hence more efficient than EVs. RPVs have no ICE, which is inefficient on short duty cycles; hence more efficient than ICE or hybrid vehicles.

d. Urban freeway lanes are used by about 11,000 vehicles/day, thus amortizing RPVS equipment better than alternative battery charging equipment in individual garages.

e. No study of the feasibility of interties was identified.

f. RPVS technology is simple and development risks are modest.

g. HVs are a poor choice:
   - Excessive ICE cold start losses.
   - Inconvenient to the consumer.

h. The RPVS is accepted with some enthusiasm by consumers because of low operating costs, convenience, and improved traffic flow and safety.

Figure 1-6. Red Team Arguments Concerning Petroleum Displacement

SECTION IV

ISSUES OF PRINCIPAL CONCERN

This section gives a brief summary of the findings of the extended analysis documented in full in Part II, Section III. This analysis was motivated by the need to clarify some of the weakest and most important elements in the arguments presented during the structured debate and to assess the overall plausibility of these arguments.

A. TRANSPORTATION IMPACTS

There are four primary transport issues that are of significant concern in the consideration of inductive coupling technology for automotive applications: availability, mobility, and modal optimization. In addition to these four issues, there are several specific technical problems of concern related to the installation and maintenance of the RPV system source in existing roadways.

1. Availability

There is no reason at this time to envision a significant expansion of limited access highways which, also at this point, appear to be the only feasible candidates for the RPV system. An obvious first constraint, therefore, to availability is the capacity of the limited access highway system. This constraint exists regardless of the means of vehicular propulsion; it is a function of the total street system, not just freeway density. Secondly, battery-only EVs can be designed to fulfill most commuter requirements right now, but cost and unavailability during recharge (8 to 12 h) are still significant impediments to their public acceptance. A similar need to recharge (availability constraint) exists for the RPV. The RPV concept does not appear to enhance availability of transport more than the electric vehicle or hybrid vehicle.

2. Mobility

Contemporary urban travel patterns have been dominated by the automobile because of its unparalleled personal mobility. Freeway systems have emphasized this mobility aspect. The automobile infrastructure, based upon a ready supply of liquid fuel, has permitted a sense of unlimited range. The RPV system concept contains, implicitly, the direct and immediate control of the power source (fuel) by government or quasi-governmental agencies (it is assumed that the roadway would not be a private road). The direct control of fuel (propulsion power) and the constraint upon vehicular operation to certa n routes (e.g., freeways), are attributes more closely associated with a fixed guideway transit operation. They are certainly severe mobility constraints to the contemporary perception of the private automobile, although not as severe as with a short range electric vehicle or extreme fuel rationing.

3. Modal Optimization

The RPV system concept lessens the mobility aspect of the automobile by confining its movements to routes with a powered roadway (e.g., freeways). Alternative access routes that are not roadway powered are not as available and this aspect promotes system failure should an accident or other incident preclude a roadway powered route from being used. The ability to equalize traffic movement and utilize alternate routes is mandatory in the automobile/highway system in every urban area.

While the potential to automate vehicle/highway interface is enhanced by the RPV system concept, the potential automation of non-RPV highway systems is just as real. The point is that the realizable benefits or implementability or legal ramifications of an automated highway is relatively unexplored. Even an optimistic assumption of doubling throughput via automation still leaves the resultant freeway capacity far short of any transit option.

4. Roadway Installation

The proposed minimum-cost strategy of emplacing the RPV source in roadways only at the time that the roadways are rehabilitated is not feasible. Large-scale rehabilitation of long lengths of highways is seldom done. Therefore, only the cutting of the slot in existing roadway surfaces was investigated. It was found that there are at least two technologically feasible methods currently available to cut a suitable slot for the RPV source in both asphaltic concrete and Portland cement concrete. The preferred method is the use of automated roadway planing machines. Although the cost estimates obtained for the different methods vary widely in both magnitude and comprehensiveness of cost items considered, they are in the general range which will not seriously influence the total package cost of installation of an RPV system.

5. Roadway Maintenance (Winter-Zone Considerations)

In the sun belt, weathering of the roadway surface and the RPV system source is not believed to be a problem. The benign environment there does not seriously degrade the roadway. The freeze-thaw cycle in the winter zone, on the other hand, poses a significant threat to the longevity of both the standard roadway surface and the RPV system source. It is not possible to know now what the resulting deterioration rate of the source will be in this environment.

The resulting chuckholes pose, in any case, a design problem to the RPV. Whenever any automobile drives through a medium or large-sized chuckhole, its frame briefly drops at least 2 in. The pickup of an RPV would have to be retracted in this event, or be able to withstand striking the ground without damage.

The proposal has been made to de-ice the RPV system freeways in freezing conditions by electrical resistance heating of the source. This is not practical. In addition to such problems as the creation of glare ice due to the refreezing of melted run-off water, the power required to do such heating is prohibitively large. To maintain an elevated temperature in the roadway at 35°F in a situation of 10°F ambient temperature, would minimally require 700 kW to 1300 kW per lane mile. This would reduce the system efficiency to less than one-third of the nonleaked value during average traffic conditions.

B. ECONOMIC VIABILITY

Since the economic attractiveness of the RPV system is a function of the nature of who is assumed to be the beneficiary of the system and who is assumed to pay for the system, two different options are examined:

(1) The benefit is private in terms of reduced overall costs to drivers on the system and costs are to be paid completely by users.

(2) The benefit is public in terms of petroleum consumption reduction, and user costs above conventional vehicle costs are to be subsidized from general revenue.

In the first case, the ratio of the system costs to gasoline cost savings is used as the figure of merit. In the second case, the ratio of the subsidy to the petroleum cost savings is the figure of merit.

1. Value of Conservation

Any petroleum displacing or conserving system including the RPV system can cost more than the market value of the petroleum it is displacing and still be justified. Apart from the market cost of purchasing petroleum there are additional public costs incurred by the nation as a whole. Contributing to these social costs are:

(1) The implication to national security from dependence on imported petroleum (i.e., the cost of protecting some portion of the world petroleum distribution system).

(2) The risk cost of potential disruption of supply and/or arbitrary price increases.

(3) The compounding of such risk by increasing the possibility of occurence by increasing the effectiveness of disruption from increased reliance on import sources.

(4) Regressive impacts of inflation resulting from higher import prices.

(5) Impairment of overall economic efficiency from inventory changes in expectation of higher rates of inflation.

Albeit determined by assumption, the cost of conserving can be quantified for this technology. However, a statement on the absolute (not relative) economic attractiveness of this, or any other conservation technology, cannot be made until there is a quantified estimate of the present worth of future petroleum conservation (i.e., a quantification of the above factors).

2. Costs of Conservation

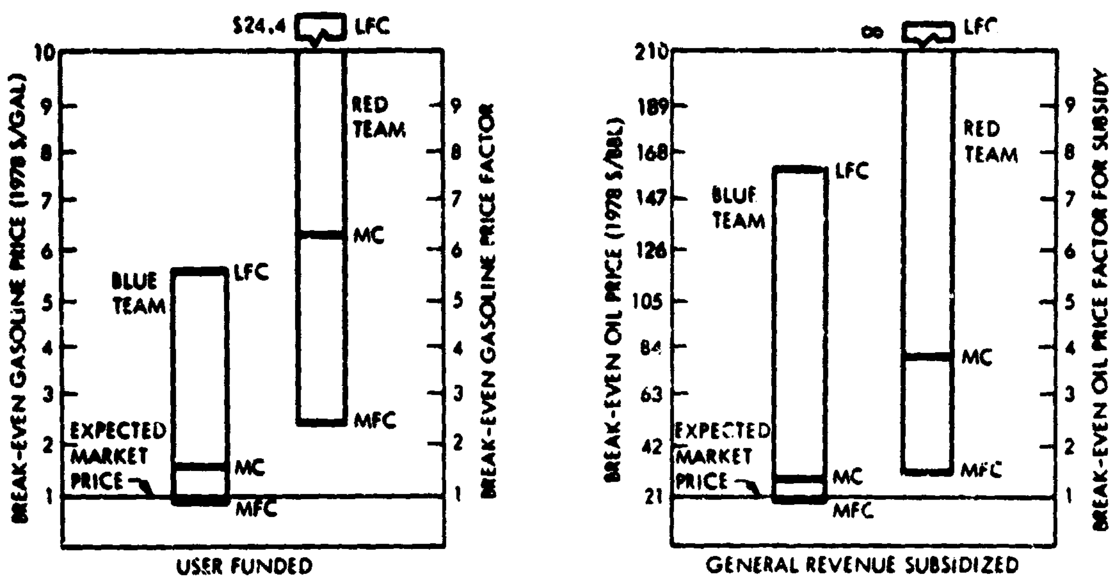
Figure 1-7 presents the break-even fuel price factors (and fuel prices) for the RPV system. The factors express how much more the fuels would have to cost above their assumed expected cost for the RPV system to be a cost-effective conservation alternative.

The two debating teams independently prepared sets of assumptions which were the input to the present value model. The Red Team had a skeptical bias while the Blue Team was advocate-biased. Each team developed three assumption sets. Credibility was defined subjectively and internally to each team (e.g., what was credible to the advocates would not necessarily be credible to the skeptics). These "bounding" assumption sets were defined as:

LFC - The least favorable set of assumptions for the RPV system that still possess credibility.

MC - The most credible set of assumptions.

MFC - The most favorable set of assumptions for the RPV system that still possess credibility.



LEGEND

LFC - LEAST FAVORABLE YET CREDIBLE ASSUMPTION SET
MC - MOST CREDIBLE ASSUMPTION SET
MFC - MOST FAVORABLE YET CREDIBLE ASSUMPTION SET
RED - SKEPTICS
BLUE - ADVOCATES

Figure 1-7. Break-Even Fuel Prices for the Two Funding Alternatives of the RPV System.

Table 1-2 presents the principal items in the assumption sets for both the advocates' and the skeptics' position on the RPV system.

The impact of the divergence in viewpoints is particularly evident in the two teams' perceptions of the economic viability of the RPV system.

For a system fully paid for by the users, the Red Team's most credible set of assumptions implied that gasoline would have to cost over six times the projected future price for the user to be economically indifferent between an RPV and a conventional vehicle. The Blue Team's assumptions implied a factor of only one and one-half.

For a system where general revenues were used to subsidize users so they would be economically indifferent between RPV and conventional systems, the Red Team's most credible assumptions implied that petroleum would need to cost almost four times the future expected price for the system to balance dollars saved in oil with dollars expended on RPV subsidies. The Blue Team's assumptions implied the future petroleum price need exceed expectations by only a very small factor for this balance of expenditures to be achieved.

C. PETROLEUM DISPLACEMENT

The analysis concerning the amount of petroleum displaced by an RPV system must take into account both the petroleum saved by not using ICE vehicles, and the petroleum used by the electric utilities to meet the added load of the RPV system. To study the petroleum requirements of the utilities, three basic data elements are required:

(1) The load profile of the RPV system.

(2) The load profile of the electric utility without the RPV system.

(3) The generation mix of the electric utility.

The analysis presented here assumes that an hourly breakdown of weekly traffic and utility load data would be adequate. The traffic data assumes an RPV system roadway network similar to the Los Angeles freeway system, and travel patterns typical of freeway driving in general. The utility load profile data is likewise similar to that of the Los Angeles area. Four sets of generation mix data were finally assumed, reflecting the nationwide variance in utility capacity mix (from petroleum to coal and hydro dominated systems).

1. Load Profiles

The assumed weekly RPV system load profile (i.e., traffic volume profile) is shown in Figure 1-8, together with the weekly (typical Los Angeles summer) load profile of the utility system without the RPV system. These load profiles were then translated into two utility load duration curves, with and without the RPV system (see Figure 1-9). A second load profile, typical for a spring/fall week, was furthermore analyzed, but no major change in the results were identified. For further detail on this case (Case E), see Part II, Section III.

Table 1-2. Principal Assumptions of the Economic Analysis

	Advocates' Blue Team			Skeptics' Red Team		
	MFC	MC	LFC	MFC	MC	LFC
Real expected rate of escalation--construction, %	1.3	2.5	2.5	2	3	4
Real expected rate of escalation--electricity, %	0	2.0	4.2	3	4.2	6.0
Real expected rate of escalation--labor, %	1.3	1.3	1.3	1.3	1.3	1.3
Real expected rate of escalation--gasoline, %	11	9	6	14	11	9
Real expected rate of escalation--oil, %	9	7	4	10	8	6
System lifetime, yr	35	35	35	35	35	35
Rate of discount--public, %	10	10	2	10	10	10
Rate of discount--private, %	2	2	2	2	2	2
Road work, k$/lane-mi	15	30	100	15	30	100
Road coil, k$/lane-mi	275	275	275	171	200	250
Power conditioning, k$/lane-mi	250	250	250	138	200	200
Maintenance, k$/lane-mi-yr	15	15	15	15	15	15
Electricity, $/kWh	0.03	0.045	0.07	0.03	0.045	0.07
Gasoline, $/gal	1.0	1.0	1.0	1.0	1.0	1.0
Oil, $/bbl	21	21	21	21	21	21
Road coil lifetime, yr	25	20	15	15	15	15
Final fraction of vehicles inductively coupled	1.0	1.0	0.3	0.3	0.2	0.1
Power plant thermal efficiency, %	0.36	0.33	0.25	0.33	0.33	0.25
System efficiency, veh mi/kWh	4	3	2	4	3	2
Baseline, mi/gal, 1985	18.1	18.1	18.1	25.5	25.5	27.5
Refinery petro fraction, 1985	1.0	1.0	1.0	1.0	1.0	1.0
Utilities petro fraction, 1985	0	0	0.35	0.05	0.40	0.80
Baseline, mi/gal, 1995	24.0	24.0	24.0	31.0	31.0	33.0
Refinery petro fraction, 1995	0.96	0.93	0.90	1.0	0.90	0.90
Utilities petro fraction, 1995	0	0	0.30	0.05	0.25	0.60
Baseline, mi/gal, 2005	26.0	26.0	26.0	31.0	31.0	33.0
Refinery petro fraction, 2005	0.95	0.85	0.75	0.85	0.65	0.60
Utilities petro fraction, 2005	0	0	0.25	0.05	0.15	0.50

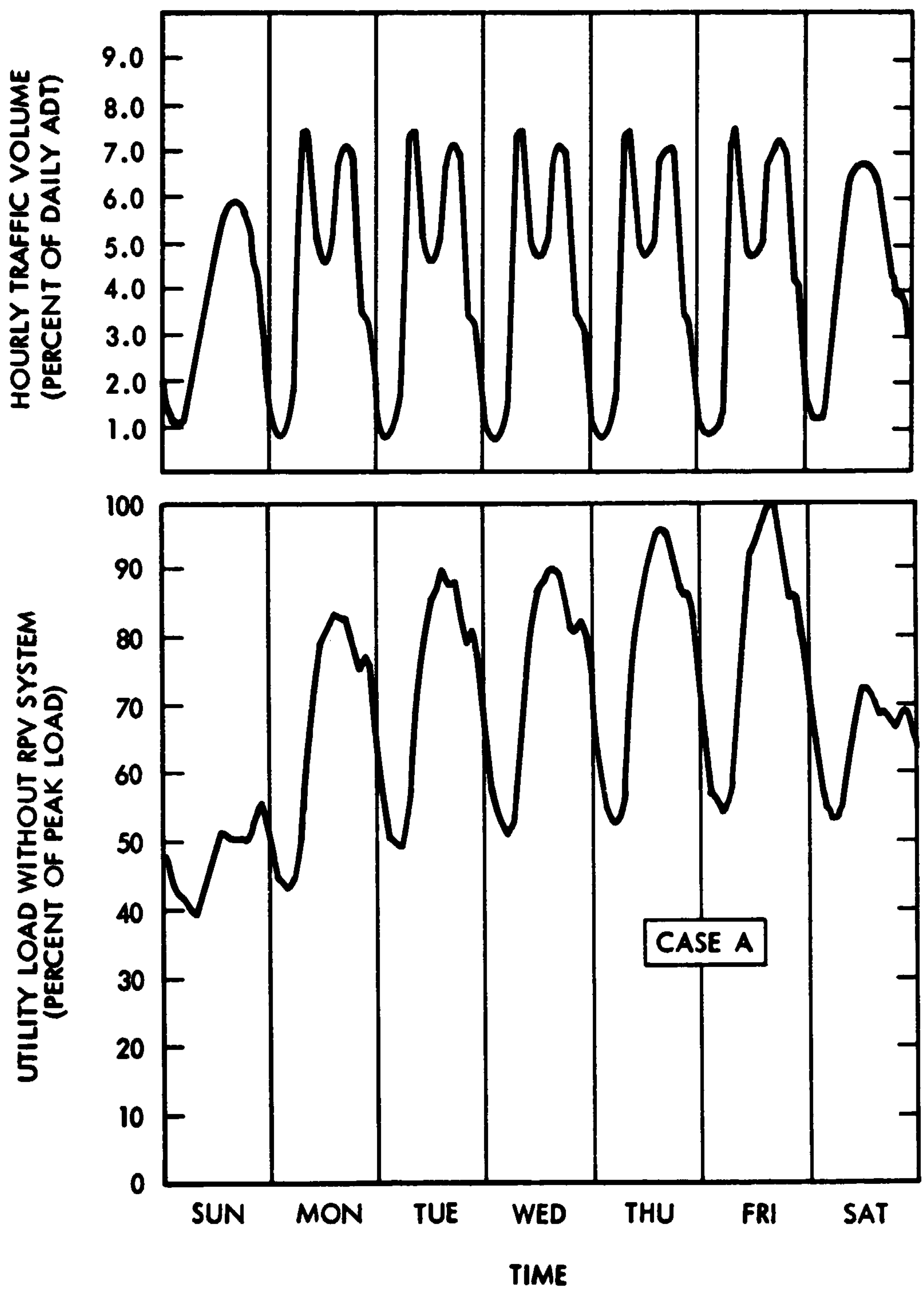


Figure 1-8. Typical Weekly Load Profiles

2. Generation Mix

Load duration curves can be used to show what percent of the time a utility will operate its base, intermediate, and peaking plants, given the generation mix of the utility. Implicit in the analysis is the assumption that a given utility has developed its generation mix based on an economic analysis of operating costs, so that economics dictate that a given type of plant will not operate for a longer period of time than it currrently does. Also implicit in the analysis is the assumption that the availability of supply depends only upon the magnitude of the load and not on the time at which the load occurs.

Given the load duration curves, various generation mixes can be analyzed to study the impact of the RPV system on the utility. The four generation mix cases analyzed are tabulated in Table 1-3.

Case 1 is representative of utilities found in the west north central (northern Midwest) and the east north central (Great Lakes) regions. Case 2 is representative of those found along the eastern seaboard for Virginia through southern New England. Case 3 is representative of utilities in the west south central region (Texas and states adjoining to the north and east) and the Southern California area. Case 4 is the Southern California Edison Company (Los Angeles area).

Table 1-3. Four Generation Mix Cases

	Case 1	Case 2	Case 3	SCE[a]
Base:				
Nuclear and hydro	24%	50%	15%	17%
Intermediate:				
Coal	60%	20%	25%	11%
Peaking:				
Oil and gas	16%	30%	60%	72%

[a]Southern California Edison Co., the largest utility in the Los Angeles area.

The load curves show that the load increment is greater at the peaking end than at the low end of load. Given curves of this shape, and assuming economic rationale, where possible, for utility plant expansion decisions, the effect on petroleum usage by the utility is summarized in the Table 1-4 and shown in Figure 1-9.

Only for the SCE example does all of the electricity for the RPV system come from petroleum. For Cases 1 and 2 the RPV system would be fully petroleum displacing. For Case 3 (Southern California - Texas) every barrel of oil not used at the gas pump because of the RPV system would result in about one-half barrel being used by the electrical utility.

In the future (1990s) the effects of escalating petroleum prices and federal conservation regulations (Fuel Use Act, etc.) would ensure that the RPV system would be petroleum displacing for all but a few utiltities.

Table 1-4. Additional Capacity and Petroleum Usage (Case A)

	Case 1	Case 2	Case 3	SCE
Additional petroleum usage				
a. In gigawatt hours	420	-660	6,510	14,400
b. In percent of RPV system energy usage	3%	-5%	45%	100%
c. In percent of original petroleum usage	16%	-6%	13%	20%
Additional capacity requirements				
a. Peak, in percent of total orig'nal capacity	2%	2%	9%	13%
b. Intermediate, in percent of total original capacity	11%	7%	4%	None
c. Base, in percent of total original capacity	None	4%	None	None

ORIGINAL PAGE IS
OF POOR QUALITY

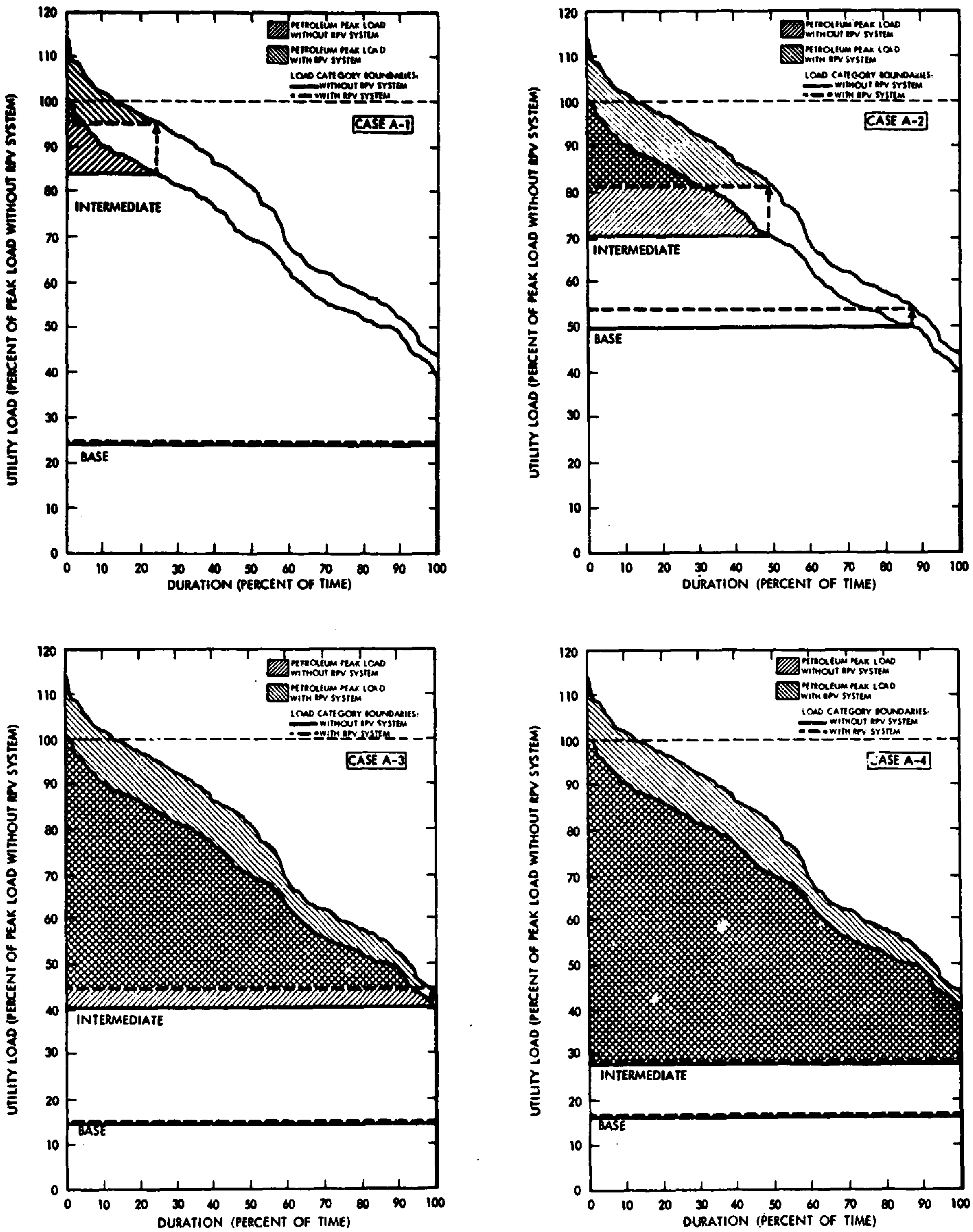


Figure 1-9. Petroleum Use for Cases 1 through 4

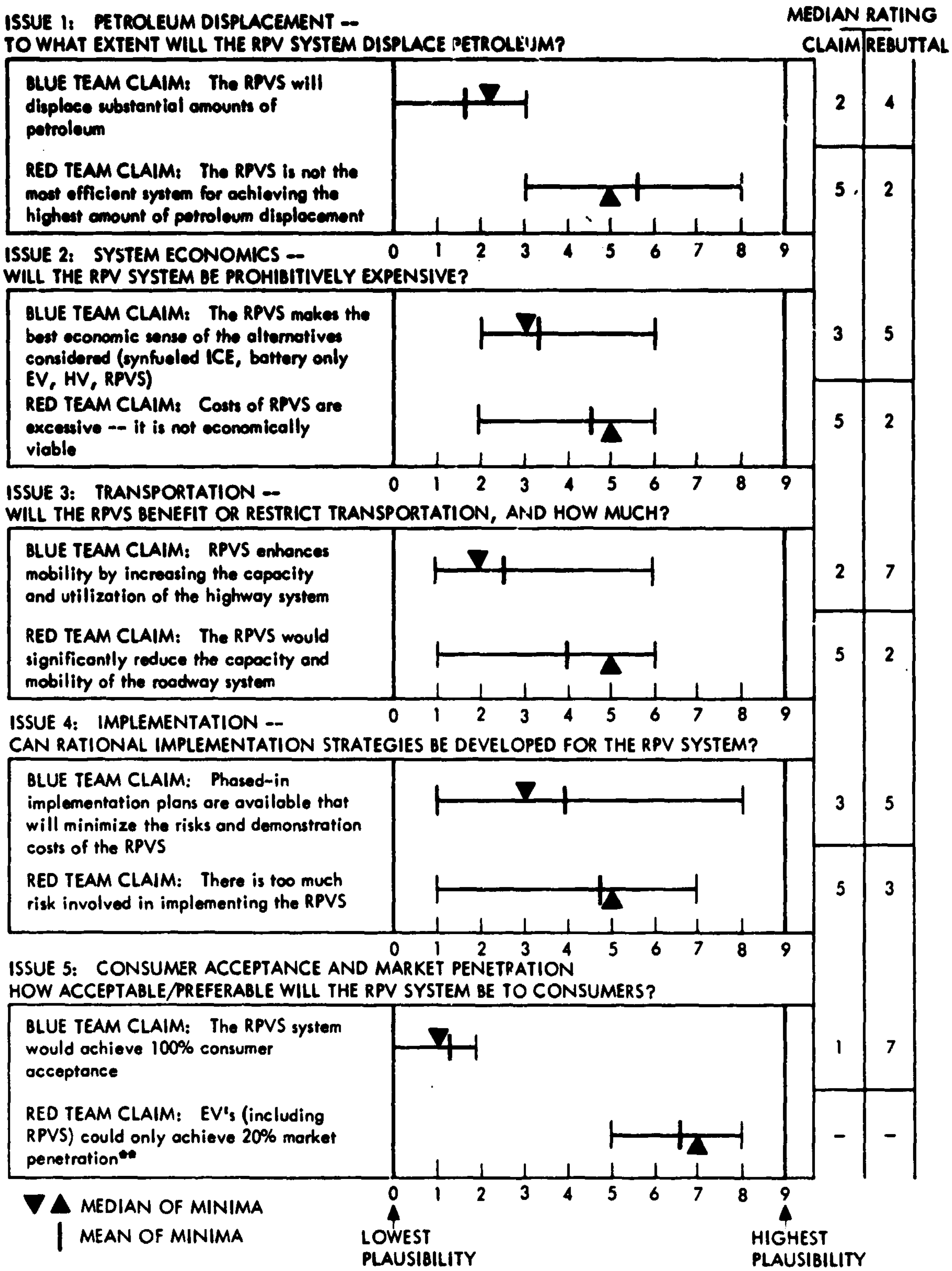
D. PLAUSIBILITY ANALYSIS

A plausibility analysis was conducted to determine the strength and relative trustworthiness (believability) of each argument. A conservative implementation of dialectic analysis would let the arguments presented by each side stand without comment before the principal decision-maker. However, because of the complexity of several issues examined, it was decided that the information presented would be more useable if an independent panel assessed the plausibility of the arguments presented.

In general, an argument is no stronger than its weakest link. This weak point may be the claim, data, warrant, or backing. A group of five participants (Appendix A lists the participants) read each issue and the corresponding arguments of each team. They rated each part of the argument according to its plausibility on a scale from zero (completely implausible) to nine (a logical truth).

The minimum values (the weakest links) for each level one argument were determined and the median (half the group above and half below) and mean (average) were calculated. Since the level one claims captured the overall issue, a comparison of level one claims was made. Figure 1-10 illustrates the results. The Blue Team's case for the RPV system is especially weak in two areas--the Blue Team's claims of significant levels of petroleum displacement and consumer acceptance (Issues No. 1 and No. 5). In contrast, the Red Team's claims were high in believability as illustrated by the polarization of the ranges, medians, and means. In fact, there is no overlap between the two teams on these issues. The considerable overlap on Issues No. 2, No. 3, and No. 4 is primarily due to uncertainties with respect to the arguments. However, there is still separation between the means and medians of the Blue Team and Red Team. The Red Team values are all on the more plausible side of the Blue Team values indicating weakness in the Blue Team arguments. Figure 1-10 presents the medians of the level one claims and rebuttals for each team. The apparent reciprocity of the plausibilities is an indicator of consistency within each issue. That is, if an issue claim was rated high, the rebuttal to the claims was rated low and vice versa. The plausibility medians for the Red Team arguments are all higher than for the Blue Team. In addition, taking the means of the box scores in Figure 1-10, the Red Team's arguments scored an average of two plausibility points higher than the Blue Team's.

The main conclusion that may be drawn from the outcome of the plausibility rating exercise is that there is more support for the claims of the Red Team than for those of the Blue Team. The process revealed certain arguments to be weak; in particular, the contention that the RPV system would increase freeway safety due to automation of the system. The group cited systems such as the San Francisco BART system where automation had not been a factor in improved safety



* ALL VALUES ARE FOR FIRST LEVEL CLAIMS

** REBUTTAL TO BLUE TEAM CLAIM

Figure 1-10. Plausibility Analysis Results

(/11/p.47 ff). It was concluded that automation was not effective in improving safety, and in some cases, had an adverse effect. The second claim that the raters found implausible was the complete market penetration of the 110 million vehicle fleet by RPV system. By insisting on complete market penetration, the Blue Team decreased the believability of their argument.

With respect to the process the participants felt the plausibility analysis was a valuable tool that aided in the decision analysis process.

PART II: PRINCIPAL FINDINGS

SECTION I

FUNDAMENTAL MERITS AND PROBLEMS

This section is a summary of the principal findings related to the fundamental merits and problems (what we know), as opposed to the issues (what we do not know), which are described in Section II. The last section of Part II, Section III, presents the results of the extended analysis of the most important issues, in an attempt to bring these issues into the realm of what we know. The more detailed analysis is Section I is given in Part III, Sections I and II.

A. ELECTRICAL DESIGN AND EFFICIENCY

The electrical behavior of the inductive coupling will be essentially as described in the LBL feasibility study /1/. It should be conceptually feasible to build and operate an RPV system as suggested by LBL, even though many engineering design problems are still to be solved.

In summary, this conclusion was reached through the examination of the following aspects.

1. Power Losses

The design point calculations on the properties of the source and the pickup presented in /1/ (p. 55, Table 4.1 and p. 59, Table 4.2) are correct. The only problem might be in the core losses, which were predicted to be about 580 W per car in the LBL feasibility study. A more realistic number seems to be at least 1000 W per car, or about 10% of the average vehicle power. The core losses in the present design are constant regardless of vehicle power, yielding a significant drop in efficiency at lower power loads. A detailed design trade-off study of the onboard power conditioning system could possibly solve this critical problem.

2. Source/Pickup Air Gap

The effect of increasing the air gap is to lower the vehicle load resistance seen by the source so that more current must flow in the roadway to produce the required vehicle power. The practical limit comes when the roadway conductors and power supply have excessive power losses from the high current.

For the design gap of 2.5 cm the source losses of 12 kW/km (/1/, p. 58) are about equal to the power required to operate one car at half power. Figure 4.5a (/1/, p. 64) shows that doubling the gap to 5 cm would reduce the resistance of the vehicle load, as seen by the source, by a factor of about two. Raising the source current a factor of two to compensate would raise the source losses to the equivalent of one full-powered vehicle per km. This is still small. Gaps up to at least 10 cm would probably be possible without prohibitive losses.

3. Reinforcing Bars in the Roadway

The maximum field under the source is about half as great as the field 30 cm above the source (/1/, p. 56). If a steel sheet were placed 30 cm under the source it would, therefore, be heated about 25 percent as much as the steel sheet placed 30 cm above the source in Figure 3.6 (/1/, p. 32). The corresponding loss is 77 W/m^2 (25 percent of the 0.2 $W/in.^2$ calculated on p. 31). If this loss extends over the 60 cm width of the source the loss would be 46 W/m, or four times the source conductor loss. It is estimated that reinforcing bars would produce only a few percent, at most, of this loss, but this is an area of possible concern.

4. Steel Objects on the Roadway

The attraction force on the vehicle pickup is 716 N (161 lbf) from Table 4.2 (/1/, p. 59). This force is distributed over an area of 0.9 m^2. Steel objects would thus be attracted with a force of, very roughly, 800 N/m^2. This is equal to the weight per m^2 of a 10 mm thickness of steel sheet. Thus, we are talking about steel objects being attracted by an amount comparable to their own weight. The behavior of steel objects dropped on the roadway would not be much different than now. The small clearance of the coupling would be the main problem.

5. Noise

Inside the vehicle, the noise from the coupling should be the same as for a 20 kVA transformer (44 dB), and hence equivalent to average office noise (40 to 50 dB) and less than inside present cars. In the LBL experiments, higher noise levels were observed, but this was attributed to factors specific to the experimental setup.

6. Magnetic Field Hazards

At worst, without shielding, the passengers would be exposed to a 120-Hz magnetic field of about 1 mT (10 G) rms amplitude (Figure 3.7a, 9 in. elevation, /1/, p. 33). Lightweight shielding could reduce this by orders of magnitude (Figure 3.6, /1/, p. 32). Household appliances produce similar fields, 1.0 to 2.5 mT for a hair dryer for example (J. E. Bridges, IEEE Trans. PAS-97, p. 19). On the other hand, someone standing on the source would receive 7 mT immediately at ground level.

Heart pacemakers might be affected. There is no current standard for magnetic field exposure of pacemakers.

7. System Efficiency

The electrical design of the RPV system indicates a potential for a higher average efficiency (RPV system source to motor) of 80 to 90%, than the present EV efficiency (wallplug to motor) of about 60 to 70%.

A realization of this potential depends, on the other hand, very much on the following parameters:

(1) The load per RPV (kW/RPV), P_c.

(2) The RPV/non-RPV ratio on the system, F_c.

(3) The vehicle density (veh/lane-mi).

Figure 2-1 shows the system efficiency versus vehicle density for various ratios between coupled and uncoupled vehicles on the system, given a full design load of 20 kW/RPV.

Figure 2-2 shows the same relationship, except for a load of only 5 kW/RPV.

While a redesign of the power conditioning system of the RPV potentially could prevent the deterioration of the efficiency at lower power loads (i.e., the difference between Figures 2-1 and 2-2), it would still leave the two other parameters as critical.

B. VEHICLE COMPARISON

Another principal merit of the RPV system is its potential as a range extender for electric vehicles (EVs), which presumably could boost the marketability of EVs. In order for this to happen, the RPV must also appear to be competitive with its alternatives in an economic sense. The focus of such comparison (with electric, hybrid, and ICE vehicles) has been to evaluate the following two parameters:

(1) Manufacturing cost ratio, MCR

(2) Life cycle break-even gasoline price, BEGP

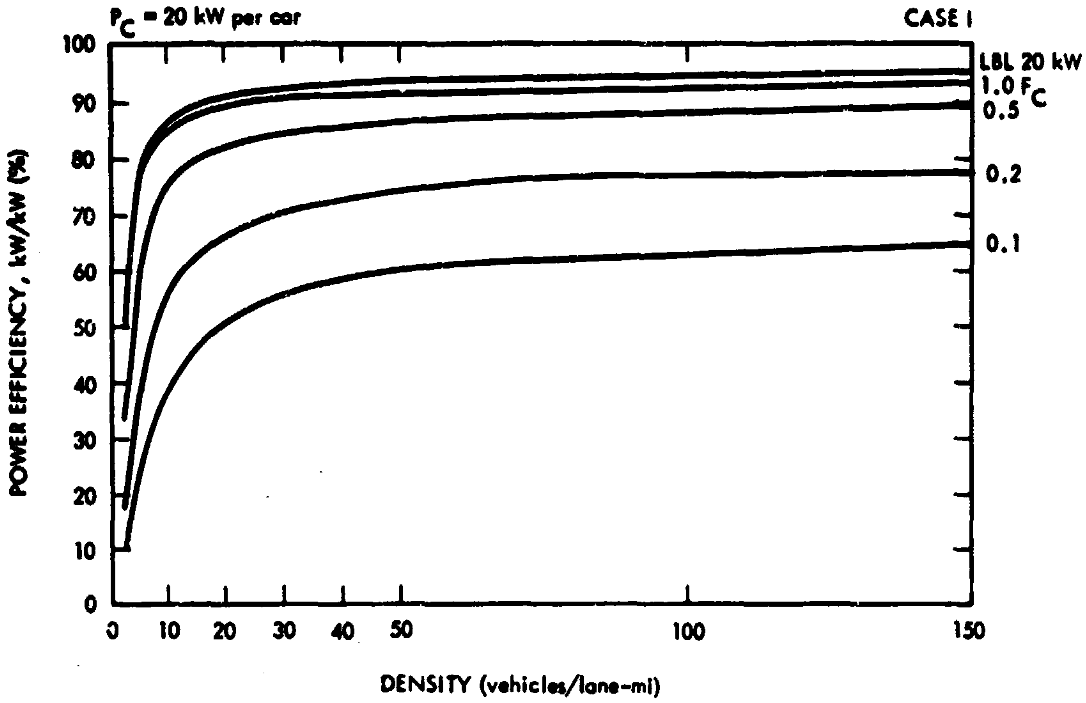


Figure 2-1. System Efficiency at 20 kW Load per RPV

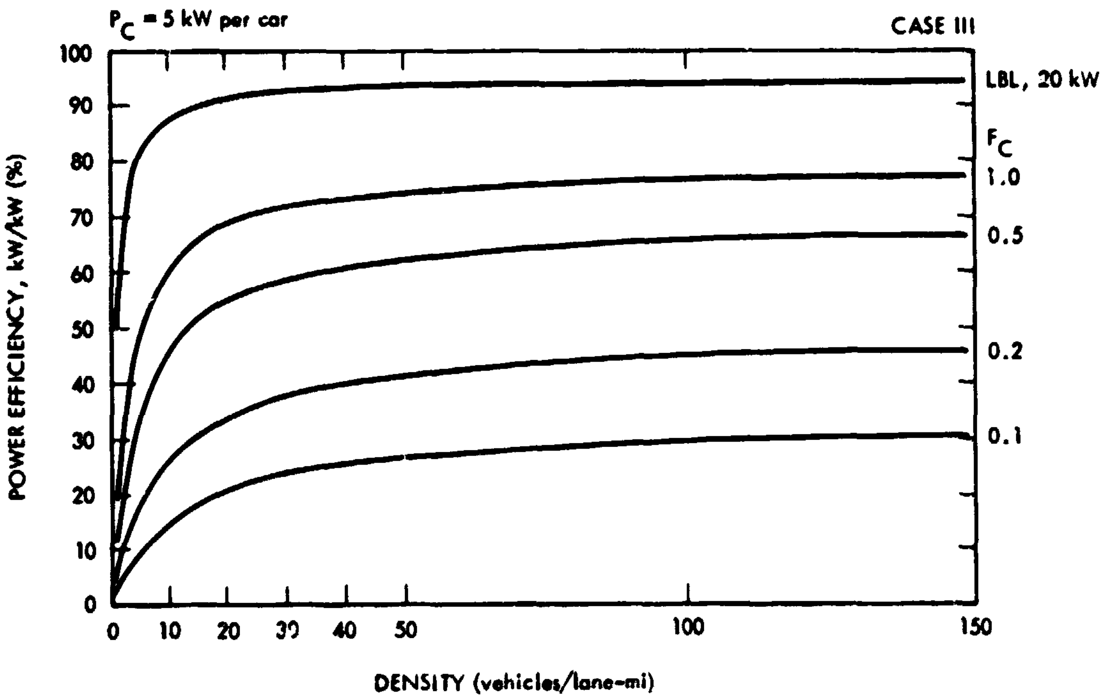


Figure 2-2. System Efficiency at 5 kW Load per RPV

The results of this comparison shows that the RPV is cost competitive, if the cost of the RPV system roadway installation and maintenance is not allocated to the vehicle. This would occur at gasoline prices of $1.50 to $2.50/gal in 1978 dollars.

1. Assumptions

The following assumptions were made with respect to the mission, performance, and battery characteristics:

a. Mission Specifications. The missions were defined as typical commuter missions, with a fixed mileage of urban driving (off the RPV system), and a variable mileage of highway driving (on the RPV system). Three missons were specified within these constraints, with three different levels of annual vehicle kilometers traveled (AVKT), as follows:

Annual vehicle travel, km	10,000	20,000	30,000
Urban/highway ratio	70:30	63:37	36:64

b. Performance Requirements. A generally overriding acceleration requirement of 0-100 km/h in 14 seconds, was determined necessary for passenger cars, in a recent JPL study of hybrid vehicles /6/. This requirement, which was derived from an analysis of freeway entrance requirements in California, has been relaxed in the design of RPVs. Since freeway on-ramps theoretically could be coupled just as the rest of the RPV system, the on-board power capability could be reduced substantially. The maximum power capability required of the RPVs is related to the need for freeway lane changing and passing maneuvers: 60 to 90 km/h in 9 seconds.

The lower power requirement for the RPVs (which is just slightly above the peak power requirement of the EPA Urban cycle) greatly affects the economic picture and makes such RPVs much more attractive compared to RPV designs which also meet the freeway entrance requirement. The difficulty in meeting this requirement is primarily due to the lack of power in a battery pack designed to have only enough energy for a 23 km range (uncoupled).

c. Battery Characteristics. The third area, where key assumptions were made, is related to the batteries. The following cycle lives were assumed, all of which are at the upper limit of what can be expected before year 2000:

Lead-acid battery:	**1500 cycles**
Nickel-iron battery:	**2000 cycles**
Nickel-zinc battery:	**500 cycles**

Assumptions on the expected battery specific power capabilities were based on projections made for the early 1980s by Argonne National Laboratory (Figure 2-3).

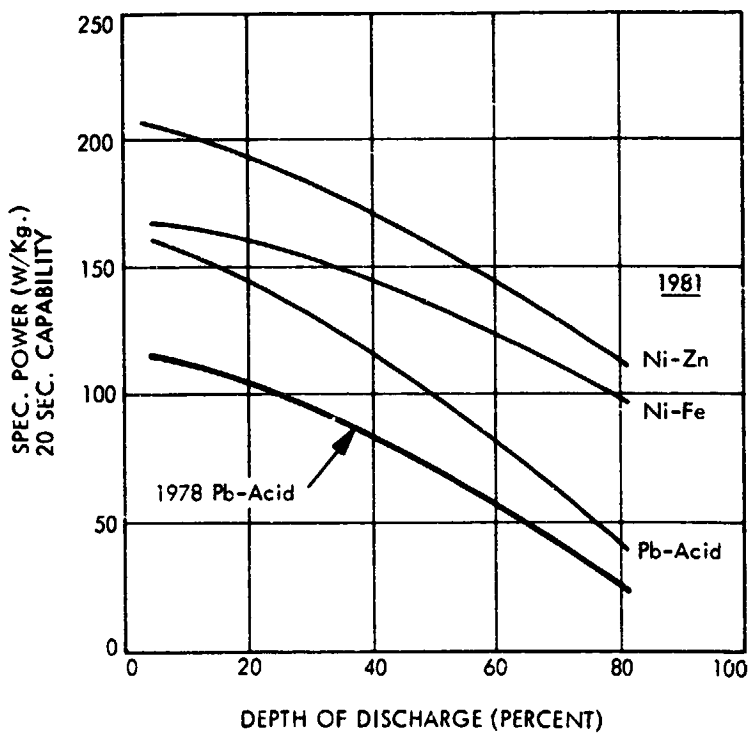


Figure 2-3. Expected Battery Specific Power Capabilities

2. Manufacturing Cost Ratio

The results of the MCR analysis are tabulated in Table 2-1, together with a more detailed specification of the developed vehicle designs.

In terms of manufacturing cost, the RPVs are expensive relative to a conventional vehicle. The mark-up for conventional vehicles varies from 1.7 to 2.4 times the manufacturing cost, but there is no assurance that the pricing policy would remain the same for this type of vehicle.

Table 2-1. Vehicle Design and Manufacturing Cost

	UNLIMITED RANGE			LIMITED RANGE							
	CONV. ICE VEHICLE	CONVENTIONAL (ICE-RPV)		ELECTRIC - 14 MILE (E-RPV)			FLYWHEEL - ELECTRIC - 14 MILE (F-RPV)			Pb-ACID ELECTRIC	
		A	B	Pb-Acid	Ni-Fe	Ni-Zn	Pb-Acid	Ni-Fe	Ni-Zn	24 MI.	48 MI.
Chassis (kg)	$1419 (805)	$1577 (895)	$1580 (897)	$1650 (936)	$1637 (929)	$1625 (922)	$1560 (885)	$1555 (882)	$1538 (878)	$1696 (962)	$1828 (1037)
Engine (kW) or Flywheel (kWh)	525 (50)	573 (61)	573 (61)				200 (1)	200 (1)	200 (1)		
Trans (kW)	70 (50)	75 (61)	85 (61)	60 (4)	60 (44)	56 (42)	140 (55)	137 (54)	134 (53)	86 (64)	107 (80)
Motor (kW)		78 (10)	150 (26)	180 (22)	180 (22)	168 (21)	130 (15)	128 (14)	126 (14)	258 (32)	322 (40)
Controller (kW)		140 (10)	460 (52)	403 (44)	403 (44)	390 (42)	220 (15)	210 (14)	204 (14)	518 (64)	601 (80)
Battery (kWh)				596 (14.9)	1510 (15.1)	966 (16.1)	180 (4.5)	450 (4.5)	270 (4.5)	920 (23)	1440 (36)
Cherger Acc				20	20	20	20	20	20	20	20
Coupling, etc. (kg)		310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)		
Vehicle Ass (Curb Weight kg)	125 (995)	160 (1218)	165 (1226)	201 (1521)	196 (1484)	191 (1447)	170 (1320)	165 (1303)	160 (1282)	222 (1678)	278 (2100)
Manufacturing Cost	$2139	$2923	$3323	$3420	$4316	$3726	$2930	$3175	$2972	$3720	$4596
MCR	1.0	1.4	1.6	1.6	2.0	1.7	1.4	1.5	1.4	1.7	2.1

3. Life Cycle Break-Even Gasoline Price

The life cycle cost of each vehicle design was compared to an ICE vehicle, designed specifically for the same mission. The method of comparison chosen uses the break-even gasoline price (BEGP) as the life cycle cost comparator. The BEGP is the necessary price of gasoline to cause the life cycle cost of the conventional vehicle to equal that of the proposed vehicle.

The resulting break-even gasoline prices, shown in Figure 2-4, illustrate the advantage of the RPV over the pure electric vehicle for longer AVKT. Also quite evident is the advantage of the flywheel-electric RPV (F-RPV) over the electric RPV (E-RPV) used in conjunction with any of the advanced batteries. As expected, the RPVs improve economically with more travel on the inductively coupled roadways with any configuration. It appears that an ICE vehicle equipped with an inductive coupling (ICE-RPV) would be very costly.

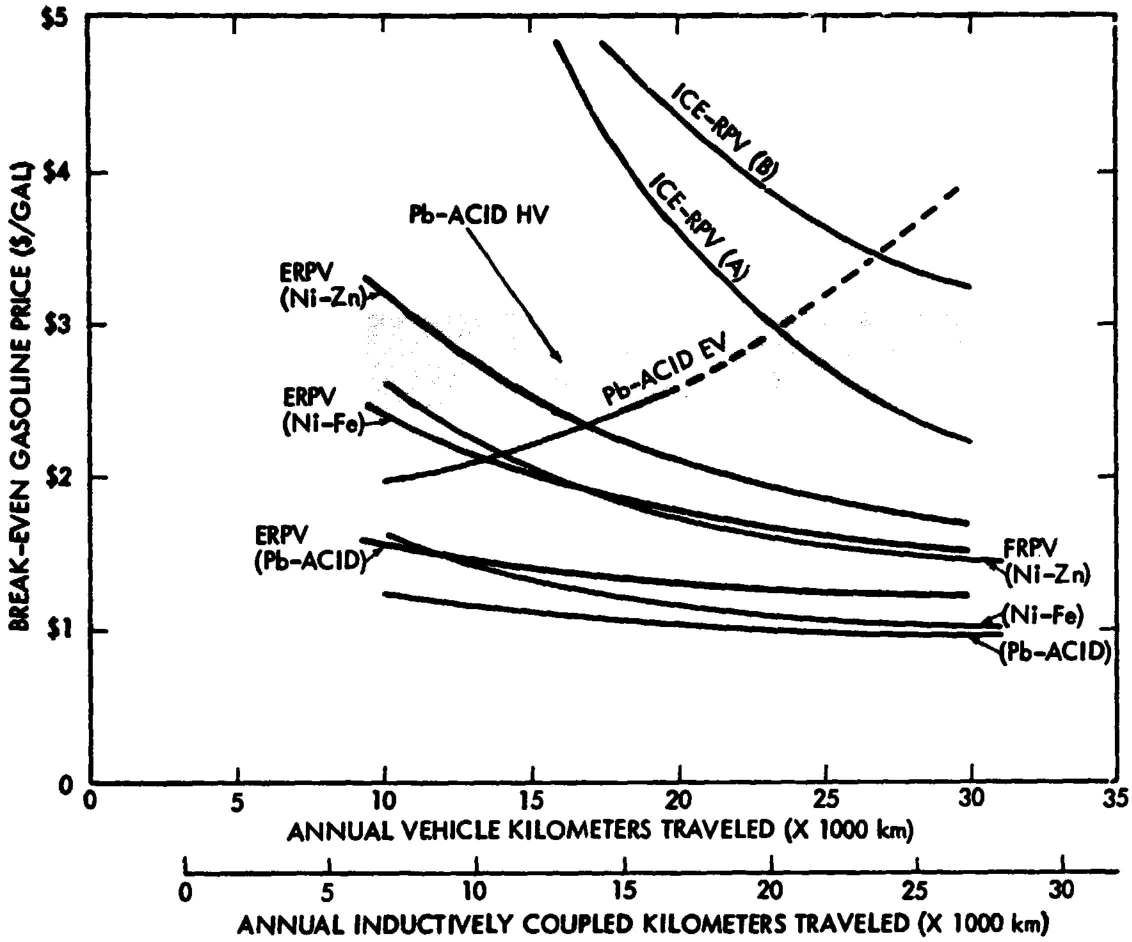


Figure 2-4. Break-Even Gasoline Prices vs AVKT

C. SYSTEM IMPLEMENTATION

When viewing the RPV system as a whole, the fundamental merits and problems become less specific and more uncertain than when looking at the subelements alone (as done in the two previous sections). Unlike the alternatives considered in this study, this system view is at the same time more pertinent, primarily because any potential increase in petroleum displacement requires front end energy and capital expenditures (risks) beyond those necessary to induce consumer interest for EHVs. The first EVs on the road will displace petroleum, while the first RPVs might not.

Apart from this overriding problem of consumer acceptance and the choice of proper implementation strategies, other inherent constraints of the RPV system implementation have been identified, and are summarized in the following subsections.

1. Roadway Installation

It has been proposed that the cost of the installation of the RPV system can be substantially reduced by installing the system simultaneously with regular rehabilitation of the existing highway system. However, such a situation would be very unlikely. The RPV system requires at least a skeletal network of connected roadways in a given area, to be initially acceptable; whereas normal rehabilitation only occurs in short sections at a time, as needed. Therefore, the entire cost (or at least a major portion thereof) of the RPV system roadway installation must be borne by the system.

This would bring the total roadway installation cost up from the original estimate of 350 k$/lane-mi (/1/, p. 102) to at least 600 k$/lane-mi.

The RPV system source seems to require a rigid roadbed in order to stay in place. This would restrict the installation to roadways made of Portland cement concrete (PCC, like most freeways), as opposed to asphaltic concrete (AC, like most surface streets), because of the semifluid properties of AC.

Most bridge sections would probably be unpowered, since they typically consist of only a 2-in layer of AC on a steel bed.

The installation of the RPV system source in an existing PCC surface appears to have no significant effect on roadbed structural integrity.

2. Roadway Operation and Maintenance

It is certain that obstacles on the roadway (detached mufflers and other debris) will be occasionally encountered by the RPVs, and other vehicles. The LBL feasibility study /1/ addresses this subject briefly, but dismisses the possible damage to the vehicle (power pickup) as being no problem, although it recognizes the danger from launched obstacles. This should be addressed more thoroughly, both in the areas of vehicle resistance to damage and roadway resistance to damage from a struck obstacle.

The subject of surface unevenness was seen by the LBL feasibility study to be a significant problem, and was investigated in some depth. However, its conclusion, that a 2.5 cm air gap between the source and pickup is sufficient to avoid damage due to surface unevenness, is not conclusively supported by other conversations with the California Department of Transportation (Caltrans). Caltrans officials in Los Angeles state that their preferred limits to high points on pavement surface are 1 cm to 1.3 cm, but that this is only a guide. No systematic or comprehensive effort is undertaken by Caltrans to assure that this is the worst unevenness encountered on the highways. In fact, measurements such as those made by the profilograph in the LBL feasibility study, are not made in connection with rehabilitation projects. Therefore, surface projections in excess of 2.5 cm are likely to be encountered occasionally.

Rehabilitation of the highway surface at some time in the future may consist of an overlay of 5 cm or more. The emplacement of an RPV system source, which prohibits such future rehabilitation, would be undesirable.

Occasionally freeway lanes are moved laterally. Where four lanes plus shoulders may have existed previously, one more lane might be added within the same area, by narrowing the lanes and moving them laterally. This would clearly be problematic, if some or all of the original lanes were RPV system lanes.

3. Nonfreeway Applications

The emplacement of an RPV system in nonfreeway roadways entails many of the same problems of freeway emplacements, only intensified. Roadway surface roughness tolerances are much wider, making air gap clearance requirements larger. The vertical and horizontal alignment of vehicle to source is made more difficult. Obstacles and debris in the roadway are far more often encountered.

In nonfreeway roadways, there are frequently utility easements below the surface of the roadway. To access these utilities would be more difficult with an RPV system installation in the roadway.

Crossing intersections pose specific problems to an RPV system. These include the geometrical problems of crossing crowned roads and drainage dips.

4. Power Generation Capacity

In the LBL feasibility study /1/ it is concluded, in Section 5, that the RPV system would not place unreasonable or unreachable demands upon the electrical generation and distribution system. The review of the LBL analysis indicates no fundamental disagreement with this conclusion, although there is some disagreement with the analysis behind it.

Estimates for the Southern California area, made by Southern California Edison (the major utility in this area), indicate an 8% annual capacity growth rate over the next 20 years, including a growth rate of 10% per year in peak capacity. A fully implemented RPV sysem for this area, and a 73% RPV market penetration, as assumed in the LBL feasibility study /1/, would require a 4% increase in total generating capacity by year 2000. If this capacity is assumed to be strictly peak capacity, it would mean a 30% increase in peaking plants, or a forward shift of about 3 years in the peak capacity addition schedule. Given that this represents an upper bound situation, no insurmountable barriers seem to exist concerning power generation capacity requirements.

The second point which should be made is that the allocation of the capital cost for the utility capacity addition to the RPV system is incorrect. Capital requirements for generating capacity are the concern of the utility, not that of the users. Rate schedules developed by the utility and approved by the State Public Utilities Commission are designed to adequately reflect the cost of capital required for capacity addition. Furthermore, the assumed cost of $360/kW installed is too low for a capital intensive baseload plant, and too high for a peaking plant. For a peaking plant, $200 to $250 per installed kilowatt capacity is a more representative number.

SECTION II

ISSUES AND ARGUMENTS

As the fulcrum of a dialectical inquiry into the question of R&D funding for RPV systems, a structured debate between supporting and opposing teams was held July 16-18, 1979. This section provides an issue-by-issue analysis of the arguments used by both teams. The analysis follows the principles of Stephen Toulmin's method of argumentation analysis. For further detail on the use of dialectical inquiry and structured debates, see Part III, Section III.

Key issues argued and analyzed were petroleum displacement, economics, transportation, implementation, and market penetration. Both teams had the opportunities to respond to an earlier draft of this argumentation analysis, and their responses are incorporated herein.

A. OVERVIEW

A dialectical inquiry analyzes an issue from two or more points of view. Dialectical inquiry is designed to deal with complex problems which are characterized by high levels of interdependency, many different values and beliefs, and no single definitive analytical formulation and solution method. The question of funding R&D for the RPV system, also referred to as the inductive coupling electrified roadway system or the dual mode electric transportation system, meets these criteria for dialectical inquiry. Two contrary points of view have been identified.

<u>The one position</u>, which favors support of RPV system research, is summarized as follows:

(1) The RPV system will displace a substantial amount of petroleum because:

   (a) The RPV will be much more efficient than synfueled ICE vehicles, lighter and more efficient than battery-only EVs, and more efficient and more acceptable to the consumer than hybrid (synfuel ICE/electric) vehicles.

   (b) The system will serve highway (electric) transit and trucks that currently use about 40% as much petroleum as cars do. The alternative technologies will not serve these modes well.

(c) The system need not use petroleum for power generation. The small increase in utility load during peak hours can be offset by adding non-petroleum base load capacity or by using the RPV system distribution system as interties between cities and time zones.

(2) The RPV system is economical. Its capital cost is comparable to or lower than the other alternatives, while its operating costs are lower.

(3) The RPV system enhances mobility by increasing highway capacity through the addition of automation to the system. This would also decrease accident rates and reduce the number of lane-miles of RPV system required.

(4) There are several implementation strategies available for bringing the technology into widespread use. These include the early implementation of self-contained transit systems (malls, people movers) as precursors to highway systems.

These claims appear to be warranted by a rather deeply held belief that the nation's need to displace petroleum and the citizens' recognition of this and their willingness to accept the RPV system technology will dominate the policy arena during the next few decades.

The second position differs markedly in these beliefs. Its claims are warranted by the basic belief that market economics will be the dominant factor in the policy arena during the next few decades. This leads them to conclude that as an energy saving transportation alternative RPV system does not possess economic viability.

One fundamental difference between the world views of the two positions involves their concept of the role of government and large institutions. The RPV system team looks to government and other large institutions to set social goals and to take a strong, active role in achieving them. The large scale systems characteristics of the RPV system technology partly necessitate this belief. The second position favors battery operated electric automobiles, hybrids and synthetic fuels. Underlying its advocation of these technologies is a strong reliance on free market economics with minimal government direct intervention.

The second position is less focused than the first. Its role is to point out the negative aspects of RPV system and to demonstrate the superiority of either battery operated, hybrid gas/electric or synthetic fuel alternatives. In summary, its position is as follows:

(1) The RPV system will not displace significant amounts of petroleum because cost and technology barriers are too substantial to overcome. In particular, RPV system creates additional peak load demand for electric generation capacity and no non-petroleum alternative source has been convincingly argued.

(2) The RPV system is uneconomical on the basis of a present-value life cycle cost levelized revenue analysis.

(3) The RPV system reduces mobility due to weather problems and the difficulties of implementing the fully electrified and automated system.

(4) The RPV system will not be successfully implemented because it fails to achieve economies of scale for private producers of vehicles. Accordingly, the automobile industry will not be supportive.

These four items form the principal issues of contention between the two points of view. The method of inquiry was to bring together representatives of these viewpoints to present the facts, assumption and modes of reasoning which led them to their differing conclusions. This was done by means of a structured debate which was held on July 16-18, 1979 at JPL.

A third party witnessed the debate and interrogated the debaters. The third party then modeled the key arguments of each position by applying argumentation analysis to the presentation of, and responses to each position. Argumentation analysis identifies the statements taken as given by a position (i.e., facts or data), the warrants (the assumptions used to interpret the givens as support for a conclusion) and the rebuttals (the conditions under which the conclusion does not follow). Further, argumentation analysis lays out the "chain of the argument" by showing how facts used in one argument may be analyzed as the product of a previous argument, or a rebuttal identified in one argument may be countered by an argument leading to a contrary conclusion. The result is a specification of the hierarchy of the argument. In this report arguments are modeled up to three levels of detail.

A full-scale application of argumentation analysis involves a process by which the plausibility or relative strength of each argument is assessed. Such a plausibility assessment was done on an experimental basis as part of the extended analysis documented in Part II, Section III.

The dialectical inquiry involving structured debate and argumentation analysis on the issue of funding R&D for the RPV system was conducted for three primary reasons:

(1) To determine the "state of the art" and current knowledge about RPV system and its alternatives as it pertains to the policy issue of R&D funding.

The argumentation analysis contained in the report is a summary of the state of the art. The general impression is that there is a lack of substantive knowledge about RPV system, perhaps because of the relatively lower levels of previous R&D funding in the field.

(2) To determine the relative significance of sub-issues and to prioritize them.

It was found that the questions; "to what extent will RPV system displace petroleum?" and "will RPV system be prohibitively expensive?" ranked equally as the most important, pro-RPV system parties favoring the former and anti-RPV system parties favoring the latter. The third most important issue is "will RPV system enhance or restrict transportation and by how much?" The fourth issue is "what is involved in the implementation of RPV system?" The argumentation analysis reveals both parties' resolutions to these issues and their supporting reasons.

(3) To provide directions for further analysis within the present study effort and for further research in the policy area.

One characteristic of dialectical inquiry is that it helps reveal the factual basis, the insights and the problem definitions of each party. This aids in the determination of the degree of support for various claims and serves to identify research projects which may resolve critical uncertainties. The following projects were identified as the focus for further analysis within this study effort:

Petroleum Displacement

(1) Will an RPV system load profile require base, intermediate or peak load electric generation capacity? Identify boundaries.

(2) Identify scenarios for future supply of fuel sources.

(3) Reexamine system efficiency parametrically under more optimistic assumptions about losses.

Economic Viability

(4) Refine analysis of levelized required revenue parametrically using 5 to 10 parameters.

Implementation

(5) Identify strategies for implementation and their major benefits and risks with respect to transportation, petroleum displacement and economic viability.

The results of these five study projects (documented in Part III, Section III) will provide valuable data to improve the quality of the arguments and understanding concerning the issue of R&D funding for RPV system.

It should be pointed out that while the participants in this study generally favored the dialectical inquiry methodology used in this report and the conclusion reached, they also voiced a few caveats and made some suggestions for improvement. Their feedback is contained in Appendix B.

B. SELECTING THE ISSUES

The theme of the structured debate was whether or not the U.S. Department of Energy ought to allocate more of its R&D budget to studying the RPV system. The RPV system involves battery powered automobiles augmented by inductive coupling devices for which power is supplied by electrified roadways. One team, called the Blue Team, (or RPV system team), took the affirmative position, while the other team, called the Red Team (or EHV team), took the negative.

The Blue Team argued for continued R&D funds on the basis of four major claims:

(1) The RPV system is a promising technology for meeting the U.S. transportation and energy conservation needs.

(2) Because of its special public nature (involving electrified roadways and public utilities) the RPV system is less likely to draw private R&D funds and therefore is more deserving of public R&D support.

(3) Given the magnitude of the energy problem facing the U.S., the Department of Energy should explore as many viable options as possible. Therefore DOE should supplement its R&D efforts on electric and hybrid cars with R&D on the RPV system.

(4) The current level of knowledge about RPV system is low. Relatively small increments of R&D funding can result in a relatively high return in terms of new knowledge.

The debate was held to test the first claim. The Blue Team produced a case in support of the promise of the inductive coupling technology. The Red Team produced a case pointing out deficiencies in the RPV system and advantages for alternatives. Both teams acccepted the assumptions that in the U.S., it is generally desirable to preserve individual mobility via private automobiles and that the basic physical principles of the inductive coupling technology are generally known.

The issues for the structured debate were identified using the following process. In the first round each team submitted issues. For the second round both teams agreed to issue statements. Finally the issues were prioritized for debate in order of importance. The results of these three rounds are summarized in Table 2-2.

Table 2-2. Summary of Issue Selection (July 16, 1979)

First Listing of Issues - for Each Team

Blue/RPV Team	Red/EHV Team
(1) Technical	(1) Petroleum Displacement
(2) Social and Institutional	(2) System Energy Efficiency
(3) Implementation	(3) Transportation Availability
(4) Preservation of Mobility	(4) Costs of Petroleum Conservation
(5) Safety	(5) Utility Capacity Addition
(6) Transportation	(6) EHV Mobility Cost Comparison
(7) Energy	
(8) Resource Requirements	
(9) Environment	

Second Listing - For Both Teams, Not Prioritized

(A) Petroleum Displacement - with Utility Implications

(B) System Energy Efficiency (later combined with A)

(C) Economics

(D) Transportation (Availability, Safety, Intermodal, Automation)

(E) Implementation (Social, Institutional, Infrastructure)

(F) Comparison with Alternatives (EV, EHV, ICE, Synfuels)

Table 2-2. (contd)

<u>Third Listing - Prioritized Listing of Issues/Agenda for the Debate</u>

I.	Petroleum Displacement	o System Energy Efficiency o Source Fuel o Peak Demand
II.	Economics	o Cost Elements o Cost Allocation o Comparison
III.	Transportation	o Automation o Modes o Availability o Safety o Capacity
IV.	Implementation Process	o Institutional o Infrastructure o Social and Environmental o Scenarios and Time Frame
V.	Comparison with Alternatives	o Electric, Hybrid, and ICE Vehicles o Synfuels

It should be noted that the order of issue No. 1 and No. 2 was determined by the flip of a coin. While the team in favor of RPV system R&D held that the issue of petroleum displacement was more important for a determination of the RPV system viability than the economics issue, the opposite was argued by the opposing team (in concurrence with the world view of the two teams). It should also be noted that the first four issues were debated directly, while the last issue was brought up only indirectly (because of time constraint, during the debate of the other issues).

C. STRUCTURE OF THE ARGUMENTS

Following the debate, the third party analyzed the outcome of the debate and placed it into a structure patterned after a model developed by Stephen Toulmin (The Uses of Argument, /29/). The results of this analysis are documented at the end of this section in summary (pp. 2-23 to 2-32), as well as in full (pp. 2-33 to 2-57).

First. An issue, such as petroleum displacement, is identified and stated as a question. Then, the major claim or position each party took on that issue is explicitly stated. A claim is a statement or inference the advocate argues is true. A major claim is a conclusion which resolves the issue under debate in favor of the advocate.

Second. The data or facts presented by the advocate as grounds for the claim are identified. Data may be factual statements or claims from other arguments. Data answers the question "what do you have to go on?" Data are the "givens" in an argument. In this report data are prefaced by the phrase "Given that ..."

Third. The warrants or justifications for interpreting the data as support for the claim are stated. Frequently warrants are not made explicit and must be inferred by the third party. Warrants answer the question "what entitles the movement from the data to the claim?" Warrants are inference- making licenses which are assumed to be true. In this report warrants are prefaced by the word "Since ..."

Fourth. The rebuttals are identified. Rebuttals are the contingencies or conditions under which the claim is not true. They may deny the data or the warrants or present counter claims. Rebuttals are of the general form, "the claim is supported unless x,y,z ..." Some rebuttals are pointed out by the opposing party, a few are acknowledged by the advocate, and some are added by the third party on the basis of experience or logical possibilities. One of the main functions of the rebuttal is to help qualify the argument and to assess its plausibility. If strong rebuttals can be presented, the argument may seem relatively weak, whereas if only weak rebuttals can be presented, the argument may seem relatively strong. In this report rebuttals are prefaced by the word "Unless ..." Further substantative rebuttals argued by the participants are distinguished from possible rebuttals provided by the third party.

Fifth. For many arguments it is useful to ask "What is the support for the warrant?" The backing is an answer to this question. Backing identifies the experience base, the theory base, social values, prior policy choices or other beliefs which underly the warrant. When backings are identified in this report they are prefaced by the word "Because ..."

These five steps are summarized by the model of an argument shown in Figure 2-5, and exemplified with the RPV system-team's basic claim on issue No. 1.

Sixth. After the major claim is analyzed into its component parts of data, warrant, rebuttal and backing, critical elements of the supporting argument are identified for further, more detailed analyses. Their subsequent analysis also applies to the Toulmin model. Two modes of sub-argument analysis are used in this report. One is to choose a critical data item in an argument and to treat it as a claim. The other, called a surrebuttal or counterrebuttal, is to refute a rebuttal by making a counterclaim. This counterclaim in turn, is analyzed. The result is to lay out the hierarchical structure of the arguments pertaining to a policy issue. Arguments in this report are carried as deep as three levels. Figure 2-6 illustrates this chain of argument structure in three levels.

Seventh. The final step in argumentation analysis is to assess each argument for its plausibility. Plausibility refers to the strength of the argument and its relative trustworthiness. Plausibility responds to the question "does the argument hold water?" In general an argument is no more plausible than the weakest link, the least plausible element, in its chain. One advantage of plausibility analysis is that it aids in pinpointing areas where additional research may be undertaken to improve the quality of an argument. Such plausibility analysis has been undertaken as part of the extended analysis of this study, and is reported in Section III.D of Part II.

Following Figures 2-5 and 2-6 is the third party documentation of the detailed structure of the arguments, organized according to issue and team. A ten-page summary of the argument structures is provided first (pp. 2-23 to 2-32), to emphasize the critical paths of the arguments, followed by a more detailed outline of the arguments with one claim per page (pp. 2-33 to 2-57).

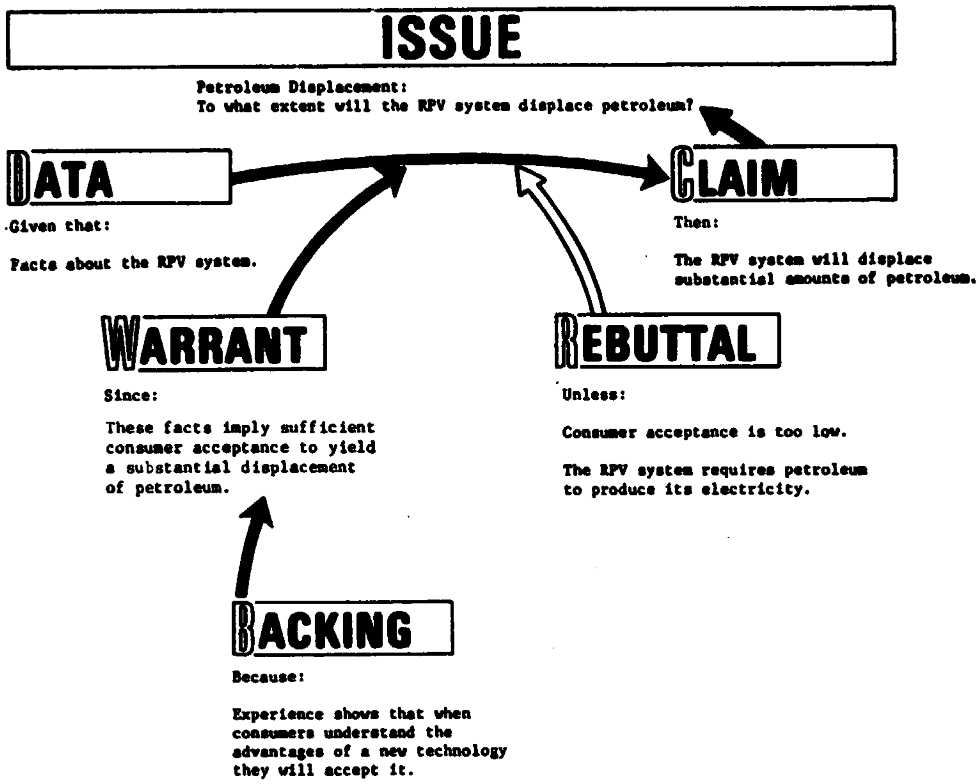


Figure 2-5. Model of an Argument (RPV System Team Issue No. 1 Claim)

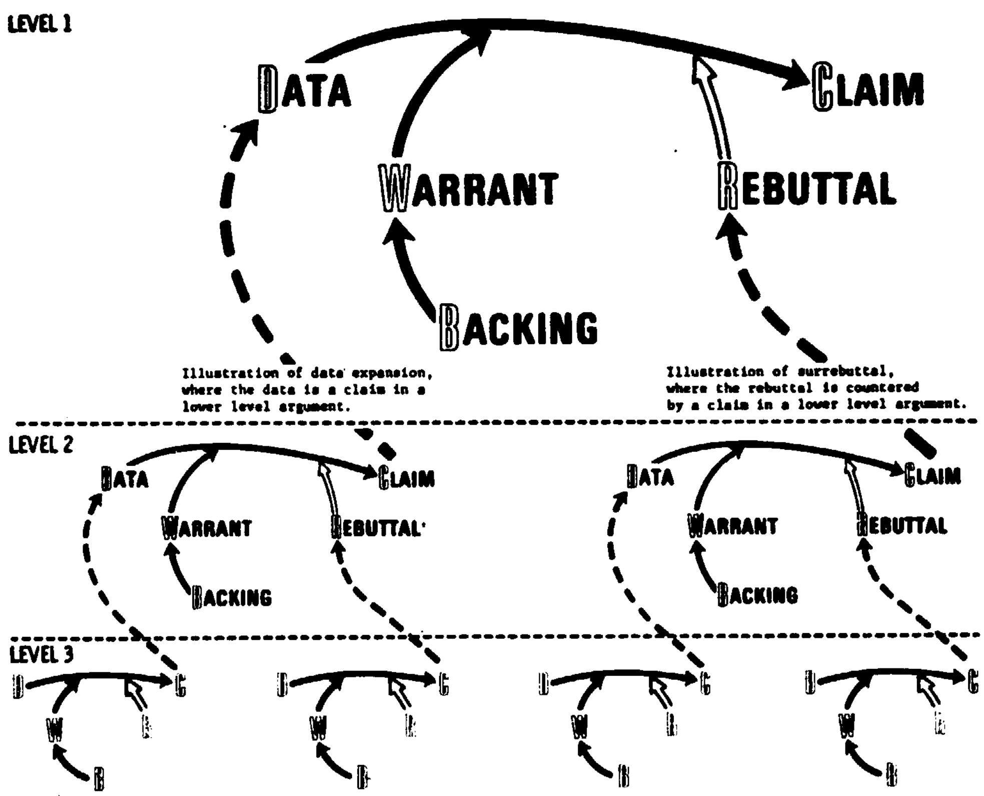


Figure 2-6. Hierarchy of Arguments

ORIGINAL PAGE IS
OF POOR QUALITY

Issue #1 - Petroleum Displacement:
To what extent will the RPVS displace petroleum?

BLUE TEAM Argument

1

THEN: CLAIM
The RPVS will displace substantial amounts of petroleum.

GIVEN THAT: DATA
A large fraction of petroleum is presently used for start-up, and only a few trips are greater than 12 miles (avg. trip is 3 miles).

Batteries will be used for start-up and short trips.

Electrified roadways can be used as the power source on freeways and major arterials.

SINCE: WARRANT
The RPVS will achieve sufficient consumer acceptance.

BECAUSE: BACKING

UNLESS: REBUTTAL
Consumer acceptance is too low.

Production and distribution of batteries for RPVs require substantial amounts of petroleum.

The RPVS will require petroleum to produce its electrical energy.

Counter rebuttal

2

THEN: CLAIM
The RPVS will not require petroleum to produce its electrical energy.

GIVEN THAT: DATA
Base load uses non-petroleum fuels.

Peak load demand from the RPVS will be minimal.

Peak load demand from the RPVS can be offset by additional base load capacity, and load leveling (e.g. east-west interchange and demand billing).

SINCE: WARRANT
Utilities will add to their base load capacity, and switch to non-petroleum fuels for most peak and intermediate loads.

BECAUSE: BACKING

UNLESS: REBUTTAL
Utilities fail to conserve petroleum through added base load capacity, load leveling, and a switch to non-petroleum fuels for most peak and intermediate loads.

Peak load demand from the RPVS will be higher than expected.

Data expansion

3

THEN: CLAIM
Peak load requirements imposed by the RPVS are minimal.

GIVEN THAT: DATA
Traffic peaks do not coincide in all cities.

The RPVS can serve as interties between cities and time zones for load leveling purposes.

SINCE: WARRANT
The RPVS load during peak hours is a small percentage of normal peak demand, and can be further reduced or eliminated by load leveling.

UNLESS: REBUTTAL
The east-west interchange system does not materialize.

The switch to non-petroleum fuels for peak loads does not materialize.

Issue #1 - Petroleum Displacement:

To what extent will the RPVS displace petroleum?

RED TEAM Argument

GIVEN THAT: ATA

1. Costs are prohibitively high.
2. No gain in roadway capacity.
3. No gain in petro displacement.
4. Massive public investment & consumer acceptance are necessary for the RPVS to be efficient.
5. Depends on successful development of other technologies:
   - Battery technology
   - Peak/off-peak power generation
   - Design of electric vehicles
6. Depends on public policy decisions in its favor:
   - Centralized/decentralized power distribution & urban development
   - Electric power/other fuels
   - Automobiles/public transit
7. East-west interchange not feasible.
8. More peak capacity required than stated in the LBL report.
9. RPVS efficiency is overstated compared to ICE or E&HV.
10. E&HVs will not add to peak load.
11. Minimal cold start losses with E&HVs.

SINCE: WARRANT

The barriers indicated by the data are insurmountable and supports the inefficiency of the RPVS.

BECAUSE: ACKING

1. Based on Red Team cost projections.
2. No new roads and no capacity increase of current system.
3. Petroleum used to build & power the system offset any petroleum displacement gained from having non-petro fueled vehicles.
4. The system is costly, it will not be developed by private industry, and consumers will not readily accept this new technology.

5&6. The RPVS will function at or above a minimally acceptable level, only if a particular scenario (within certain parameters) proves true.

7. Red Team's assessment, and research done by power companies substantiates this data.
8. Based on Red Team calculations.

9-11. Based on Red Team findings.

THEN: LAIM

The RPVS is not the most efficient system for achieving the highest amount of petroleum displacement.

UNLESS: EBUTTAL

Blue Team arguments are correct and the major barriers can be overcome.

The data are refuted as follows:

a. Capital costs are similar to or lower than for the alternatives, and operating costs are lower.

b. Automation of the RPVS will smooth traffic flow and allow vehicles to travel closer together; and hence reduce energy consumption and increase roadway capacity.

c. RPVs are lighter than EVs and use less battery energy; hence more efficient than EVs. RPVs have no ICE, which is inefficient on short duty cycles; hence more efficient than ICE or hybrid vehicles.

d. Urban freeway lanes are used by about 11,000 vehicles/day, thus amortizing RPVS equipment better than alternative battery charging equipment in individual garages.

e. No study of the feasibility of interties was identified.

f. RPVS technology is simple and development risks are modest.

g. HVs are a poor choice:
   - Excessive ICE cold start losses.
   - Inconvenient to the consumer.

h. The RPVS is accepted with some enthusiasm by consumers because of low operating costs, convenience, and improved traffic flow and safety.

Issue #2 - Economics

Will the RPVS be prohibitively expensive?

BLUE TEAM Argument

1

GIVEN THAT: DATA

Capital costs for the alternatives are comparable to or greater than for the RPVS.

Direct energy transfer reduces costs and losses.

RPVS operating costs involves no identified major risks.

RPVS R&D involves no major risks.

Automation will improve safety.

Synfuels have severe drawbacks.

SINCE: WARRANT

Capital costs are based on findings of the Blue Team & the LBL Study.

RPVS cost is much less than the Interstate freeway system cost.

BECAUSE: BACKING

THEN: CLAIM

The RPVS makes the best economic sense of the alternatives considered (EHV, synfuel ICE, RPVS)

UNLESS: REBUTTAL

Blue Team capital cost calculations are not accurate.

High energy losses for RPVS.

Obstacles to synfuel can be overcome.

Life cycle capital costs alone are not sufficient to make comparisons.

→ Data expansion

2

GIVEN THAT: DATA

Marginal capital costs (mcc), beyond those of an equivalent gasoline powered ICE vehicle system:

Synfuel system mcc	:	300-400 B$+
EV system mcc	:	565 B$+
HV system mcc	:	434 B$
RPV system mcc	:	400 B$

SINCE: WARRANT

The cost models are valid, and the expected error of the estimates would not invalidate the conclusions.

BECAUSE: BACKING

Blue Team experience in cost estimating, using published data and system design & fabrication expenses.

THEN: CLAIM

Capital costs for converting 100 mill. automobiles to the RPVS are similar to or less than for the alternatives.

UNLESS: REBUTTAL

The economic model using only capital costs is inappropriate.

Operating costs for the RPVS offset capital cost advantages.

The figures are sensitive to the fleet size assumption (110 million).

(See next page)

→ Data expansion

3

GIVEN THAT: DATA

Manufacturing facilities	:	200-300 B$
Distribution facilities	:	100 B$

Coal mining & distribution costs should also be added.

SINCE: WARRANT

110 mill. veh. fleet is a reasonable basis for comparison.

Synfuels are more corrosive than crude oil & petroleum, and require hence new distribution facilities.

THEN: CLAIM

Marginal capital costs for synfueled ICE system are: 300-400 B$+

UNLESS: REBUTTAL

Synfuels can use present facilities because the corrosive properties are not damaging to them.

Issue #2 - Economics

Will the RPVS be prohibitively expensive?

BLUE TEAM Argument (continued)

→ Data expansion

GIVEN THAT: DATA

First battery pack : 275 B$

Battery charger : 290 B$.

Upgraded utility power distribution costs should be added.

SINCE: WARRANT

110 mill. veh. fleet is a reasonable basis for comparison.

Battery cost is about 100 $/kWh.

Battery chargers are similar to golf cart chargers (250 $/kW).

THEN: CLAIM

Marginal capital costs for battery only EV system are: 565 B$+

UNLESS: REBUTTAL

Smaller chargers could be used.

→ Data expansion

GIVEN THAT: DATA

Synfuel manuf. fac. : 100 B$

Synfuel distr. fac. : 40 B$

Extra prop./storage : 88 B$

First battery pack : 110 B$

Battery charger : 96 B$

SINCE: WARRANT

110 mill. veh. fleet is a reasonable basis for comparison.

40%/60% ICE/electric use is typical.

Extra propulsion/storage is 800 $/veh.

Battery cost is about 100 $/kWh.

First battery pack is 1000 $/veh.

Battery chargers are similar to golf cart chargers (250 $/kW).

THEN: CLAIM

Marginal capital costs for ICE/battery HV system are: 434 B$.

UNLESS: REBUTTAL

Less ICE/synfuel use is required.

Synfuels can use present facilities.

Two small propulsion systems cost less than one large.

R&D lowers battery costs.

R&D lowers battery chargers costs.

→ Battery charger

GIVEN THAT: DATA

RPVS roadway : 133 B$

Baseload capacity : 22 B$

First battery pack : 110 B$

Battery charger : 96 B$

Power pickup & control : 39 B$

SINCE: WARRANT

RPVS require 265k lane miles at a cost of 0.5 M$/lane mile.

RPVS require 49 GW base load capacity at a cost of 450 $/kW.

Battery cost is about 100 $/kWh.

Battery chargers are similar to golf cart chargers (250 $/kW).

Power pickup & control cost is 350 $/vehicle.

THEN: CLAIM

Marginal capital costs for RPV system are: 400 B$

UNLESS: REBUTTAL

Additional peak load required added peak load capacity, not base.

Base load capacity capital costs are a minimum 1000 $/kW.

R&D lowers battery costs.

R&D lowers battery charger costs.

Issue #2 - Economics

Will the RPVS be prohibitively expensive?

RED TEAM Argument

Argument 1

GIVEN THAT: DATA

The cost of saving one barrel of petroleum with the RPVS ranges from $42 to $4812 under a wide range of assumptions. This suggests that the cost per gallon saved ranges from $1.00 to $115.00.

SINCE: WARRANT

Cost figures are based on a present value life cycle cost and levelized required revenue model.

The time sequence of implementation and execution is critical.

BECAUSE: BACKING

Red team experience in forecasting costs, using economic model.

Accepted economic models.

THEN: CLAIM

Costs of the RPV system are excessive; it is not economically viable.

UNLESS: REBUTTAL

The time sequence factors used in the model are inappropriate.

The assumed data is inappropriate.

The analysis was admitted to be parametric in nature, with little or no relationship to a consistent set of projections for the RPVS.

The present value life cycle cost model is of limited value for this type of social investment.

Data expansion

Argument 2

GIVEN THAT: DATA

Variable values according to the attached data table.

The RPV and ICE vehicle systems have equal net thermal efficiencies.

11,000 vehicles per lane mile day.

Growth rates are based on DRI Interindustry Transactions Model.

15 year implementation cycle, as outlined in the LBL Feasibility Study.

15 year lifetime for road coils.

35 year lifetime for power plants.

SINCE: WARRANT

Levelized required revenue (LRR) model is based on:
Heft, R.C., and C.S. Borden, "Cost and Energy Efficiency of a Dual-Mode System", Jet Propulsion Laboratory, Arpil 30, 1977. Prepared for the U.S. Department of Transportation, UMTA-RD-CA-06-0088-76-2.

The calculations of the cost per barrel saved is based on the LRR model. First, the present value of the life cycle cost (PVLCC) is calculated. Second, the required revenue per vehicle mile (RRPVM) is calculated, based on the PVLCC and the vehicle miles traveled (VMT). Third, the cost per barrel saved is derived by dividing the RRPVM with the barrels saved per vehicle mile.

THEN: CLAIM

Costs of saving one barrel of petroleum with the RPV system ranges from $42 to $4812.

UNLESS: REBUTTAL

The net thermal efficiency of the RPVS is about twice that of the ICE vehicle system.

The lifetime of the roadway power source is more than 15 years.

The time to full utilization of a typical new RPVS lane will be short. RPVS lanes will be added on a strictly demand-responsive schedule, once a skeletal RPVS network is in place.

The roadway cost factors, as high as 100 times cost estimates obtained from Caltrans, are unrealistically high.

The ICE vehicle fleet MPG's are unrealistically high.

The output of the model bears no relationship to rational projections of actual sets of conditions; it is a parametric exercise.

Issue #3 - Transportation:

Will the RPVS Enhance or Restrict Transportability and by how much:

BLUE TEAM Argument

Argument 1

GIVEN THAT: DATA

The RVPS is inherently flexible in application; it can supply power to a spectrum of vehicle types.

Automated transit systems exhibit low accident rates.

The RPVS will increase roadway capacity because it can be adapted to provide vehicle guidance, detection, position sensing, speed sensing, bidirectional communication and headway (spacing) control.

The RPVS is no more vulnerable to weather than is the present ICE/highway system.

SINCE: WARRANT

The RPVS provides transportation at lower cost than alternatives, increasing its availability to the public.

BECAUSE: BACKING

LBL Feasibility study, and Blue Team investigation of RPVS bus applications.

THEN: CLAIM

RPVS enhances mobility by increasing the capacity and utilization of the highway system.

UNLESS: REBUTTAL

RPVS has limited availability. It will be restricted to highways and other major arterials.

Problems exist in installing the roadway power source in roads that are surfaced with materials other than Portland Cement Concrete.

There will be limited consumer acceptance of the RPVS.

RPVS lanes will be inoperable in adverse weather conditions (snow and ice) and, if the lane breaks down, the entire system will not function and the consequent redistribution of traffic may exceed the battery range.

Counter Rebuttal

Argument 2 (Data Expansion)

GIVEN THAT: DATA

Reduced headways at any given speed increase the throughput of the lane proportionally.

A standardized uniform traffic speed will smooth traffic flow.

SINCE: WARRANT

Closer headways, increased speeds and smoother traffic flow are conditions for improving the capacity and utilization of roads.

BECAUSE: BACKING

Queuing theory.

THEN: CLAIM

RPVS automation will increase the capacity and utilization of roads on which it is installed.

UNLESS: REBUTTAL

In any case, automated systems will not achieve benefits as rapidly as possible because of unforeseen optimization, software and implementation problems.

Argument 2 (Data Expansion)

GIVEN THAT: DATA

The power pickup below the vehicle is capable of scraping snow and ice, and will be sealed against moisture.

The losses in the roadway can be deliverately increased during early morning hours to de-ice the roadway near the power source.

SINCE: WARRANT

The power pickup is a rugged steel structure capable of withstanding physical abuse.

Heating in the roadway can be provided by increasing the source current in the power system.

THEN: CLAIM

The RPVS is no more vulnerable to adverse weather conditions than the existing roadway/vehicle system.

UNLESS: REBUTTAL

Experiments on sidewalks in Philadelphia revealed that heat melting:

a) created glare ice
b) clogged sewers
c) increased pavement damage because it increased the freeze/thaw cycle frequency.

Issue #3 - Transportation:

Will the RPVS Enhance or Restrict Transportability and by how much?

RED TEAM Argument

1

GIVEN THAT: DATA

The RPVS is inoperable if the powered lane breaks down for any reason.

Roads in some Eastern states are not maintained at a level to provide a sufficient quality road surface for the RPVS power source to be installed due to low state road maintenance budgets.

Attachment problems exist with road surfaces other than Portland Cement Concrete.

Inclement weather, mainly snow and ice, which is prevalent in many parts of the country will interfere with efficient operation of the system.

SINCE: WARRANT

These barriers are insurmountable in the near future.

THEN: CLAIM

The RPVS will significantly reduce the capacity and mobility of the roadway system.

UNLESS: REBUTTAL

The RPVS will have approximately the same reliability as the utility system. When failures occur, vehicles will continue at reduced speed to the next operating section of the RPVS.

Because of RPVS thermal input to lane during (eastern) winters, freezing damage will be reduced.

The RPVS will tolerate typical surface conditions provided by asphaltic concrete.

Weather conditions do not affect the functioning of the RPVS.

Data Expansion

2

GIVEN THAT: DATA

Ice and snow are problems in many geographical areas during the winter time and their presence on the roadway will create problems for the efficient operation of the RPVS.

SINCE: WARRANT

Ice and snow will restrict the operation of the RPVS.

THEN: CLAIM

Inclement weather, mainly snow and ice, will interfere with operation of the system.

UNLESS: REBUTTAL

The presence of ice and snow have no effect on the electro-magnetic power coupling. Periodic passage of vehicle power pickups will keep snow scraped above the source.

Heat can be provided to the roadway for de-icing near the power source by deliberately increasing the current (and losses) in the source.

Even if RPVS were installed only in warmer climate, substantial benefits would accrue

Issue #4 - Implementation:

Can rational implementation strategies be developed for the RPV system?

BLUE TEAM Argument

1

GIVEN THAT: DATA

Identified possible applications in receptive environments include:

Downtown malls - Denver, Sacramento

Street transit - Denver, Santa Barbara

Freeway busway - Los Angeles

Freeway demonstrations are feasible on short, high density commuting routes for automobiles and buses.

Comprehensive RPVS implementation on existing roads can be the final program phase.

SINCE: WARRANT

Successful demonstration projects that will elicit support for further installations from federal, state and city governments include mall, street transit, busways on freeways, and truck systems.

BECAUSE: BACKING

The theory of innovation transmission.

THEN: CLAIM

Phased-in implementation plans are available that will minimize the risks and demonstration costs of the RPVS.

UNLESS: REBUTTAL

Malls, busways and trucks may be unsuccessful.

Consumers still will not purchase RPVS automobiles.

Government, utilities and others will not make the decisions necessary to permit implementation of the RPVS.

The phased-in implementation plan takes far too much time to be completed to be feasible.

Data Expansion

2

GIVEN THAT: DATA

The freeway system must be nearly totally resurfaced in the near future. Provision for the RPVS installation can be made during this work.

Positional tolerances required for the RPVS are compatible with asphaltic concrete characteristics.

Machines can readily be built that can rapidly and accurately cut or resurface concrete and asphalt roads.

.
.
.
.

SINCE: WARRANT

The power system can (preferably) be installed on existing roads that would be resurfaced with asphalt concrete to repair the lane and establish a surface flush with the power source.

.
.

BECAUSE: BACKING

THEN: CLAIM

Comprehensive RPVS implementation on existing roads can be the final program phase.

UNLESS: REBUTTAL

The high cost and low performance of the new machine and the diamond saw/jackhammer method make full-scale implementation uneconomical.

Issue #4 - Implementation:

Can rational implementation strategies be developed for the RPV system?

RED TEAM Argument

1

GIVEN THAT: DATA

The RPVS will not be implemented because scale economics necessary to produce a cost-competitive vehicle will not be realized due to small size of production runs.

There is no information on who will buy or build the vehicles so consumer acceptance is potentially low.

RPVS is not likely to replace private passenger cars because of lack of flexibility and range.

RPVS requires large federal, state and local government funding which is unlikely to materialize.

SINCE: WARRANT

These barriers to implementation will not be overcome.

BECAUSE: BACKING

The automobile industry will pursue its own economy of scale.

People will demand flexibility and range.

Governments generally do not engage in large scale coordinated funding projects.

THEN: CLAIM

There is too much risk involved in implementing the RPVS.

UNLESS: REBUTTAL

Vehicles are very similar to conventional EVs in design and construction, are less complex than HVs.

Development risks are small.

Initial RPVS use may be public transit, thus guaranteeing a reasonable level of use.

RPVS offers the public significant incentives for its use; public support can be expected.

Vehicles can be built at economic level at smaller volume or demand will exceed 120,000/year.

Counter Rebuttal

Data Expansion

2

GIVEN THAT: DATA

The threshold for economies of scale in automobile manufacture is approximately 120,000 vehicles per year.

The link between the Harbor and San Diego Freeway on the Santa Monica.

- 4 million vehicle miles/lane
- 11,000 vehicles per day
- 10% new vehicles per year
- 1000 new vehicles per year

Only 1/2 live within 7 miles

= 500 vehicles

x 20% market penetration

= 100 vehicles

1200 links necessary (i.e., 100 x 1200 = 120,000 vehicles/yr.)

SINCE: WARRANT

1200 links go beyond the scale and phase in economics of industry and government.

RPVS vehicle estimation model.

BECAUSE: BACKING

Red Team's experience indicates that the model's assumption are reasonable.

THEN: CLAIM

The RPVS will not be implemented successfully because the scale economies and phase-in economics are not favorable.

UNLESS: REBUTTAL

The model's assumptions are inappropriate

a) Off inductive coupling roadway range is potentially greater than 14 miles, increasing the 1/2 factor.

b) Replacement rate is greater than 10% per year.

c) Market penetration is greater than 20%.

The Santa Monica Freeway is not representative.

Despite these seemingly negative economics, government or industry will pursue the RPVS anyways. For example, manufacturers may produce fewer than 120,000 vehicles.

There exists an implementation plan which averts the adverse aspects of this model.

Issue #5 - Consumer acceptance and market penetration:

How acceptable/preferable will the RPV system be to the consumers?

BLUE TEAM Argument
w/ RED TEAM Rebuttal

GIVEN THAT: DATA

Features of the RPVS which will lead consumers to purchase RPVs:

a. The RPV is very simple.

b. The RPV only has one power system.

c. Only casual monitoring is required by the driver. Your never have to go to a service station to get gas, or plug it in if you don't want to. Therefore, the RPV is very convenient.

d. Improved safety, accident prevention, and traffic flow will be realized with the automated RPVS.

e. RPVs can range in design from extremely high performance through small economy vehicles.

f. Energy will always be available. No gas lines, no fuel supply problem.

g. RPVs provide the user with full range of performance, expected from a vehicle: Long range and high speeds on freeways, economical operation and reasonable acceleration.

There exists a vigorous implementation plan which includes the following steps: Pilot projects, questionnaires, incentives to encourage expansion. Limited pilot projects will show consumer acceptance or rejection very quickly. Surveys will demonstrate marketability of the RPVS.

It is irrational to have less than 100% of freeway traffic on RPVS lanes in the long run.

SINCE: WARRANT

Virtually 100% of the potential customers will recognize these features and be compelled to purchase accordingly.

This implementation and technology diffusion plan will show consumer acceptance and lead to virtually 100% adoption.

People will not act irrationally.

BECAUSE: BACKING

People are perceptive and willing to adopt innovations which appear to offer improvements.

Theory of Technological Diffusion (Everett Rogers & Jerry Zaltman). In addition, the following plan could be implemented: When you have a highway segment that serves the commuting needs of some population group you could use a questionnaire to determine if people using this corridor would like to see the system expanded. Ask the users how satisfied they are with the vehicle and its performance and if they would like to see the system expanded. You would need to educate people to the various systems available before taking the survey. You could also use direct observation of lane usage.

Man is a rational animal.

THEN: CLAIM

The RPV system will achieve virtually 100% market penetration.

UNLESS: REBUTTAL

Red Team believes that electric vehicles will only achieve 20% of the market share under the current RPVS plan and possibly reach a maximum of 50% share if, in fact, the RPVS adds significant benefits to electric vehicles.

Better market research is unnecessary to establish the claim to 100% market penetration. But, existing market research methods are inadequate to provide reliable data on this issue.

The proposed plan is risky because it is likely that the early electric vehicle technology will be made obsolete by breakthroughs in electro-chemical storage and other technical developments, thereby making battery-only operated vehicles more attractive.

Issue #1 - Petroleum Displacement: To what extent will the Roadway Powered Vehicle System (RPVS) displace petroleum?

Blue Team Argument

Level 1 Claim: The RPVS will displace substantial amounts of petroleum.

DATA ("Given that......")

1. Batteries (not an ICE) are used for start-up, thus eliminating use of petroleum in start-up as required for ICEs & EHVs. Large % of overall petroleum is consumed in starting up these vehicles.

2. Batteries are used for short trips. The average trip is 3 miles; few trips are greater than 12 miles.

3. Electrified roadways are used as the power source for freeways and major arterials.

WARRANTS ("Since ....")

1. The all-electric RPVS will achieve sufficient consumer acceptance to yield a substantial displacement of petroleum.

REBUTTALS ("Unless........")

1. Consumer acceptance is at too low a level to displace substantial amounts of petroleum with RPVS.

2. The production or distribution of batteries for RPVS cars requires substantial amounts of petroleum.

3. Roadway electric sources are produced with petroleum.

Counter Rebuttal

Level 2 Claim

Blue Team Argument

Level 2 Claim: RPVS will not require petroleum to produce its electrical energy.

DATA ("Given that......."

1. Base load power needs can be met by non-petroleum-fired generating plants.
2. Peak load additional requirements (fired by petroleum) from the RPVS are minimal.
3. Any peak load increases can be offset by additional non-petroleum base load capacity.
4. Peak load increases from RPVS can be constrained by demand billing.
5. RPVS electrical demands have a better demand factor than the national average.

(Data items 2–4 → Data Expansion → Level 3 Claim)

WARRANTS ("Since ....")

1. Utilities will continue to use non-petroleum sources for base load power, add to their base load capacity, switch to non-petroleum sources for most intermediate and peaking requirements (and use interties for load leveling, and may constrain RPVS peak hour demand by demand billing).

REBUTTALS ("Unless ....")

1. Utilities fail to realize significant petroleum-conserving sources of power.
2. Peak load demand of RPVS is higher than expected and cannot be powered by non-petroleum sources.
3. No adequate replacements for petroleum are found to produce intermediate and peak power.

Data Expansion

Level 3 Claim

Blue Team Argument

Level 3 Claim: Peak load requirements imposed by RPVS are minimal.

DATA ("Given that ....")

1. Automation will permit more predictability and control of traffic peaks and flows.
2. The RPVS distribution systems can serve as interties between time zones and cities. These interties can blend non-concurrent peaks in interconnected areas, because traffic peaks in all cities don't coincide.
3. The feasibility study indicated only a 5% increase in peak load in the Los Angeles basin from RPVS addition.

WARRANTS ("Since ....")

1. If the power generating system needs can be predicted and balanced so that no substantial peaks occur, then petroleum usage can be minimized.
2. The RPVS load during peak hours is a small percentage of normal peak demand and can be further reduced or eliminated by load leveling techniques, such as the use of east/west interties and demand billing.

REBUTTALS ("Unless ....")

1. The east/west intertie doesn't materialize.
2. Driving habits (current as well as any new ones that develop) perpetuate present peaks and/or lead to new ones.
3. Automation of the RPVS and its resultant benefits are delayed.
4. RPVS requires more peak load capacity than anticipated.
5. It is not possible to replace petroleum with other fuels to meet peak load demand.

Red Team Argument

Level 1 Claim: The RPVS is not the most efficient system for achieving the highest amount of petroleum displacement.

DATA ("Given that ....")

1. Cost projections of the RPVS are prohibitively high.
2. There is no gain in roadway capacity.
3. There is no gain in energy efficiency of petroleum displacement.
4. Massive public investment and consumer acceptance are necessary for the RPVS to be efficient.
5. The RPVS depends on successful development of other technologies:

   a) battery technology
   b) peak/off peak power generation
   c) design of electric vehicles
   d) public policy decisions in its favor

   - centralized vs. decentralized power distribution
   - electric power vs. other fuels
   - centralized vs. decentralized urban development
   - automobiles vs. mass transit system.
6. The East/West intertie is not feasible, either technologically or economically.
7. The RPVS will add more to the necessary peak capacity than stated in the LBL report.
8. RPVS efficiency is overstated compared to ICE or EHV.
9. EHV's will not add to the peak load factor in any way.
10. Cold start losses with EHVs are minimal and insignificant.

WARRANTS ("Since ....")

1. The set of barriers indicated by the data is insurmountable and supports the inefficiency of the RPVS.

BACKINGS ("Because ......")

1. Based on cost projections presented by the Red Team.
2. No new roads will be built and RPVS does not increase capacity of current system.
3. Energy and petroleum used to build and power the system offset any petroleum displacement gained from having non-petroleum-fueled vehicles.
4. The system is costly, it will not be developed by private industry, and consumers will not readily accept this new technology.
5. The RPVS will function at or above a minimally acceptable level, only if a particular scenario (within certain parameters) proves true.
6. The Red Team's assessment and research already done by power companies substantiates this data.
7. This statement is based on the Red Team's calculations.

8-10. These statements are based on findings of research done by Keith Hardy.

REBUTTALS ("Unless ....")

1. The Blue Team's arguments are correct and the major barriers are overcome.
2. The data are refuted as follows:

   a) Capital costs of the RPVS would be similar to or lower than for equal implementation of alternatives. Operating costs would also be lower.

   b) RPVS can incorporate automation that will smooth traffic flow and thus reduce energy consumption as well as allow vehicles to travel closer together.

   c) RPVS vehicles are lighter than battery-only EV's and use less energy from batteries; hence are more efficient. RPVS vehicles do not have an ICE (which is inefficient in short duty cycles) and are thus more efficient than ICE-only or ICE/EHV hybrid vehicles.

   d) Urban freeway lanes are used by about 11,000 vehicles/day, thus amortizing RPVS equipment better than alternative battery-charging equipment in individual garages.

   e) No study of the feasibility of interties was identified; data does not support lack of feasibility of interties.

   f) RPVS technology is straightforward and development risks are modest.

   g) Hybrid vehicles are a poor choice comparatively:

   - excessive cold start losses in the ICE because of abbreviated duty cycles.
   - inconvenient to the consumer because of the need to refuel two energy systems and maintain two propulsion systems.

   h) The RPVS may be accepted with some enthusiasm by the consumer because of low operating cost convenience and improved traffic flow and safety.

Issue #2 - Economics: Will an RPVS be prohibitively expensive?

Blue Team Argument

Level 1 Claim: The RPVS makes the best economic sense of the alternatives considered (synfueled ICE, battery-only EV, HV, RPVS).

DATA ("Given that ......")

1. Capital costs of the alternatives are comparable to or greater than the RPVS.
2. Energy transfer in real time reduces costs and losses.
3. Operating costs of RPVS involves no identified major risks.
4. R&D for the RPVS involves no identified major risks.
5. Automation will improve safety, as demonstrated by new automated transit systems.
6. Synfuels (hence synfueled-vehicles) have severe drawbacks:
   - o technology (development risks)
   - o manufacturing facilities are very costly
   - o 30-45% of energy is lost in production
   - o new distribution facilities will be required
   - o there are massive environmental penalties
   - o synfuels may be very costly at the retail level
   - o large extra investments are required for coal mining and transportation.

WARRANTS ("Since ....")

1. Bolger's figures are the basis for capital cost comparison (Exhibit V) plus the feasibility study.
2. Power is not stored.
3. Once the roadway source is installed, there is no maintenance and little wear and tear.
4. Automation will improve safety and thus achieve savings related to the costs of property damage, injuries, and deaths.
5. The RPVS is required on a modest inventory of well-traveled lanes. Amortization of power system costs will be rapid.
6. RPVS are useful to transit systems and trucks.
7. The cost to implement the RPVS nationally would be much less than was the case fo the freeways. The time to implement the system may be similar, i.e., on the order of 15 years. the freeway system was constructed without major financial dislocations.

REBUTTALS ("Unless ....")

1. Bolger's figures are not accurate; costs for RPVS are considerably higher than for other systems.
2. There is high energy loss with RPVS.
3. Operating costs will be higher than anticipated.
4. Obstacles to synfuels can be overcome and they become cost-effective as well.
5. The degree of market penetration achieved by RPVS doesn't support the cost figures.
6. More costs are incurred by the RPVS than petroleum is saved.
7. Present value analysis shows other systems to be more cost-effective.
8. Life cycle capital costs alone are not sufficient to make comparisons among the alternatives.

Data Expansion

Level 2 Claim

Issue #2 - Economics (continued)

Blue Team Argument (Exhibit V amplified)

Level 2 Claim: Major capital costs for converting the 110 million vehicle of automobiles to the RPVS are similar to or less than alternatives.

DATA ("Given that ....")

1. Synthetic fuel major costs = $300-$400x10^9
2. Battery-only = $565x10^9 electric vehicle system costs
3. Hybrid = $434x10^9 ICE/EV system costs
4. RPVS costs = $400x10^9

Data Expansion

Level 3 Claims

WARRANTS ("Since ....")

1. The models for each of these 4 data estimates are valid, and expected error of estimates would not invalidate the conclusions drawn.
2. The cost factors given for each of the 4 data estimates (which are detailed as Level III Items 1-4) all assume the following warrants in arriving at the respective total estimates:

   a) the list of major factors is exhaustive.

   b) the factors are additive.

   c) the time sequence of implementation is non-critical.

   d) vehicle costs are costs of extra equipment, i.e., the incremental costs beyond those of an equivalent gasoline-powered ICE vehicle.

BACKING ("Because ....")

1. Bolger's experience in cost estimating using published data and system design and fabrication expense.

REBUTTALS ("Unless ....")

1. The economic model using only capital costs is inappropriate.
2. Operating costs for RPVS swamp out capital cost advantages.
3. The resulting figures are sensitive to the 110 million vehicle fleet assumption.

EXHIBIT V

Issue #2 - Economics: Blue Team Argument - Level 2 Claim

- Major capital requirements of implementing a national inductive coupling system are comparatively low:

(Based on a 110 Million Vehicle Fleet)

1. Synfuel I.C.

Manufacturing Facilities	200 - 300 B$	
Distribution Facilities	100 B$	
	300 - 400 B$	+ Costs of Coal Mining and of Coal Distribution

2. Battery (only) E.V.

First Battery Packs (75 mile)	275 B$
Battery Chargers	290 B$
Extra Distribution Capacity	?
	565 B$

3. Hybrid IC/EV (40% IC - 60% Electric)

Synfuel Mfg. Facilities	100 B$
Synfuel Distrib. Facilities	40
Extra Propulsion System @ 800 $/veh.	88
First Battery Pack (30 mile)	110
Battery Chargers	96
	434 B$

4. Roadway Electrification (Inductive Coupling) System

Roadway Power Systems (265,000 lane miles)	133 B$
Additional Baseload Capacity (4.9×10^6 kW) (equal to added peak hour increment)	22
First Battery Pack (30 mile)	110
Battery Chargers	96
Vehicle Power Pickups	39
	400 B$

Issue #2 - Economics (continued)

Blue Team Argument

Level 3 Claim: Item 1 from level 2: Synfueled ICE system capital costs are \$300 to 400x10^9 plus costs of extra coal mining and transportation that is required by energy wasted in manufacture.

DATA ("Given that ....")

1. Manufacturing Facilities cost \$200 to 300x10^9
2. Synfuel Distribution Facilities cost about \$100x10^9
3. Coal Mining (extra capacity required by energy wasted)
4. Coal Distribution (extra capacity required by energy wasted)

WARRANTS ("Since ....")

1. Fleet remains at 110,000,000 vehicles and is a reasonable basis for comparing alternatives.
2. Synfuels are more corrosive than crude oil or gasoline and require new distribution facilities.

REBUTTALS ("Unless ....")

1. Synfuels could use present pipelines and storage facilities because corrosive properties are not damaging to present distribution facilities.

Issue #2 - Economics (continued)

Blue Team Argument

Level 3 Claim: Item 2 from Level 2: Battery Only Electric Vehicle Extra Capital Costs are $\$565 \times 10^9$ + Costs of Extra Electric Power Distribution.

DATA ("Given that ....")

1. First battery pack cost: 275 B$*
2. Battery charger cost: 290 B$**
3. Extra utility power distribution costs.

WARRANTS ("Since ....")

1. 110×10^6 vehicles (as in the vehicle fleet) is a reasonable basis for comparing alternatives. 75 mile range battery pack whose cost is 2.5 times that of a 30 mile pack.
2. Battery charger costs similar to electric golf car chargers, i.e., 250$/kWe
3. Cost of batteries is approximately 100 $/kWh

REBUTTALS ("Unless ....")

1. A smaller charger could be used.

*$75 \text{ miles} \times .33 \frac{\text{kWh}}{\text{mile}} \times 100 \frac{\$}{\text{kWh}} \times 110 \times 10^6 \text{ vehicles} \cong 275 \text{ B\$}$

**$75 \text{ miles} \times .33 \frac{\text{kWh}}{\text{mile}} \times .35 \frac{\text{kW}^{\#\#}}{\text{kWh}} \times (250 + {}^{\#}50) \frac{\$}{\text{kW}} \times 110 \times 10^6 \text{ vehicles} \cong 290 \text{ B\$}$

#allowance for heavier electrical service in garage.

##typical ratio for existing systems.

Blue Team Argument

Level 3 Claim: Item 3 from Level 2: Hybrid Internal Combustion - Electric Vehicles have extra Capital Costs of $\$434 \times 10^9$ for a fleet of 110 million vehicles.

DATA ("Given that ....")

1. Synfuel manufacturing cost = 40% of 250 B$ (above) = 100 B$
2. Synfuel distribution cost = 40% of 100 B$ (above) = 40 B$
3. Extra propulsion/storage system estimated to be 88 B$*
4. First battery pack: 110 B$**
5. Battery charger cost: 96 B$***

WARRANTS ("Since ....")

1. 110×10^6 vehicles as in the vehicle fleet is a reasonable basis for comparing alternatives.
2. 40% ICE use/60% electric use in typical operations. Synfuel required for ICE operation.
3. Cost of extra propulsion/storage system is $800/vehicle.
4. Cost of battery chargers similar to golf cart chargers, i.e., $250/kWe
5. Cost of batteries is approximately $100/kWh.
6. Cost of first battery back is $1000/vehicle.

REBUTTALS ("Unless ....")

1. A smaller percentage of ICE use is required and/or synfuel is not required for ICE operation.
2. Synfuels can use present distribution system and no new facilities are required.
3. The cost of two small propulsion systems is less than the cost of a large one.
4. R&D efforts on improved battery packs reduces their cost.
5. R&D efforts lower battery charger costs.

*$700 extra motor and power transmission
$100 extra propulsion control equipment
$800 total extra cost/vehicle x 110 x 10^6 vehicles = 88 B$

** $30 \text{ miles} \times .33 \frac{\text{kWh}}{\text{mile}} \times 100\ \$/\text{kWh} \times 110 \times 10^6 \text{ vehicles} = 110 \text{ B\$}$

*** $30 \text{ miles} \times .33 \frac{\text{kWh}}{\text{mile}} \times .35 \frac{\text{kW}}{\text{kWh}} \times 250 \frac{\$}{\text{kW}} \times 110 \times 10^6 \text{ vehicles} = 96 \text{ B\$}$

Blue Team Argument

Level 3 Claim: Item 4 from Level 2: RPVS capital costs are $\$400 \times 10^9$

DATA ("Given that ....")

1. Cost of roadway power system: 133 B$ *
2. Cost of baseload capacity: 22 B$ **
3. Battery charger cost as in hybrid estimate = 96 B$
4. Battery cost as in hybrid estimate = 110 B$
5. Power pickup and power control cost: 39 B$***

WARRANTS ("Since ....")

1. 265,000 lane miles of RPVS are required at a cost of .5 M$/lane mile to supply 1.33×10^{12} VM/yr.
2. Baseload generating capacity is provided equal to the RPVS demand in peak hours, conservatively estimated to be 49×10^6 kW, at a cost of $450/kW.
3. Cost of battery chargers is similar to golf cart chargers, i.e., $250/kW.
4. Cost of batteries is $100/kWh.
5. Cost of power pickup and power control is $350/vehicle.

REBUTTALS ("Unless ....")

1. Additional peak load is met solely by added peak load capacity and not by additional base load.
2. Base load capacity capital costs are a minimum of $1000/kW.
3. R&D lowers costs on advanced battery packs.
4. R&D lowers battery charger costs.

*Lane miles required = $\dfrac{1.33 \times 10^{12} \times 40\% \text{ (on freeways)}}{5500 \frac{VM^{\#}}{\text{lane-mile day}} \times 365 \frac{\text{days}}{\text{year}}}$ = 265,000 lane miles

= 265,000 × .5 × 10^6 \$/lane mile = 133 B$

**kW required = $\dfrac{1.33 \times 10^{12} \frac{VM}{yr}}{365\ D/yr} \times .4$ on freeways × 40%/6 peak hours × 20 $\dfrac{kw}{\text{vehicle}}$ / 40 miles = 49×10^6 kW

49×10^6 kW × 450 \$/kW = 22 B$

***260 lbs at 1+\$/lb = \$300/vehicle power pickup
Power control, est. 50/vehicle
350 \$/vehicle

\$350 × 110 × 10^6 vehicles = 39 B$

#estimated average = half of average for Calif. urban freeways, i.e., 11,000/2 = 5500.

Red Team Argument

Level 1 Claim: Costs of RPVS are excessive; it is not economically viable.

DATA ("Given that ....")

1. The cost of saving 1 barrel of petroleum with RPVS ranges from $41.75 to $4812 under a wide range of assumptions. This suggests that the cost per gallon ranges from about $1.00 to $115.00.

Data Expansion → Level 2 Claim

WARRANTS ("Since ....")

1. Cost figures obtained by using a present value life cycle cost and levelized required revenue model. The time sequence of implementation and execution is critical.

BACKING ("Because ....")

1. Ron Heft's experience in forecasting costs using economic models.
2. Accepted economic methods.

REBUTTALS ("Unless ....")

1. The time sequence factors used in the model are inappropriate.
2. The assumed data is inappropriate.
3. The analysis was admitted to be parametric in nature with little or no relationship to a consistent set of projections for the RPVS.
4. Present value life cycle cost model is of limited value for this type of social investment.

Red Team Argument

Level 2 Claim: Cost of saving one barrel of petroleum with RPVS ranges from $41.75 to $4812.

DATA ("Given that ....")

1. Variable values assumed according to attached Data Table.
2. Internal combustion engine vehicle system and Roadway powered vehicle have been assumed to have equal thermal efficiency in ascertaining petroleum displaced.
3. Volume of vehicles per lane-mile day is 11,000, i.e., freeway volume.
4. Growth rates are based on DRI Interindustry Transactions Model.
5. 15 year implementation cycle used as outlined in LBL RPVS Report.
6. 15 year lifetime assumed for road coils.
7. 35 year lifetime assumed for power plants.

WARRANTS ("Since ....")

1. Levelized Required Revenue Model developed by Ron Heft. (Reference - R.C. Heft and C.S. Borden, "Costs and Energy Efficiency of a Dual-Mode System", DOT Report UMTA-RD-CA-06-0088-76-2, Department of Transportation, Washington, D.C., April 30, 1977.)

   Costs per barrel are determined using a model similar to a "Levelized Required Revenue Model" that first calculates the present value of life cycle costs (PVLCC). The present value of life cycle costs and vehicle miles traveled (VMT) are then used to calculate required revenue per vehile mile (RRPVM). Required revenue per vehicle mile divided by barrels of fuel saved yields cost per barrel saved. See Appendix I for further detail of model.

REBUTTALS ("Unless ....")

1. The net thermal efficiency of the RPVS is approximately twice that of ICE vehicles.
2. The life of the roadway power source can be expected to be longer than 15 years.
3. The time to full utilization of typical new RPVS lanes will be short; RPVS lanes will be added on a strictly demand-responsive schedule once a skeletal RPVS network is in place.
4. 'Roadway Cost Factors' used, i.e., as high as 100 times cost estimates obtained from Caltrans, are unrealistic.
5. The assumed fleet MPG for ICE's is unrealistically high.
6. The output of the model is a parametric exercise that bears no relationship to rational projections of actual sets of conditions.

Issue #2 - Economics: Red Team Argument - Level 2 Clain (Data Item 1)

Model Symbol	Data Table							
FPD	Percent Petroleum Displaced	100	80	50	20	10	%	
VMT	Percent IC Penetration	100	80	50	20	10	%	
$\frac{RW}{24,000}$	Roadway Cost Factor re $24k/lane mi	1	1	2	10	100		
E	Efficiency of IC System	.25	.30	.5	.6	.7	KWHR/mile	DATA
P	Price of Electricity	3	4	5	6	8	¢/KWHR	
g_2	Rate of Power Escalation	0	2.0	4.2	5.0	7.0		
mpg	Mpg of ICE	22	25	27	30.0	32	MGP	
	Cost (in cents) Levelized for Full Payment	4.51	6.07	12.72	42.37	358.0	¢/mile(VMT)	CLAIMS
	Barrels Saved (x 10^{-3})	1.08	0.75	0.86	0.79	0.744	42 Gal Bbls	
	Dollars Per Barrel Saved	41.75	63.9	148.2	536.3	4812	$/Bbl	

Issue #3 - Transportation: Will the RPVS enhance or restrict transportability and by how much?

Blue Team Argument

Level 1 Claim: RPVS enhances mobility by increasing the capacity and utilization of the highway system.

DATA ("Given that ....")

1. The RPVS is inherently flexible in application; it can supply power to a spectrum of vehicle types.
2. Automated transit systems exhibit low accident rates.
3. The RPVS will increase roadway capacity because it can be adapted to provide vehicle guidance, detection position sensing, speed sensing, bidirectional communication and headway (spacing) control.
4. Over 80% of ICE on-the-road failures are due to engine systems; the electric RPVS will provide improved reliability.
5. The RPVS is no more vulnerable to weather than is the present ICE/highway system.
6. The RPVS power system is designed to be removable in short sections to enhance access for service and to tolerate local roadway surface and flexure.

WARRANTS ("Since ....")

1. The RPVS provides transportation at lower cost than alternatives, increasing its availability to the public.
2. The RPVS will serve electric bus transit and freight modes in addition to automobiles.
3. The addition of automation to the RPVS at relatively low cost can reduce accident rates, smooth traffic flow, and increase freeway and arterial capacities.

BACKING ("Because ....")

1. Feasibility study, D.B. Turner's chart, H.R. Ross' investigation of RPVS bus applications.

REBUTTALS ("Unless ....")

1. RPVS has limited availability. It will be restricted to highways and other major arterials.
2. RPVS lanes will be inoperable in adverse weather conditions (snow and ice) and, if the lane breaks down, the entire system will not function and the consequent redistribution of traffic may exceed the battery range.
3. This scenario is not accurate.
4. The problem of aligning the vehicles with the roadway power source is not solved.
5. In some states highways are not maintained at a high enough level to allow for installation of roadway power source.
6. Problems exist in installing the roadway power source in roads that are surfaced with materials other than Portland Cement Concrete.
7. There will be limited consumer acceptance of the RPVS.
8. Necessary utility access beneath many road precludes the installation of RPVS power sources on some surface streets.

Data Expansion (Data 3 → Level 2 Claim)

Level 2 Claim

Data Expansion (Data 5) and Counter Rebuttal (Rebuttal 2) → Level 2 Claim

Level 2 Claim

Blue Team Argument

Level 2 Claim: RPVS automation will increase the capacity and utilization of roads on which it is installed.

DATA ("Given that ....")

1. Reduced headways at any given speed increase the throughput of the lane proportionally.
2. A standardized uniform traffic speed will smooth traffic flow.
3. Automation can be added to the RPVS on an evolutionary, non-disruptive schedule.
4. Vehicle detection, communication, and central control monitoring capabilities will be developed.

WARRANTS ("Since ....")

1. Closer headways, increased speeds and smoother traffic flow are conditions for improving the capacity and utilization of roads.

BACKING ("Because ....")

1. Queuing theory.

REBUTTALS ("Unless ....")

1. Automation is not specific to the RPVS. All the alternatives have the potential of automation and it is therefore not a competitive advantage.
2. In any case, automated systems will not achieve benefits as rapidly as possible because of unforeseen optimization, software and implementation problems.

C-2

Blue Team Argument

Level 2 Claim: The RPVS is no more vulnerable to adverse weather conditions than the existing roadway/vehicle system.

DATA ("Given that ....")

1. The power pickup below the vehicle is capable of scraping snow and ice, and will be sealed against moisture.
2. The losses in the roadway can be deliberately increased during early morning hours to de-ice the roadway near the power source.

WARRANTS ("Since ....")

1. The power pickup is a rugged steel structure capable of withstanding physical abuse.
2. Heating in the roadway can be provided by increasing the source current in the power system.

REBUTTALS ("Unless ....")

1. Experiments on sidewalks in Philadelphia revealed that heat melting:
   a) created glare ice
   b) clogged sewers
   c) increased pavement damage because it increased the freeze/thaw cycle frequency.

Issue #3 - Transportation (continued)

Red Team Argument

Level 1 Claim: The RPVS will significantly reduce the capacity and mobility of the roadway system.

DATA ("Given that ....")

1. The RPVS will not increase the capacity of the roadway system because no new roads will be built.
2. The RPVS is inoperable if the powered lane breaks down for any reason.
3. Roads in some Eastern states are not maintained at a level to provide a sufficient quality road surface for the RPVS power source to be installed due to low state road maintenance budgets.
4. Attachment problems exist with road surfaces other than Portland Cement Concrete.
5. Utility access beneath some streets precludes installation of RPVS power sources on some streets.
6. Inclement weather, mainly snow and ice, which is prevalent in many parts of the country will interfere with efficient operation of the system. → Data Expansion → **Level 2 Claim**
7. In some cities, the RPVS would require that new freeways and arterials be constructed.
8. RPVS vehicle range is limited to a specified number of miles from the powered roadways.
9. The benefits of the automated system can only be achieved when almost all roadways are electrified because of balancing and optimization requirements.
10. Mass transit adds more capacity than the RPVS because a roadway capacity of 2000 vehicles/hour/lane x 2 people/vehicle yields 400 people/lane/hour vs. 25,000 people/hour/track on mass transit.

WARRANTS ("Since ....")

1. These barriers are insurmountable in the near future.

REBUTTALS ("Unless ....")

1. There will be no need for new roadways because of increased lane capacity with the RPVS.
2. The RPVS will have approximately the same reliability as the utility system. When failures occur, vehicles will continue at reduced speed to the next operating section of the RPVS.
3. Because of RPVS thermal input to lane during (eastern) winters, freezing damage will be reduced.
4. The RPVS will tolerate typical surface conditions provided by asphaltic concrete.
5. The RPVS source will be designed to facilitate removal in short sections for service or access to utilities.
6. Weather conditions do not affect the functioning of the RPVS.
7. RPVS vehicles will be equipped with energy storage to suit the individual consumer's off-system travel requirements.
8. Rail mass transit systems have proved to be inflexible, prohibitively expensive, and suited to a very small number of applications. Bus transit systems are more flexible and cost effective; they will be enhanced by the RPVS technology.

Red Team Argument

Level 2 Claim: Inclement weather, mainly snow and ice, which is prevalent in many parts of the country, will interfere with efficient operation of the system.

DATA ("Given ....")

1. Ice and snow are problems in many geographical areas during the winter time and their presence on the roadway will create problems for the efficient operation of the RPVS.

WARRANTS ("Since ....")

1. Ice and snow will restrict the operation of the RPVS.

REBUTTALS ("Unless ....")

1. The presence of ice and snow have no effect on the electro-magnetic power coupling. Periodic passage of vehicle power pickups will keep snow scraped above the source.
2. The RPVS will provide guidance to vehicles even if it can't be seen.
3. Heat can be provided to the roadway for de-icing near the power source by deliberately increasing the current (and losses) in the source.
4. Even if RPVS were installed only in warmer climate, substantial benefits would accrue.

Issue #4 - Implementation: What is involved in the implementation issue for RPVS?

Blue Team Argument

Level 1 Claim: Phased-in implementation plans are available that will minimize the risks and demonstration costs of the RPVS.

DATA ("Given that ....")

1. Identified possible applications in receptive environments include:

   Downtown malls - Denver, Sacramento

   Street transit - Denver, Santa Barbara

   Freeway busway - Los Angeles

2. Freeway demonstrations are feasible on short, high density commuting routes for automobiles and buses.

3. Electric buses and trucks on RPVS lanes would justify expenditures for the systems, and thereby permit marginal analysis for automobiles.

4. Tax incentives or reduced (or no) cost energy on RPVS can be made available to stimulate RPVS vehicle acquisition and use.

5. Comprehensive RPVS implementation on existing roads can be the final program phase.

→ Data Expansion → **Level 2 Claim**

WARRANTS ("Since ....")

1. Successful demonstration projects that will elicit support for further installations from federal, state and city governments include mall, street transit, busways on freeways, and truck systems. These projects will influence governments to implement the RPVS in their jurisdictions.

BACKING ("Because ....")

1. The theory of innovation transmission.

REBUTTALS ("Unless ....")

1. Malls, busways and trucks may be unsuccessful.

2. Consumers still will not purchase RPVS automobiles.

3. Government, utilities and others will not make the decisions necessary to permit implementation of the RPVS.

4. The phased-in implementation plan takes far too much time to be completed to be feasible.

Blue Team Argument

Level 2 Claim: Comprehensive RPVS implementation on existing roads can be the final program phase.

DATA ("Given that ....")

1. The freeway system must be nearly totally resurfaced in the near future. Provision for the RPVS installation can be made during this work.
2. Positional tolerances required for the RPVS are compatible with asphaltic concrete characteristics.
3. Machines can readily be built that can rapidly and accurately cut or resurface concrete and asphalt roads. The slot on existing roadways can be cut using a new machine which will do 1.5 miles/day cutting as much as 3" off an asphalt or concrete highway and leaving a surface level to within 1/8 inch.

WARRANTS ("Since ....")

1. The power system can (preferably) be installed on existing roads that would be resurfaced with asphalt concrete to repair the lane and establish a surface flush with the power source.
2. The power system alternatively could be installed in a slot cut into Portland Cement Concrete roadways.

REBUTTALS ("Unless ....")

1. The high cost and low performance of the new machine and the diamond saw/jackhammer method make full-scale implementation uneconomical.

Issue #4 - Implementation (continued)

Red Team Argument

Level 1 Claim: There is too much risk involved in implementing the RPVS.

DATA ("Given that ....")

1. The RPVS will not be implemented because scale economies necessary to produce a cost-competitive vehicle will not be realized due to small size of production runs.
2. There is no information on who will buy or build the vehicles so consumer acceptance is potentially low.
3. Special vehicles will likely be more expensive and therefore less available to poor people creating inequality problems.
4. RPVS is not likely to replace private passenger cars because of lack of flexibility and range.
5. RPVS requires large federal, state and local government funding which is unlikely to materialize.

WARRANTS ("Since ....")

1. These barriers to implementation will not be overcome.

BACKING ("Because ....")

1. The automobile industry will pursue its own economy of scale.
2. People will demand flexibility and range.
3. Governments generally do not engage in large scale coordinated funding projects.

REBUTTALS ("Unless ....")

1. Vehicles are very similar to conventional EVs in design and construction, are less complex than HVs.
2. Development risks are small.
3. Initial RPVS use may be public transit, thus guaranteeing a reasonable level of use.
4. RPVS offers the public significant incentives for its use; public support can be expected.
5. Investment risks will be small because of the availability of cost effective demonstration strategies.
6. Vehicles can be built at economic level at smaller volume or demand will exceed 120,000/year.

Data Expansion

Counter Rebuttal

Level 2 Claims

Red Team Argument

Level 2 Claim: The RPVS will not be successfully implemented because the scale economies and phase-in economics are not favorable. Unit costs are high and manufacturers will not build RPVS vehicles because of limited production volume.

DATA ("Given that ....")

1. The threshold for economies of scale in automobile manufacture is approximately 120,000 vehicles per year.

2. The link between the Harbor and San Diego Freeway on the Santa Monica.

   - 4 million vehicle miles/lane
   - 11,000 vehicles per day
   - ~10% new vehicles per year
   - 1000 new vehicles per year

   Only 1/2 live within 7 miles

   = 500 vehicles

   x 20% market penetration

   = 100 vehicles

   1200 links necessary (i.e., 100x1200 = 120,000 vehicles/yr.)

WARRANTS ("Since ....")

1. 1200 links go beyond the scale and phase in economics of industry and government.

2. RPVS vehicle estimation model.

BACKING ("Because ....")

1. Ron Heft's experience indicates that the model's assumptions are reasonable.

REBUTTALS ("Unless ....")

1. The model's assumptions are inappropriate

   a) Off inductive coupling roadway range is potentially greater than 14 miles, increasing the 1/2 factor.

   b) Replacement rate is greater than 10% per year.

   c) Market penetration is greater than 20%.

2. The Santa Monica Freeway is not representative.

3. Despite these seemingly negative economics, government or industry will pursue the RPVS anyway. For example, manufacturers may produce fewer than 120,000 vehicles.

4. There exists an implementation plan which averts the adverse aspects of this model.

Issue #5: Consumer Acceptance and Market Penetration

As stated earlier, in the section "On the Method and Its Use," one of the purposes of argument analysis is to bring out discrepancies, differences and gaps in the arguments and procedures of the opposing parties. One such difference in the claims of both sides concerns the consumer acceptance and market penetration of the RPVS, as well as the alternative systems that were discussed. Major gaps appear in the arguments of both teams when questioned as to the assumptions, data and warrants behind their statements on market penetration. The third party has reviewed the transcript and reconstructed the key arguments concerning the consumer acceptance issue. In this section the arguments advanced by the Blue Team are summarized and analyzed. The Red Team's position is displayed as rebuttals.

Blue Team

Claims:

1. Mobility of goods and people is of utmost importance to Americans.

2. RPVS system is the transportation system alternative that preserves the highest degree of mobility.

3. RPVS will achieve virtually 100% market penetration.

Assumptions:

1. If you do enough hardware development, and are reasonably certain of the cost of the system and the cost to the user; if the vehicle looks, drives, costs and smells like an automobile, consumers will identify the RPVS vehicle as an automobile and then you will be able to sell it as you would an automobile.

2. If you can demonstrate that a Roadway Powered Vehicle System is a benign technology that really gives consumers something that they haven't had before, or at least matches what have now, they could project virtually 100% market penetration. Certainly, a level of penetration at least as rapid as any other vehicle system can be assumed as a long range solution to the transportation problem, whereas other vehicle technologies are interim solutions.

As was pointed out in the debate, we cannot precisely predict what will transpire in the next several decades. But every forecaster and market researcher faces this situation and must do the best he or she can. An attempt needs to be made to fill in the information gaps regarding consumer acceptance and market penetration. At the very least, alternative scenarios should be postulated and penetration rates ascribed to them. At some point a judgment does need to be made.

Blue Team Claims

DATA ("Given that ....")

1. Features of RPVS vehicle that will lead consumers to purchase one:

   a) The vehicle is very simple.

   b) The vehicle only has one power system.

   c) Only casual monitoring is required by the driver - never have to go to a service station to get gas - never even have to plug it in if you don't want to - therefore, vehicle is very convenient.

   d) Improved safety, accident prevention and traffic flow will be realized with the automated RPVS.

   e) RPVS vehicles can run a range of design from extremely high performance through small economy vehicles.

   f) Energy will always be available - no gas lines - no fuel supply problems.

   g) RPVS vehicles provide user with full range of performance he expects from a vehicle - long range and high speeds on freeways for trips, economical operation and reasonable performance.

2. There exists a vigorous implementation plan which includes the following steps: pilot project, questionnaire, incentives to encourage expansion. Limited pilot projects will show consumer acceptance or rejection very quickly. Busways will demonstrate marketability of the RPVS.

3. It is irrational to have less than 100% of freeway traffic on inductively coupled lanes in the long run.

WARRANTS ("Since ....")

1. Virtually 100% of the potential customers will recognize these features and be compelled to purchase accordingly.

2. This implementation and technology diffusion plan will show consumer acceptance and lead to virtually 100% adoption.

3. People will not act irrationally.

BACKING ("Because ....")

1. People are perceptive and willing to adopt innovations which appear to offer improvements.

2. Theory of Technological Diffusion (Everett Rogers & Jerry Zaltman). In addition, the following plan could be implemented: When you have a highway segment that serves the commuting needs of some population group you could use a questionnaire to determine if people using this corridor would like to see the system expanded. Ask the users how satisfied they are with the vehicle and its performance and if they would like to see the system expanded. You would need to educate people to the various systems available before taking the survey. You could also use direct observation of lane usage.

3. Man is a rational animal.

REBUTTALS ("Unless ....")

(by Red Team)

1. Red Team believes that electric vehicles will only achieve 20% of the market share under the current RPVS plan and possibly reach a maximum of 50% share if, in fact, the RPVS adds significant benefits to electric vehicles.

2. Better market research is necessary to establish the claim to 100% market penetration. But, existing market research methods are inadequate to provide reliable data on this issue.

3. The proposed plan is risky because it is likely that the early electric vehicle technology will be made obsolete by breakthroughs in electro-chemical storage and other technical developments, thereby making battery-only operated vehicles more attractive.

SECTION III

EXTENDED ANALYSIS

A. TRANSPORTATION IMPACTS

There are four primary transport issues that are of significant concern in the consideration of inductive coupling technology for automotive application: availability, mobility, modal optimization, and modal utilization. Each of these issues, to be completely addressed, would require investigation well beyond the scope of this task. However, the collective effect of initial and intuitive research into each issue yields a significant concern about this particular application of inductive coupling technology, i.e., the RPV system (see also Part II, Section II.A). In addition to a discussion of these four issues, this section deals furthermore with some of the specific technical problems related to the installation and maintenance of the RPV system source in existing roadways (see also Part III, Section I.C).

1. Availability

Ignoring the requirement of concurrent massive commitment of public and private investment and assuming a complete limited access highway application, the questions remains: who will use it? There is no reason, at this point in time, to envision a significant expansion of limited access highways which, also at this point, appear to be the only feasible candidate for the RPV system. Therefore, an obvious first constraint to availability is the capacity of the limited access highway system. This constraint exists regardless of the means of vehicular propulsion; it is a function of the total street system, not just freeway density.

A prime motive behind the RPV system is to promote the electrification of the automobile fleet by extending the range of the EV. The availability of the EV is directly related to the need to recharge; therefore the RPV is still constrained (rendered unavailable) by the need to recharge. Battery only EVs can be designed to fulfill almost all commuter requirements right now, but cost and unavailability during recharge (8-12 h) are still significant impediments to their public acceptance. The RPV system mitigates neither of these concerns.

2. Mobility

Contemporary urban travel patterns have been dominated by the automobile because of its unparalleled personal mobility. Freeway systems have emphasized this mobility aspect. The automobile infrastructure, based upon a ready supply of liquid fuel, has permitted a sense of unlimited range. No urban area on Earth is so dominated by the automobile mode as Los Angeles. The freeway system there forms a grid such that the RPV would have access to at least 75% of the Los Angeles area (Figure 2-7).

Before one assumes that the RPVs could provide the necessary mobility for a substantial portion of the urban trip makers in the Los Angeles area, certain facts must be reviewed. There are 24.2 million trips taken on an average work day in the Los Angeles urban area. Of those, 7.4 million are work trips and 16.7 are nonwork trips. Only 37% (2.7 million) of the work trip and 26% (4.3 million) of the nonwork trip occur on freeways. The combined total of less than 30% of all trips in the Los Angeles area use freeways. All of these figures are considerably lower in all other urban areas.

Vehicular fuel has played a significant role in automotive development. It is no accident that the internal combustion engine, complicated as it is, won the contest over the electric at the beginning of this century. The use of storable liquid fuel yielding range and speed were telling factors, and they still are despite intermittent shortages that have and will occur. The RPV system concept contains, implicitly, the direct and immediate control of the power source (fuel) by government or quasi-governmental agencies. The direct control of fuel (propulsion power) and the constraint upon vehicular operation to certain routes are attributes more closely associated with a fixed guideway transit operation. They are certainly severe mobility constraints to the contemporary perception of the private automobile.

3. Modal Optimization

The optimization of a particular transport mode implies encouragement of its intrinsic strengths (e.g., mobility) and the discouraging of its weaker applications (e.g., inefficient peak travel period capacity). The RPV system concept negatively affects the mobility aspect of the automobile by confining its movements to routes with a powered roadbed (freeways). Alternative access routes that are not roadway powered are not available and this aspect promotes system failure should an accident or other incident preclude a roadway powered route from being used. As an example: a freeway carrying 10,000 vehicles per hour during peak movement is blocked by an accident. No interchange could handle this exit volume and no surface street could support the volume; therefore the vehicles can not simply get off at the interchange before the accident and get on at the next interchange after the accident. They will have to be dispersed throughout the system on alternate routes. There exist many other incidents that could preclude the use of a particular freeway

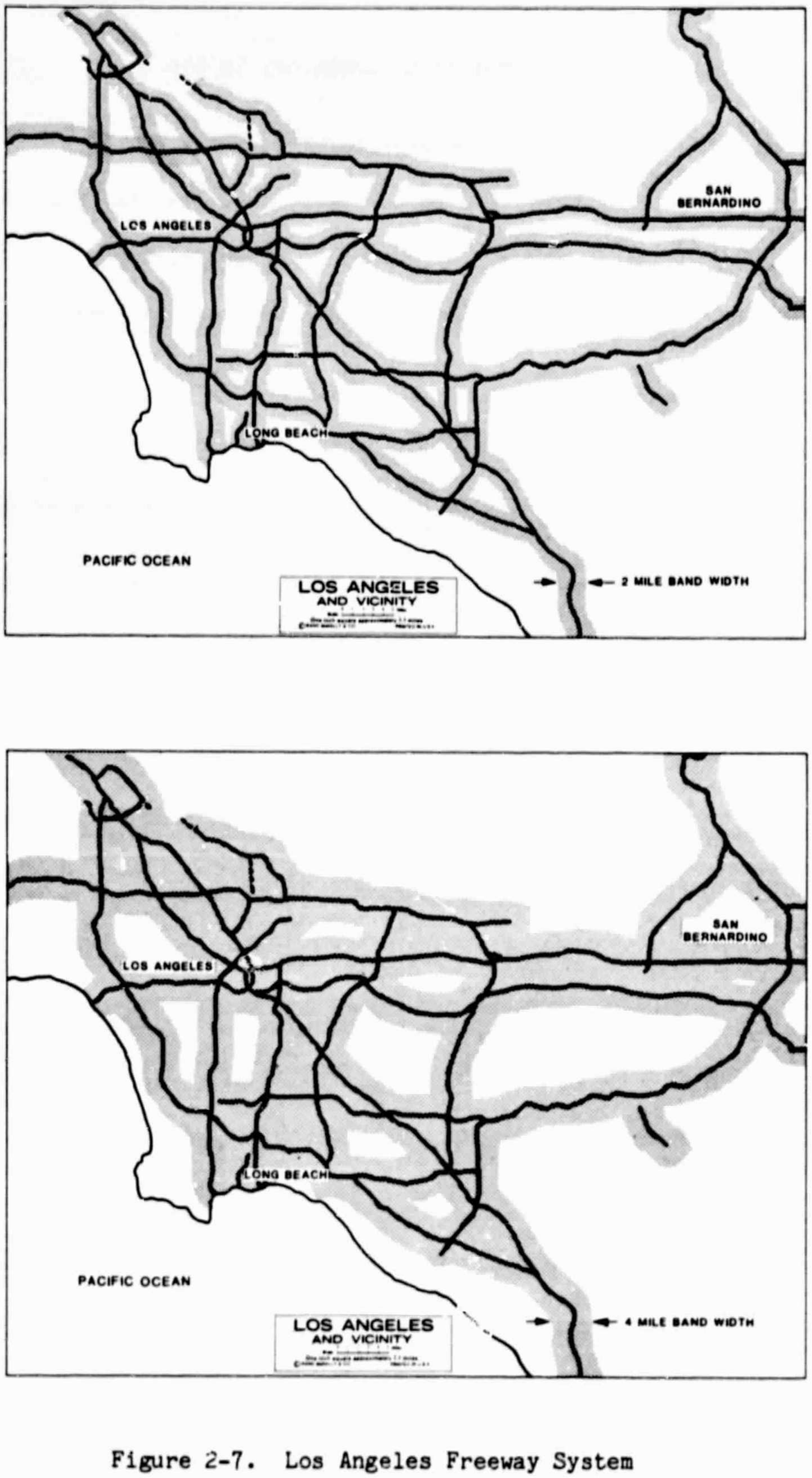


Figure 2-7. Los Angeles Freeway System

link (e.g., electrical failure). The ability to equalize traffic movement and utilize alternate routes is mandatory in the automobile/highway system in every urban area.

While the potential to automate vehicle/highway interface is enhanced by the RPV system concept, the potential automation of non-RPV system highway systems is just as real. The point is, that the realizable benefits or implementability or legal ramifications of an automated highway is relatively unexplored. An optimistic assumption of doubling throughput still leaves the freeway capacity far short of any transit option. In addition, doubling the freeway volume carrying capability would mandate similar improvements to on-ramps, off-ramps and the entire peripheral nonfreeway road system.

4. Modal Utilization

As the density in an urban area increases, so does the utility of mass transit. Likewise, dense corridor development also encourages mass transit. This applies particularly to work trips. The urbanization process has actually developed in the reverse manner with transport availability dictating density. The latest density dictator, in the manifestation of the automobile, has resulted in contemporary urban sprawl. As with all transport modes, the automobile-based society experiences peak congestion during the work trips in the morning and the afternoon. The main attributes of the automobile are mobility and the ability to carry people (e.g., a family) for basically a single fixed cost. As a work trip mode, it is less efficient than any of the mass transit modes on a people carrying basis. The automobile also requires double storage space when used for work trips. The RPV system concept would perpetuate and promote the automobile in the work trip role at the expense of more efficient transport options that could be the recipient of public funding.

An analysis of one mode of transport cannot be meaningful without considering the synergistic effect with other transport modes. Indeed, transportation cannot be dealt with apart from the total urban process. Clearly, the four elements addressed here appear to mitigate against an application of the RPV system concept to the automobile/freeway syndrome. They are, however, only transport issues. Should the concept be pursued further, a more important issue is the relationship between this mode and the total urban process.

5. Roadway Installation

A key question regarding the technical feasibility issue of installation of the RPV system source in an existing highway system is: how can the slot which accommodates the source conductor and windings be cut in existing roadway surfaces? JPL has conducted telephone interviews on this subject with several organizations involved in different phases of highway maintenance: companies which perform roadway removal and resurfacing, the company which leases the roadway planer referenced by the Blue Team during the debate, the company which designed and built that machine, and the California Department of Transportation. Much of the investigation occurred after the debate.

The proposed minimum-cost strategy of placing the slot in roadways only at the time that the roadways are rehabilitated is not feasible. Large-scale rehabilitation of long lengths of highways is seldom done. Rehabilitation is normally done in small segments, where and when it is required. The probability of this event occurring at the time and location at which RPV system source emplacement is desired is extremely low. Therefore, only the cutting of the slot in existing roadway surfaces was investigated. In all interviews, cutting a slot of 7.5 cm by 60 cm cross-section was the task discussed.

Installation of the source in asphalt or in asphaltic concrete is probably contraindicted by their malleability and high creep index. However, if it were desired to install the source in either of these materials, cutting the slot would be a straightforward application of existing techniques. Roadway planers such as those referenced by the Blue Team (the CMI PR-575 Roto Mill) can easily remove the top 7.5 cm of either surface material in one pass, and a special-order cutter assembly of the proper width (60 cm) can readily be made. Two American companies are the principal suppliers of these machines: CMI Corporation and Barber-Green.

Cutting the slot in Portland cement concrete (a much harder material which is prevalent in the Interstate Highway System) and other limited-access highways is much more difficult. The rest of this discussion pertains to this problem.

Three general methods of cutting the slot were advocated:

(1) Modify a machine similar to the referenced roadway planer so that it could cut the slot directly to the required dimensions.

(2) Use hand-guided carbide-blade saws and pavement breakers to cut the slot directly as required.

(3) Use hand-guided saws and pavement breakers to remove a strip of pavement of the desired width but to the full depth of the concrete (i.e., remove all pavement within the strip down to the next layer); and then refill with new concrete to the desired lower height of the slot bottom.

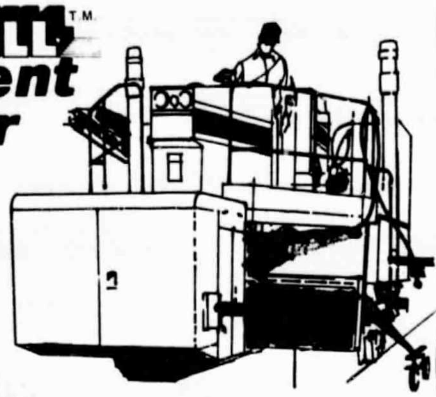
Of the three possible methods, the second is the least technically feasible. Removal of part of a layer of concrete with impact tools entails high risk of cracking the remaining concrete. The structural integrity of the highway would be unacceptably weakened.

The third method does no such structural damage, and hence is more practical. It is also the only method capable of creating a slot with smooth sides and bottom (smoothness better than plus or minus 2 mm), and it provides the opportunity to place in the wet bottom concrete vertical tie-down bolts for the secure fastening of the RPV system source. (Since detailed engineering of the source and its installation has yet to be done, these advantages are not known to be needed, but they would certainly lessen the constraints upon that engineering task.) This method is also the only one of the three which can be used on steel-reinforced concrete (a material which was used on some existing highways). Its drawbacks are the extra time and expense of the pouring of new concrete, and the debatable structural integrity of the resulting roadway surface. That structural integrity is believed to be adequate (at least in lanes carrying no truck traffic), but analysis would be required to assure this adequacy (particularly in trucking lanes).

Because of the difficulties with the other two methods, the first method will be the best method, provided that a modified planer would be capable of performing the task and that the resultant slot is within the tolerances necessary (which, as just mentioned, are not yet precisely defined). The CMI Corporation, which is reputed to be the innovator and leader in this field, states that its planers are certainly capable of performing the task (except in reinforced concrete). (The planers made by the other major manufacturer of roadway planers, Barber-Green, are reportedly not capable of planing Portland Cement concrete.) The company makes a series of planers (officially designated planer-reprofilers, the PR-xxx series of machines) of varying horsepower and cutter width, all of which are capable of planing Portland cement concrete as well as asphaltic concrete. Although 60 cm is not a standard cutter width, it could be readily custom-fitted to a standard machine. The model PR-375 Roto-Mill (Figure 2-8) or the smaller PR-225 Roto-Mill could be used.

These machines all have approximately the same cut-depth capability. Although they can cut well over 7.5 cm in a single pass on asphaltic materials, their preferred single-pass limit on Portland cement concrete is 2.5 cm with almost 4 cm being a possible alternate single-pass limit. Thus the machines can accomplish the 7.5 cm cut in at the most three passes. The surface smoothness tolerance will be plus or minus 3 mm at the very best, and plus or minus 6 mm normally, plus any holes left by dislodged aggregate. The future detailed engineering of the RPV system source can probably be successfully accomplished using this surface smoothness.

PR-375 ROTO-MILL™ pavement profiler



PR-375

- •PAVEMENT PROFILING
- •PAVEMENT REMOVAL
- •SURFACE TEXTURING
- •HYDROPLANE TEXTURING
- •SCARIFICATION
- •IN-PLACE REBUILDING
- •PAVEMENT RECYCLING

SPECIFICATIONS

ENGINE
Caterpillar
Horsepower. . .375 (380.25 Metric) at 2,100 RPM
Cycle. . .4
Number of cylinders. . .6
Electrical system. . .24 volt
Starting method. . .electrical

WEIGHT
(Approximate). . .65,000 lbs. (29, 483.50 kg)

DIMENSIONS
Length. . .51'2" (15.60 M)
without conveyor. . .
Width. . .10'6" (3.20 M)
Height. . .10'6¾" (3.21 M)
(cab and beacon removed)

ROTARY CUTTER ASSEMBLY
(Bolted to main frame, removable)
Length. . .9'3" (2.82 M)
Diameter. . .28" (.711m) Bolt-on Flighting
Hydrostatic Drive

CUTTER BITS
Number of bits. . .178
Tungsten carbide tip
Forged steel holders

MOLDBOARD (FLOATING)
Length. . .9'2" (2.79 M)
Hydraulic down pressure for cleanup

SPEEDS
Working range. . .0-70 FPM (0-21.34 MPM)
Forward and reverse. . .0-200 FPM (60.96 MPM)

TRANSMISSION
Hydrostatic

HYDROSTATIC DRIVES
Axial piston variable displacement pumps driven by engine through a four output drive gearbox.

CRAWLER TRACK ASSEMBLIES
Three (3) hydrostatically powered
Width. . .16" (40.64 CM)
Length. . .8'8" (2.64 M)

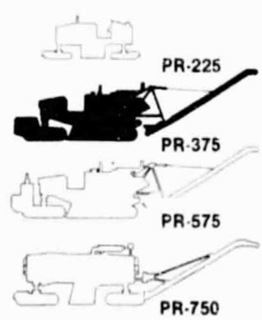


Figure 2-8. A Typical Roadway Plane

In summary, there are at least two technologically feasible methods currently available to cut a suitable slot for the RPV system source in both asphaltic concrete and Portland cement concrete. The preferred method is the use of automated roadway planing machines. Although the cost estimates obtained for the different methods vary widely in both magnitude and comprehensiveness of cost items considered, they are in the general range which will not seriously influence the total package cost of installation of an RPV system.

6. Roadway Maintenance (Winter-Zone Considerations)

In the sun belt, weathering of the roadway surface and the RPV system source is not believed to be a problem. The benign environment there does not seriously degrade the roadway, and appropriate choice of exposed construction materials for the source can probably make it equally hardy.

The freeze-thaw cycle in the winter zone, on the other hand, poses a significant threat to the longevity of both the standard roadway surface and the RPV system source. It also indirectly impacts vehicle design requirements.

The freeze-thaw cycle found in the winter zone of this country is seriously deteriorating our highways /12/ /13/. This harsh environment would also damage the RPV system source in the roadway surface. It is not possible to know now what the deterioration rate of the source will be in this environment: it may degrade faster than the concrete surface, or slower, or at the same rate. This must be a primary design consideration when engineering the source, if placement in the winter zone is envisioned.

The highway chuckholes themselves pose a design problem to the RPV system vehicles. Whenever any automobile drives through a medium- or large-sized chuckhole, its frame briefly drops at least 5 cm. The pickup on an RPV system vehicle will strike the ground during this event. The vehicle and its pickup (and the source itself) must be hardy enough to withstand this abuse without sustaining damage.

The proposal has been made to de-ice the RPV system freeways in freezing conditions by electrical resistance heating of the source. This is not practical. In addition to such problems as the creation of glare ice due to the refreezing of melted runoff water, the power required to do such heating is prohibitively large.

The approximate power required to maintain the concrete roadway surface at an elevated temperature on a cold day was calculated for the following sunless but conservative (i.e., optimistic) winter conditions: $10^{o}F$ ambient air temperature, no wind (minimum convective cooling), no water or ice present (no evaporative cooling or melting), pavement uniformly maintained at 35°F (just above freezing), and differing cloud-cover conditions. The power required to raise the pavement temperature to this value from ambient was not considered. The power required to merely maintain this elevated temperature varied with cloud cover from a minimum of 700 kW per lane mile (for full cloud cover) to a maximum of 1300 kW per lane mile (for clear sky with more radiative cooling). With RPVs using 20 kW propulsive power per vehicle, these heating power levels are equivalent to powering 35 and 65 veh/lane-mi, respectively. Since 10 to 20 veh/lane-mi are typical actual values experienced during heavy traffic flow, it can be seen that the proposed heating energy would generally be more than the propulsive energy drawn, and that the system efficiency during heating would be less than half its nonheated value. Such a power requirement makes the proposal untenable.

B. DETERMINANTS OF ECONOMIC VIABILITY

This section examines the economic efficiency of the RPV system as a petroleum displacing technology. Since the economic attractiveness of this system is a function of who is assumed to be the beneficiary of the system and who is assumed to pay for the system, two different assumption sets are examined:

(1) The benefit is assumed to be private in terms of reduced over the road costs to drivers on the system and costs are assumed to be paid completely by the users.

(2) The benefit is assumed to be public in terms of petroleum consumption reduction, and user costs above conventional vehicle costs are assumed to be subsidized from general revenues.

In the first case, the ratio of system costs to gasoline cost savings is the figure of merit, in the second case, the ratio of cost of the subsidy to the petroleum cost savings is the figure of merit. It should not be inferred that these figures of merit are verifiable or refutable numbers, rather they are determined by a set of assumptions on the nature of future conditions. Since they are determined by the assumptions made, the position on the assumptions is presented for both the advocates and the skeptics.

1. Value of Conservation

Any petroleum displacing or conserving system including the RPV system can cost more than the market value of the petroleum it is displacing and still be justified. Apart from the private cost incurred in purchasing petroleum there is an additional public cost above the market cost suffered by the nation as a whole. Contributing to this social cost are:

(1) The implication to national security from dependence on imported petroleum.

(2) The risk cost of potential disruption of supply and/or arbitrary price increase.

(3) The compounding of such risk by increasing the possibility of occurrence by increasing the effectiveness of disruption from increased reliance on import sources.

(4) Regressive impacts of inflation resulting from higher import prices.

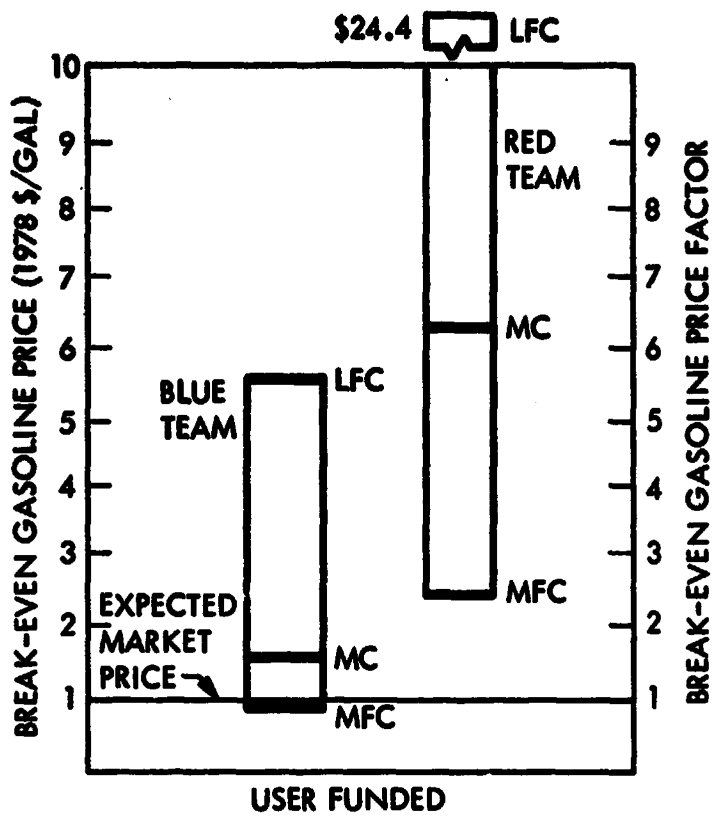
(5) Impairment of overall economic efficiency from inventory changes in expectation of higher rates of inflation.

Albeit determined by assumption, the cost of conserving can be quantified for this technology. However, a statement on the absolute (not relative) economic attractiveness of this, or any other conservation technology, cannot be made until there is a quantified estimate of the present worth of future petroleum conservation (i.e., a quantification of the above factors).

2. Costs of Conservation via RPV

Figures 2-9 and 2-10 present the break-even gasoline price factor, denoted as BEGF for brevity in the text, for the RPV system. This factor expresses how much more these fuels would have to cost above their assumed expected cost for the RPV system to be a cost-effective conservation alternative. Alternatively, if this technology <u>is</u> a cost-effective conservation alternative, it implies that the social and external cost of petroleum consumption is equal to or greater than $(1 - \beta)$ times the assumed expected price of the fuel. The meaning of Figures 2-9 and 2-10 can be clarified with the following explanations.

a. <u>Break-Even Gasoline Price Factor (BEPF)</u>. For each funding alternative, the net present benefit of the system was assumed to be the difference between the total benefits minus the total cost. The "first order" oil (or gasoline) price dependency was then explicated as the parameter (i.e., how the benefits and the cost and therefore the net benefit changed with a scaling factor on the assumed price of the fuel). Next, the net benefit was set equal to zero, that is, benefits were assumed to be equal to costs, and the equation was then solved for the value of the scaling factor. A more thorough explanation for each of the funding alternatives may be found following the figures and the methodological details supporting this can be found in Part III, Section II.

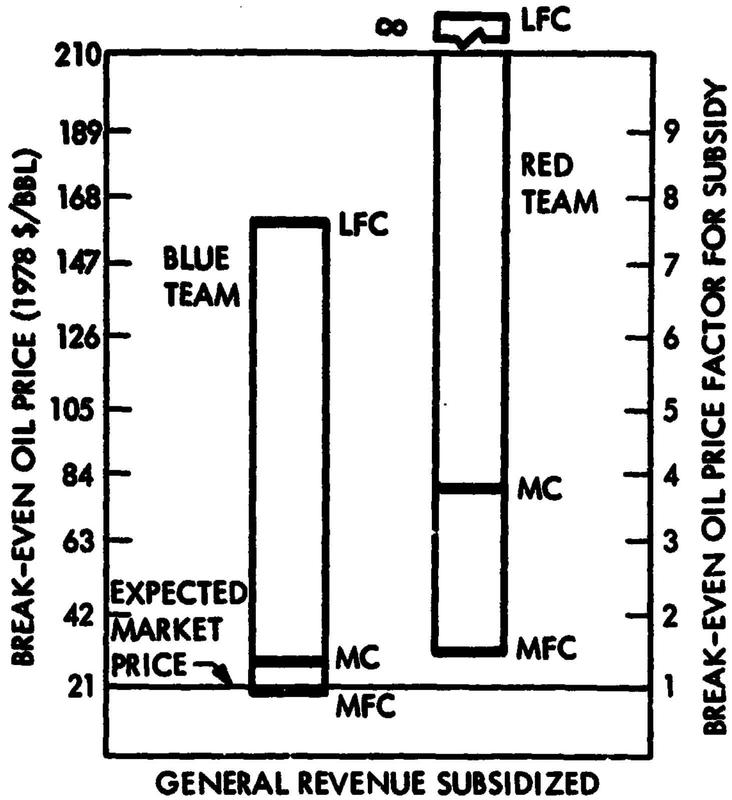


LFC - Least favorable yet credible assumption set
MC - Most credible assumption set
MFC - Most favorable yet credible assumption set
Red - Skeptics
Blue - Advocates

Figure 2-9. Break-Even Gasoline Price for User-Funded System

b. Red and Blue Teams. The two teams independently prepared sets of assumptions which are the input to the present value model. The Red Team had a skeptical bias while the Blue Team was advocate-biased.

MFC, MC, LFC. Each team developed three assumption sets. Credibility was defined subjectively and internally to each team (e.g., what was credible to the advocates would not necessarily be credible to the skeptics). These "bounding" assumption sets are defined as:



LFC - Least favorable yet credible assumption set
MC - Most credible assumption set
MFC - Most favorable yet credible assumption set
Red - Skeptics
Blue - Advocates

Figure 2-10. Break-Even Oil Price for General Revenue-Subsidized System

LFC - The least favorable set of assumptions for the RPV system which still possess credibility.

MC - The most credible set of assumptions.

MFC - The most favorable set of assumptions for the RPV system which still possess credibility.

<u>Example 1 (see Figure 2-9)</u>. The skeptics' most favorable and still credible set of assumptions implies that if a permanent 140% tax

on the retail price was added to gasoline, the RPV would be economically competitive with the conventional vehicle system.

Example 2 (see Figure 2-10). The advocates' most credible set of assumptions implies that the RPV is currently cost-effective at current market price of oil with government subsidization to user costs.

Table 2-3 presents the principal items in the assumption sets for both the advocates' and the skeptics' position on the RPV system technology.

The main factors causing the divergence between Blue and Red are the final fraction of RPVs on the RPV system lane, and the percent petroleum going into electrical utilities. Figure 2-11 presents the sensitivity of the BEPF of each side to the assumption of final factor fraction of RPV system.

Explanation of Measures of System Energy Conservation Economics

(1) If the users of the system were to fully pay for the system costs,

then

the users would be economically indifferent between paying for the system and buying gasoline for a conventional vehicle

when

the difference in present value at the private rate of discount between the system and the gasoline is zero as shown in Equation (2-1)

$$\Delta PV = PPVSYS - PPVGAS \tag{2-1}$$

where PPVSYS = present value of use charges for the system.

Explicating the first order gasoline price dependence yields Equation (2-2)

$$\Delta PV(\beta) = PPVSYS - \beta * PPVGAS = 0 \tag{2-2}$$

where PPVGAS = private present value of gasoline cost avoided

or Equation (2-3)

$$\beta = \frac{PPVSYS}{PPVGAS} \tag{2-3}$$

Table 2-3. Principal Assumptions of the Economic Analysis

	Advocates' Blue Team			Skeptics' Red Team		
	MFC	MC	LFC	MFC	MC	LFC
Real expected rate of escalation--construction, %	1.3	2.5	2.5	2	3	4
Real expected rate of escalation--electricity, %	0	2.0	4.2	3	4.2	6.0
Real expected rate of escalation--labor, %	1.3	1.3	1.3	1.3	1.3	1.3
Real expected rate of escalation--gasoline, %	11	9	6	14	11	9
Real expected rate of escalation--oil, %	9	7	4	10	8	6
System lifetime, yr	35	35	35	35	35	35
Rate of discount--public, %	10	10	2	10	10	10
Rate of discount--private, %	2	2	2	2	2	2
Road work, k$/lane-mi	15	30	100	15	30	100
Road coil, k$/lane-mi	275	275	275	171	200	250
Power conditioning, k$/lane-mi	250	250	250	138	200	200
Maintenance, k$/lane-mi-yr	15	15	15	15	15	15
Electricity, $/kWh	0.03	0.045	0.07	0.03	0.045	0.07
Gasoline, $/gal	1.0	1.0	1.0	1.0	1.0	1.0
Oil, $/bbl	21	21	21	21	21	21
Road coil lifetime, yr	25	20	15	15	15	15
Final fraction of vehicles inductively coupled	1.0	1.0	0.3	0.3	0.2	0.1
Power plant thermal efficiency, %	0.36	0.33	0.25	0.33	0.33	0.25
System efficiency, veh mi/kWh	4	3	2	4	3	2
Baseline, mi/gal, 1985	18.1	18.1	18.1	25.5	25.5	27.5
Refinery petro fraction, 1985	1.0	1.0	1.0	1.0	1.0	1.0
Utilities petro fraction, 1985	0	0	0.35	0.05	0.40	0.80
Baseline, mi/gal, 1995	24.0	24.0	24.0	31.0	31.0	33.0
Refinery petro fraction, 1995	0.96	0.93	0.90	1.0	0.90	0.90
Utilities petro fraction, 1995	0	0	0.30	0.05	0.25	0.60
Baseline, mi/gal, 2005	26.0	26.0	26.0	31.0	31.0	33.0
Refinery petro fraction, 2005	0.95	0.85	0.75	0.85	0.65	0.60
Utilities petro fraction, 2005	0	0	0.25	0.05	0.15	0.50

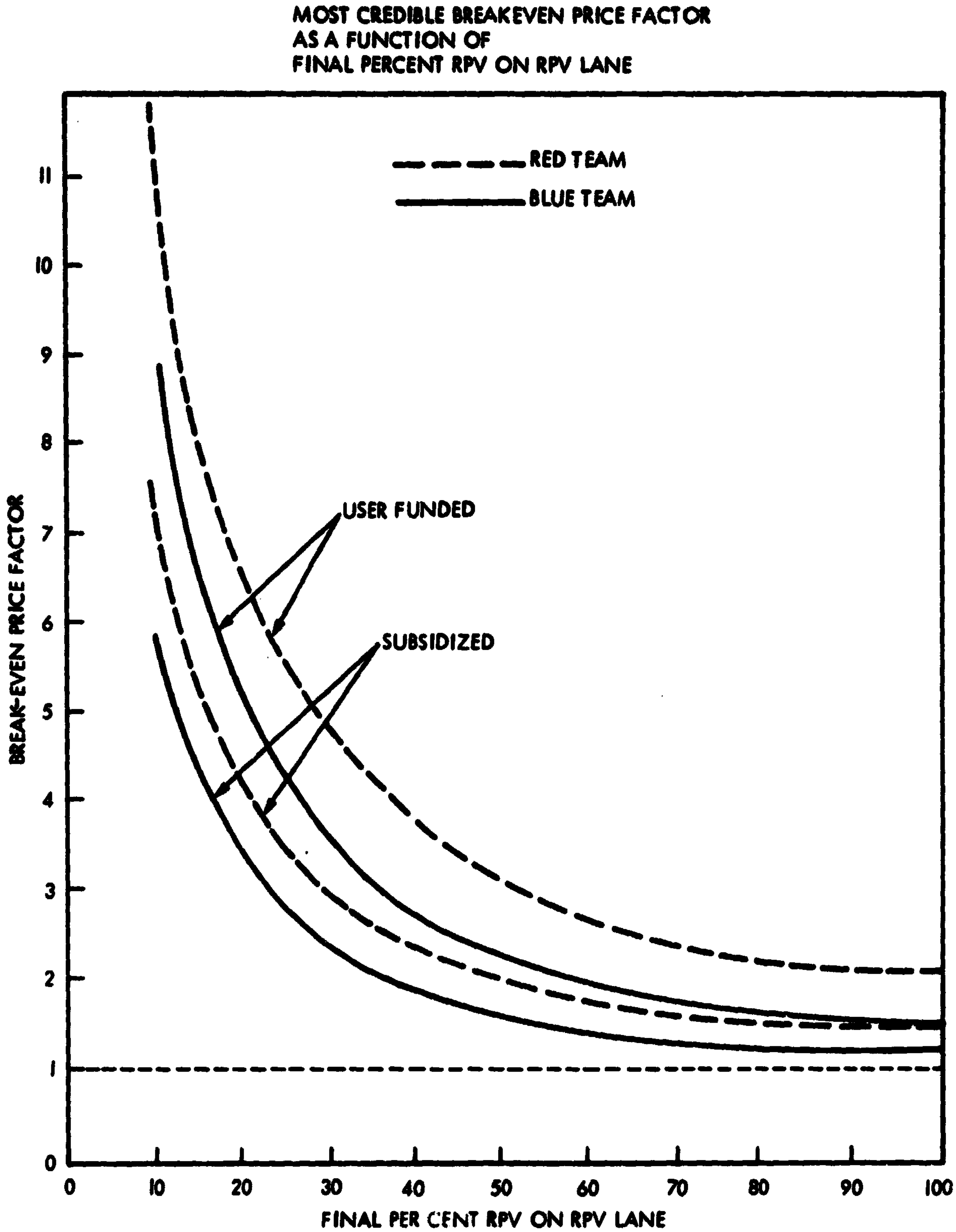


Figure 2-11. The Effect of RPV system Utilization on Break-Even Fuel Price Factors

hence gasoline must cost β times that assumed for the system to be attractive to the user.

(2) If the costs of the system are shared between general revenues and users by the government providing a subsidy to compensate the users for costs above that which they would have experienced with conventional vehicles,

then

the expenditures of general revenue funds for such a subsidy would be justified

when

the net present value of the stream of subsidy payments discounted at the public rate of discount is zero as shown in Equation (2-4).

$$\Delta PV = PVSUB \qquad (2\text{-}4)$$

where PVSUB = present value of subsidies

or Equation (2-5)

$$PVSUB = TPV - PVGAS \qquad (2\text{-}5)$$

and PVGAS = present value of gasoline expenditures avoided (at public rate of discount)

Explicating the first order oil price dependence yields Equation (2-6)

$$\Delta PV = (TPV - PVOILU + \beta * PVOILU) - (PVGAS - PVOILS + \beta * PVOILS) \qquad (2\text{-}6)$$

$$\Delta PV = PVSUB + \Delta PVOIL - \beta * \Delta PVOIL$$

$$\Delta PVOIL = PVOILS - PVOILU$$

or Equation (2-7)

$$\beta = \frac{PVSUB + \Delta PVOIL}{\Delta PVOIL} \qquad (2\text{-}7)$$

Hence, oil must cost at least β times that assumed for such expenditures to be justified. (or the social/external cost of oil consumption must be at least $(\beta - 1)$ times the assumed market price.)

C. PETROLEUM DISPLACEMENT

The analysis concerning the amount of petroleum displaced by an RPV system must take into account both the petroleum saved by not using ICE vehicles, and the petroleum used by the electric utilities to meet the added load of the RPV system. To study the petroleum requirements of the utilities, three basic data elements are required:

(1) The load profile of the RPV system.

(2) The load profile of the electric utility without the RPV system.

(3) The generation mix of the electric utility.

The analysis presented here assumes that an hourly breakdown of weekly traffic and utility load data would be adequate. The traffic data assumes an RPV system roadway network similar to the Los Angeles freeway system, and travel patterns typical of freeway driving in general. Two sets of utility load profile data is furthermore assumed to exemplify both an afternoon and a morning peaking system. Four sets of generation mix data were finally assumed, reflecting the nationwide variance in utility capacity mix (from petroleum to coal and hydro dominated systems).

1. RPV System Load Profile

The Los Angeles area was chosen as a base case with respect to total lane miles and traffic volume (LARTS region, Figure 2-12). The average daily vehicle miles traveled (ADT) in the LARTS region is approximately 200 million miles. The ADT on the freeway system alone is approximately 75 million miles, involving about 7400 freeway lane miles (1977 data from Caltrans, Los Angeles).

The assumed variance in traffic volume (and hence utility load) throughout a typical week is shown in Figure 2-13, together with three other cases:

(1) Santa Monica Freeway (Caltrans data).

(2) Calumet Freeway (/9/ p. 32).

(3) Los Angeles Freeways (/1/ p. 106).

In urban traffic situations, the weekday ADT is just above the weekly average, peaking on Fridays (due to weekend travel), and dropping again on Saturday. Sunday is typically well below the weekly average (Figure 2-14, /8/ p. 81). While the traffic peaks occur in the early morning and late afternoon on weekdays, there are no distinct peaks on weekends except for the early evening traffic on Sundays (/8/ p. 77).

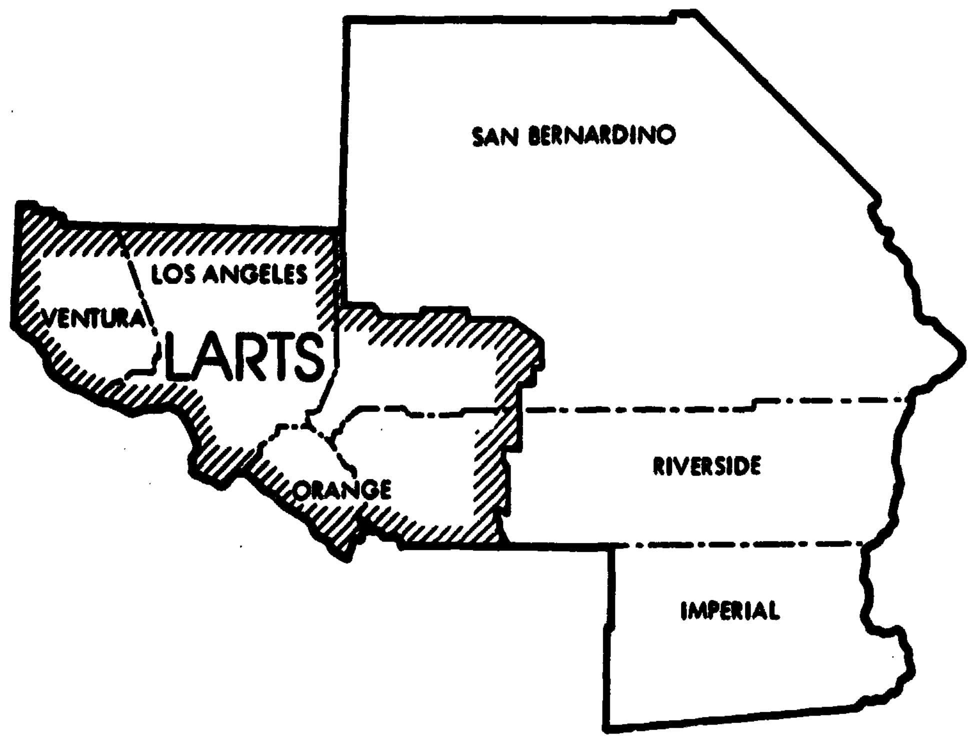


Figure 2-12. The Base Case Area (Los Angeles)

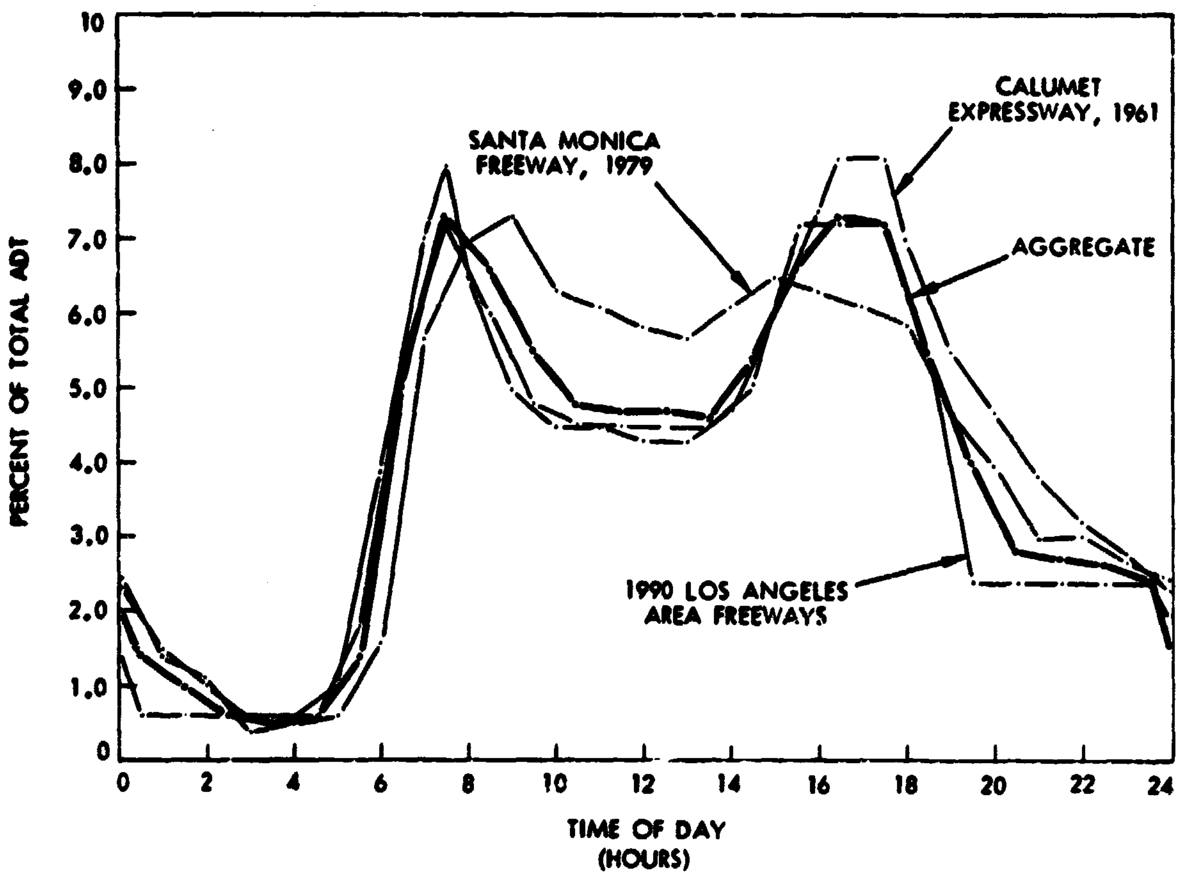


Figure 2-13. Daily Traffic Volume

Adjusted for the above mentioned general characteristics of urban driving throughout a week, the hourly traffic volume has been estimated for a full week as shown in Figure 2-15. The MW load scale on the right represents the Los Angeles base case, assuming: (1) 75 million vehicle miles per day; (2) 7400 lane miles; (3) 0.5 kWh/vehicle mile; and (4) 19.1 kW/lane mile in constant losses.

2. Utility Load Profile

The utility load profiles assumed in this analysis are based on data provided by the Electric Power Research Institute (EPRI) /19/. This data was developed in an attempt to provide a systematic method of assessing alternative new technologies or new developments on utlity systems throughout the country. Six synthetic utilities, identified as Systems A through F, are defined in terms of load, generating mix and capacity, and distribution systems. Hourly load data in terms of percent of peak is given for a summer week, a winter week, and a spring/fall week for each synthetic utility. The two utility load profile cases presented here use the summer week data of scenario A (Case A) and the spring/fall week data of scenario E (Case E). The first one was chosen since it was also characteristic for the Los Angeles area. Table 2-4 gives the daily peak hours (weekday) for each scenario.

Table 2-4. Peak Hour for Each Synthetic Utility Scenario

	Spring/Fall	Summer	Winter
Scenario A	11 a.m.	4 p.m.	6 p.m.
Scenario B	8 p.m.[a]	1 to 6 p.m.[b]	6 p.m.[a]
Scenario C	8 a.m.	12 a.m.	5 p.m.
Scenario D	11 a.m.[c]	3 p.m.	6 p.m.
Scenario E	10 a.m.	4 p.m.	6 p.m.[a]
Scenario F	12 a.m.	12 a.m.	6 p.m.

[a]Additional morning peaks. [b]Additional evening peaks.
[c]Additional afternoon peaks.

Figure 2-16 shows the two original utility load profiles (Cases A and E) as specified in /19/. Once the percent of load data was chosen, the magnitude of the utility system needed to be fixed. Since

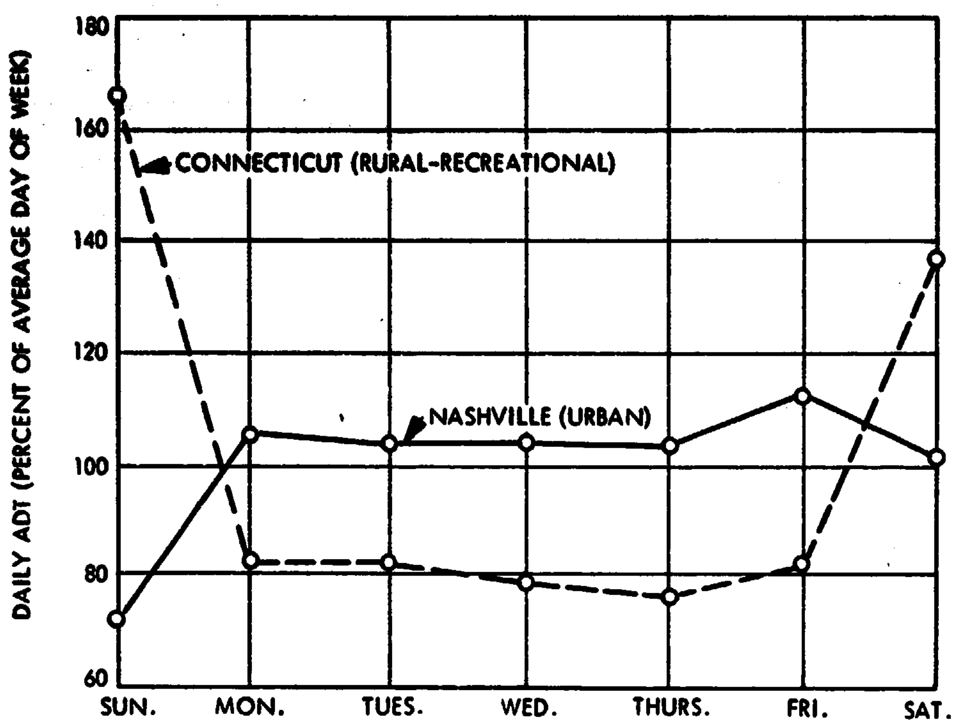


Figure 2-14. Weekly Traffic Volume

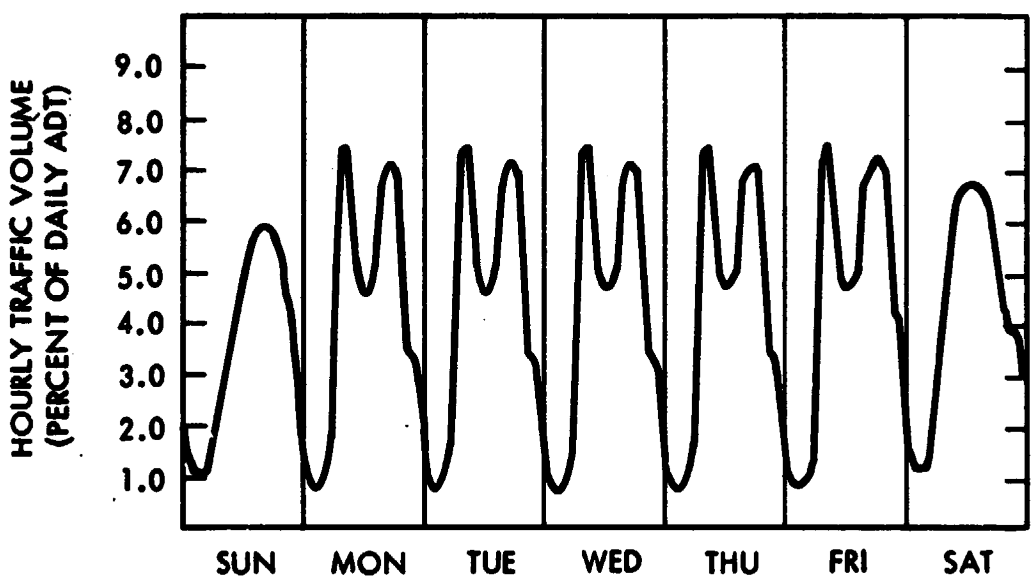
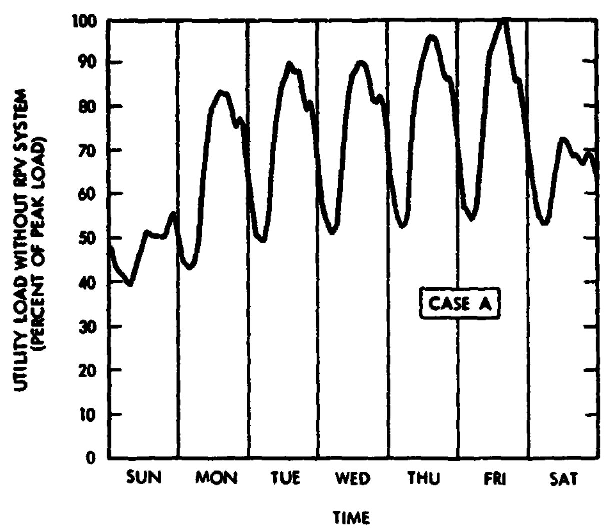


Figure 2-15. Weekly RPV Systems Load Profile

the traffic load data is related to the Los Angeles Basin, the utility load of that area was approximated by adding the capacities of the smaller municipal generating system to that of Southern California Edison. This was estimated to give a peak load of roughly 20,000 MW. With this data, the traffic load requirements by hour could be translated to percent of peak data to be added to the utility percent of peak data. The 100% base was left at the original peak figure of 20,000 MW.

Each of the hourly load curves (Figures 2-15 and 2-16) can now be translated into a load duration curve with the simplifying assumption that the "typical" week could be expanded to represent a "typical" year, i.e., that the week's data could translate to data, representing 100% of the time. Figure 2-17 shows the two load duration curves, and Figure 2-18 illustrates the magnitude of the gap between them.



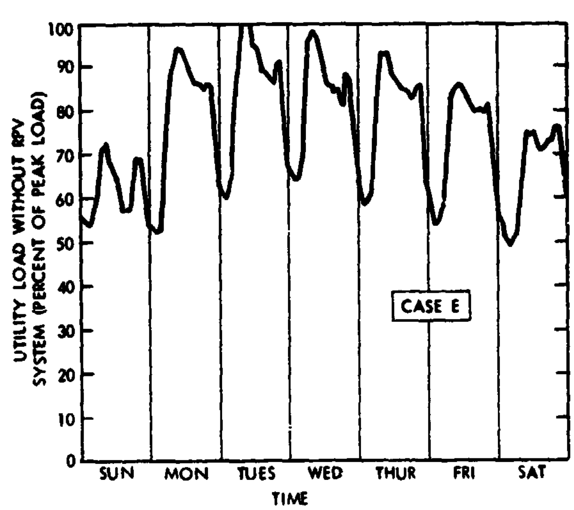


Figure 2-16. Weekly Utility Load Profiles Without the RPV System (Cases A and E)

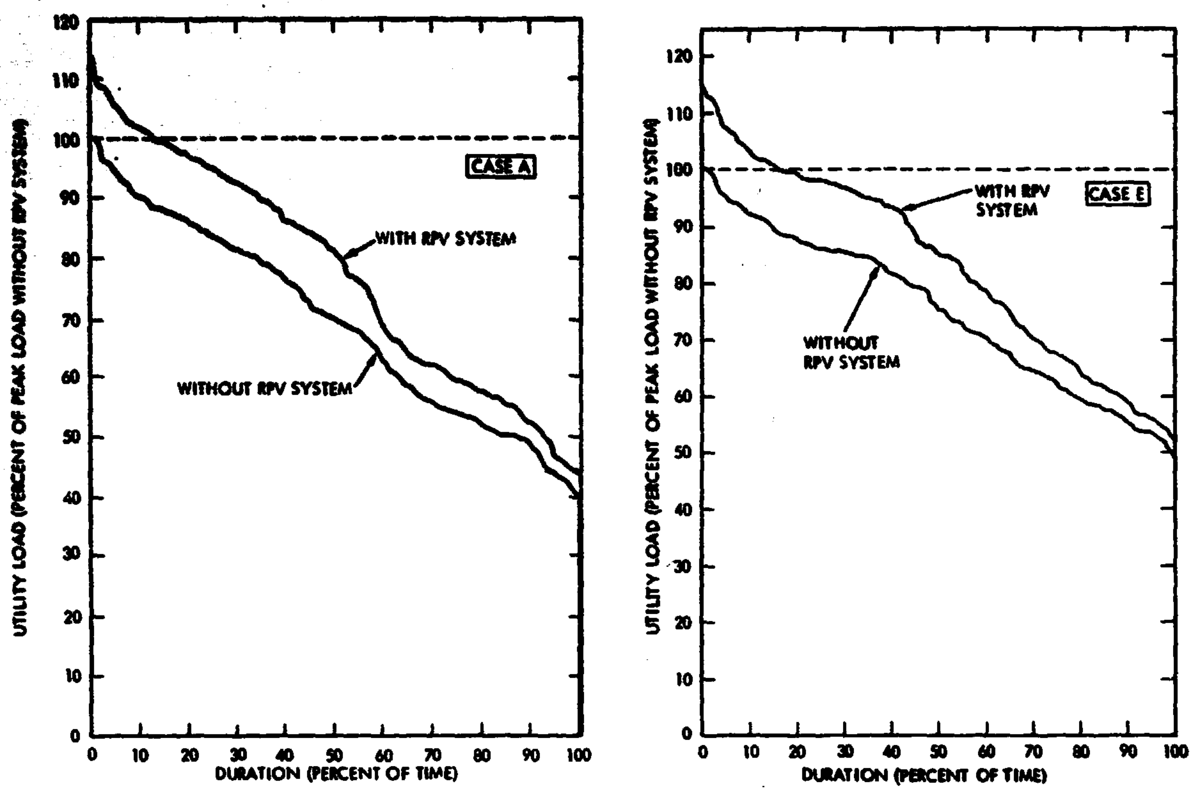


Figure 2-17. Utility Load Duration Curves (Cases A and E)

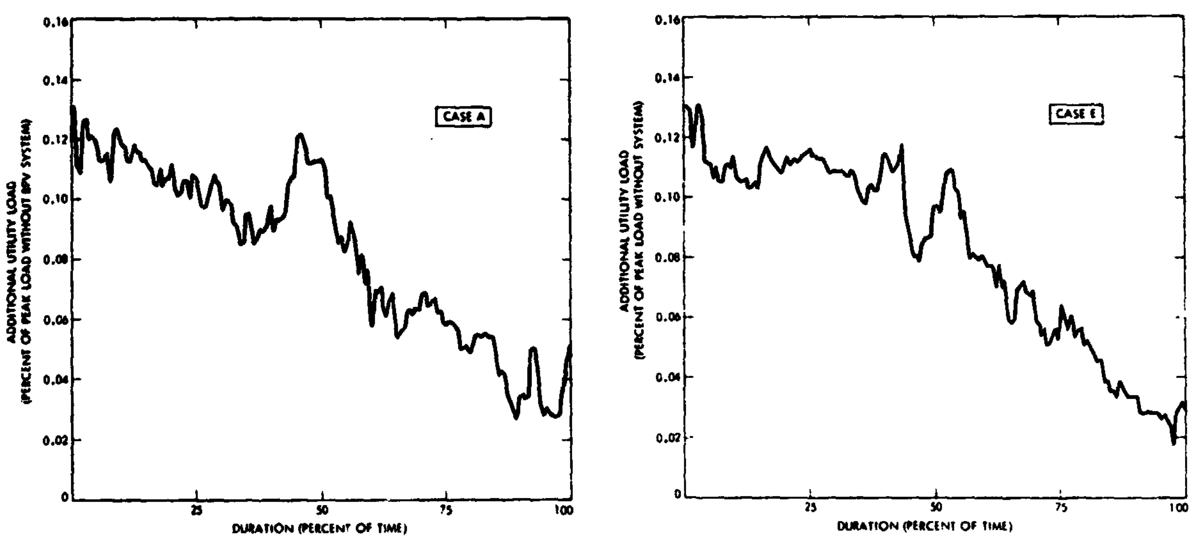


Figure 2-18. Changes in the Load Duration Curves (Cases A and E)

3. Generation Mix

The load duration curves can be used to show what percent of the time a utility will operate its base, intermediate, and peaking plants, given the generation mix of the utility. Implicit in the analysis is the assumption that a given utility has developed its generation mix based on an economic analysis of operating costs, so that economics dictate that a given type of plant will not operate for a longer period of time than it currently does. Also implicit in the analysis is the assumption that the availability of supply depends only upon the magnitude of the load and not on the time at which the load occurs.

Given the load duration curves (Figure 2-18), various generation mixes can be analyzed to study the impact of the RPV system on the utility. The synthetic utilities /19/ were used to provide the data on generation mix. Southern California Edison data were also used to provide a generation mix case. The four cases analyzed can be summarized (in percent of peak capacity) as shown in Table 2-5.

Table 2-5. Capacity Distribution for Each Synthetic Utility Senario

	Case 1 (Scenario A)	Case 2 (Scenario B)	Case 3 (Scenario C)	Case 4 SCE[a]
Base:				
Nuclear & hydro	24%	50%	15%	17%
Intermediate:				
Coal	60%	20%	25%	11%
Peaking:				
Oil and gas	16%	30%	60%	72%

[a]Southern California Edison Co., Los Angeles region.

The first case uses the generation mix data given in Scenario A /19/ (24% base, 60% intermediate, and 16% peaking). Given an additional peaking requirement of 13%, the question is how much petroleum would be needed to meet the load. If the utility could, it is obvious from the load duration curves (Figure 2-19), that all base load would be added, not affecting the peaking capacity. However, there is apparently an impediment such as regulation or availability to adding base, or they would already have more than 24% base capacity. Assuming that base cannot be added, the alternative is to add intermediate. However, the intermediate generation plants are economically restricted to operate only about 24% of the time for Case A1 and 36% for Case E1. The result would be that about 11% of the load would be added as intermediate for case A1 (10% for Case E1), whereas only 2% would be added peaking capacity for Case A1 (3% for Case E1).

What this means in terms of petroleum usage is designated by the change in the shaded areas. The difference between the shaded areas (with and without the RPV system) is equal to the change in petroleum usage. Detailed calculation shows a 420 GWh increase in petroleum usage, which is 16% above the original use for Case A1. The corresponding number for Case E1 is 760 GWh additional petroleum usage, which is 21% above the original use.

4. Summary

Similar calculations have been made for the rest of the cases analyzed here. The load duration curves developed for a hypothetical utility before the addition of a RPV system, and after, show that the load increment is greater at the peaking end than at the low end of load. Given curves of this shape, and assuming economic rational, where possible, for utility plant expansion decisions, the effect on petroleum usage by the utility is summarized in Tables 2-6 and 2-7.

Table 2-6. Additional Capacity and Petroleum Usage, Case A

	Case A1	Case A2	Case A3	Case A4
Additional petroleum usage				
In gigawatt-hours	420	660	6,510	14,400
In percent of RPV system RPV system energy usage	3%	-5%	45%	100%
In percent of original petroleum usage	16%	-6%	13%	20%
Additional capacity requirements				
Peak, in percent of total original capacity	2%	2%	9%	13%
Intermediate, in percent of total original capacity	11%	7%	4%	None
Base, in percent of total original capacity	None	4%	None	None

Table 2-7. Additional Capacity and Petroleum Usage, Case E

	Case E1	Case E2	Case E3	Case E4
Additional petroleum usage				
In gigawatt-hours	760	2,630	14,400	14,400
In percent of RPV system RPV system energy usage	5%	18%	100%	100%
In percent of original petroleum usage	21%	17%	24%	18%
Additional capacity requirements				
Peak, in percent of total original capacity	3%	2%	13%	13%
Intermediate, in percent of total original capacity	10%	8%	None	None
Base, in percent of total original capacity	None	3%	None	None

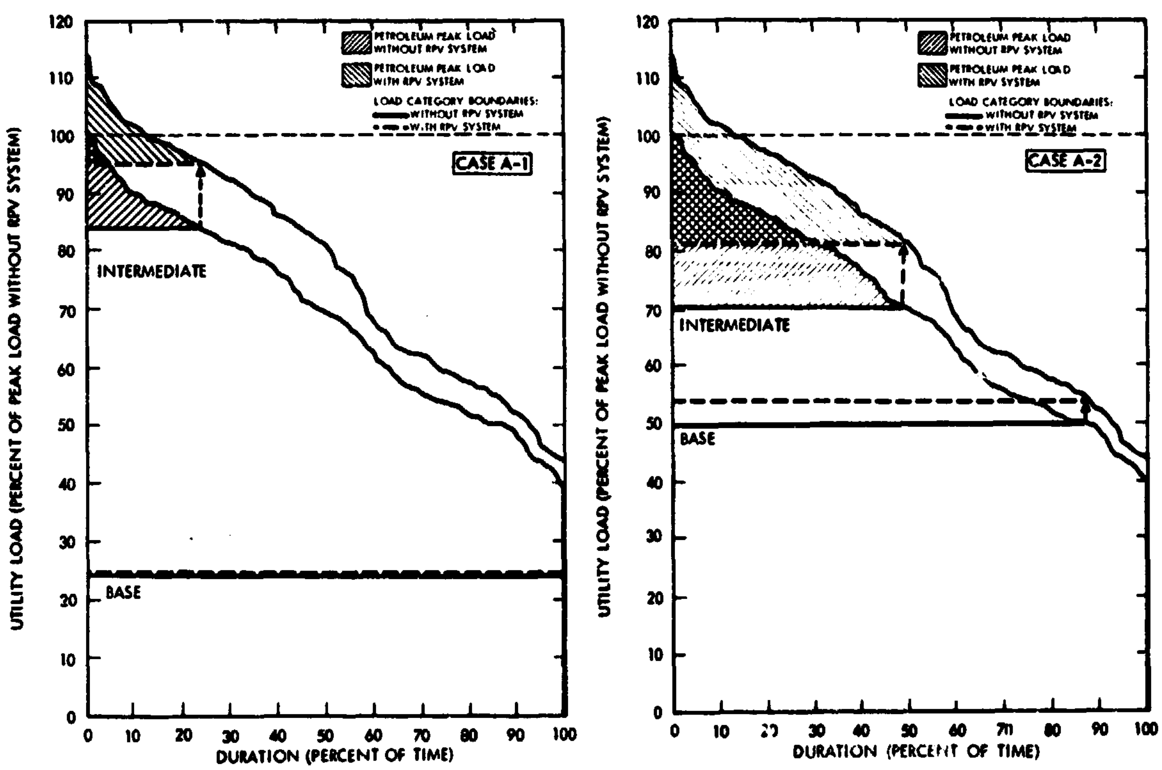


Figure 2-19. Petroleum Use for Case A1 and Case A2

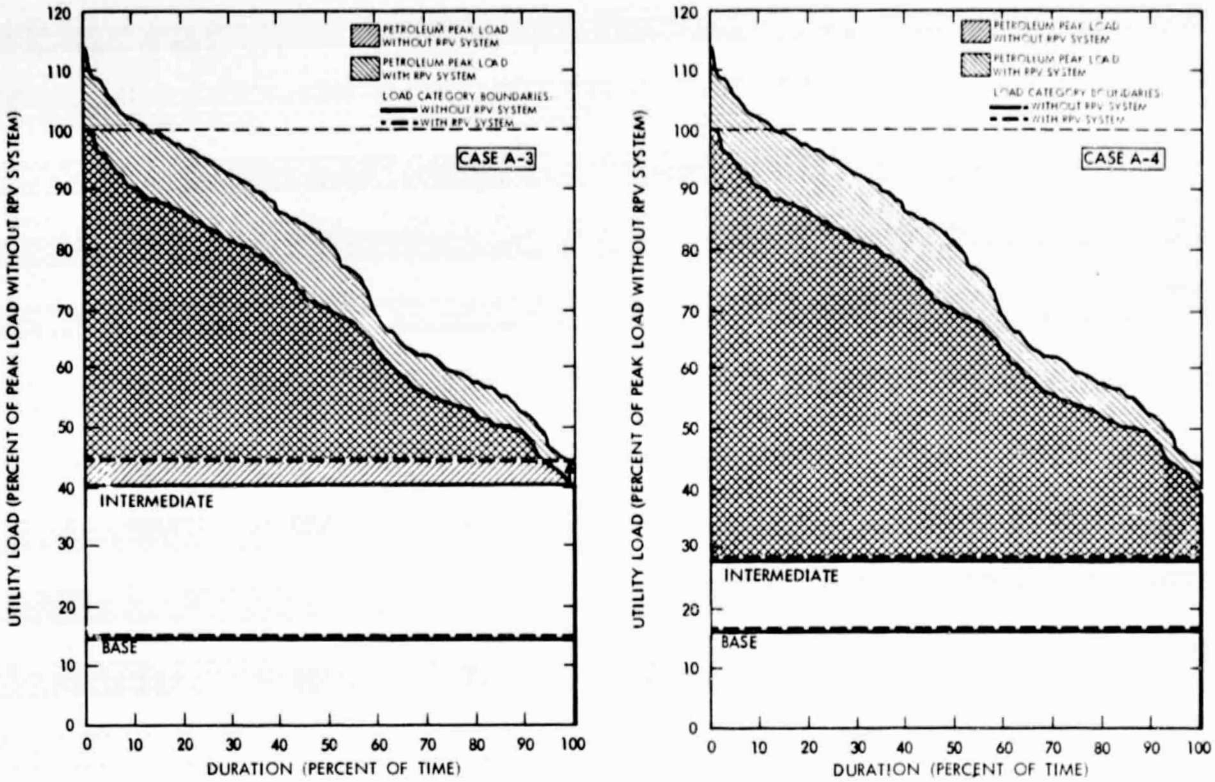


Figure 2-20. Petroleum Use for Case A3 and Case A4

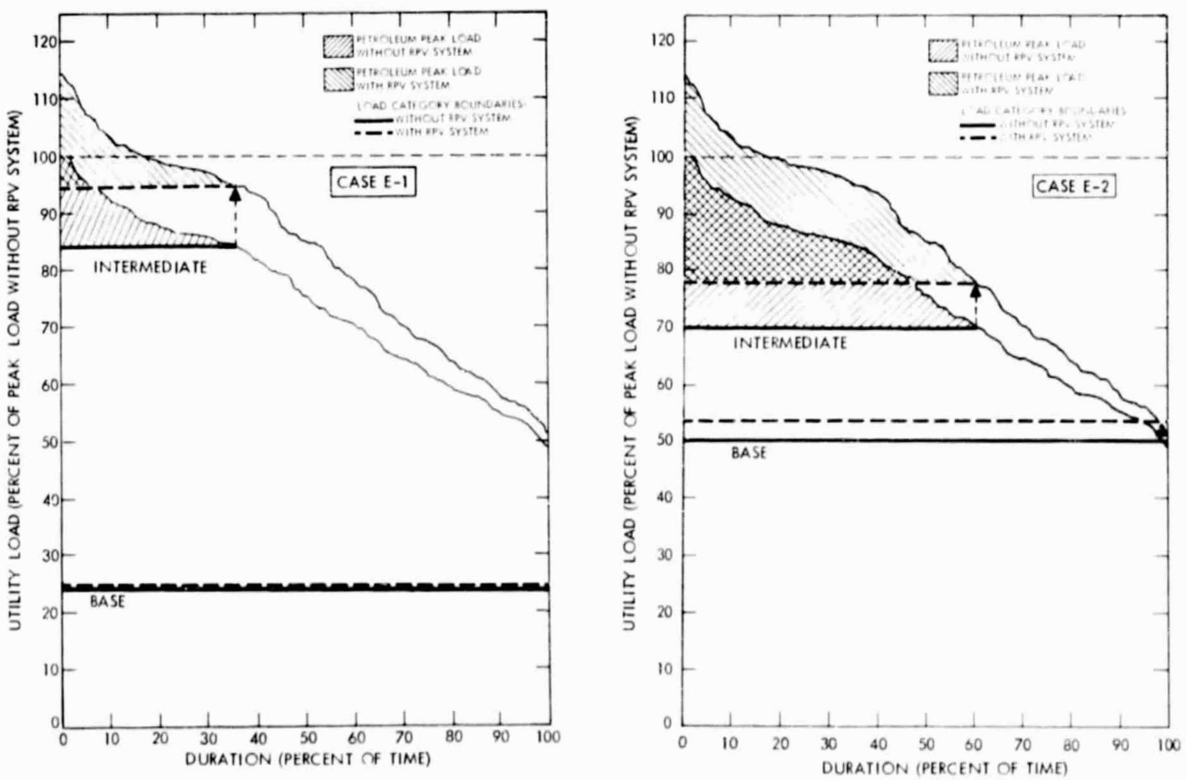


Figure 2-21. Petroleum Use for Case E1 and Case E2

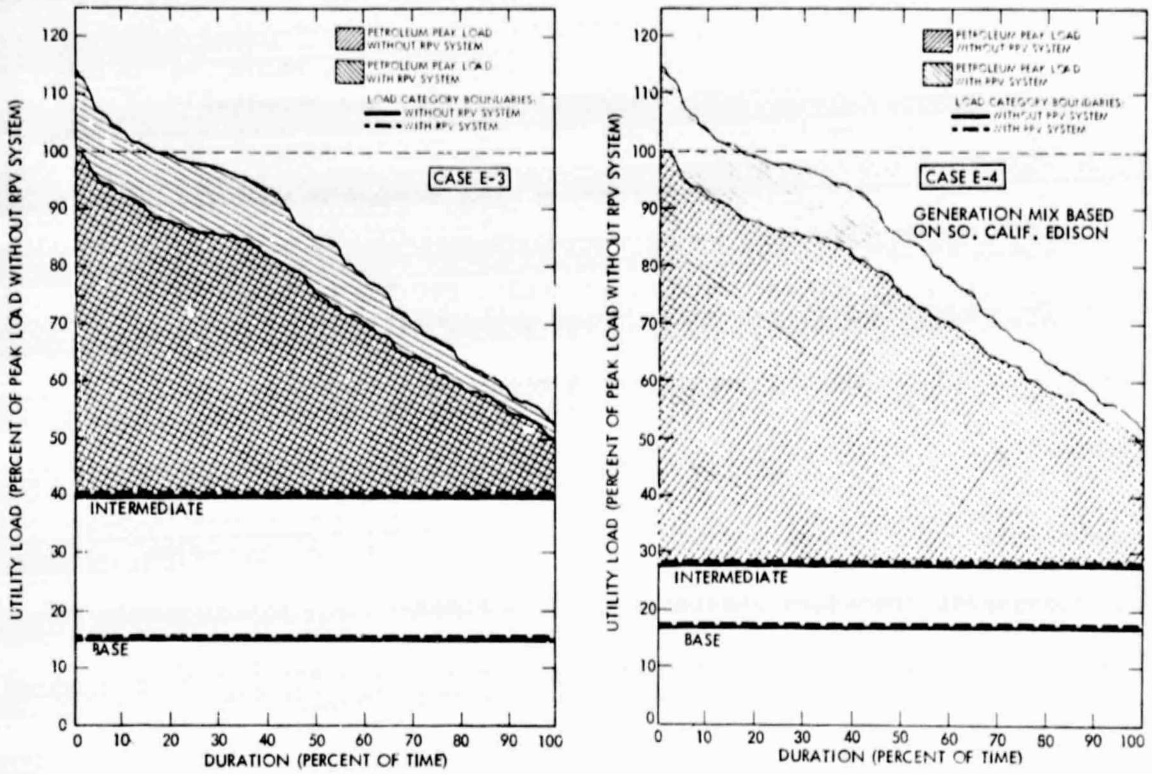


Figure 2-22. Petroleum Use for Case E3 and Case E4

D. PLAUSIBILITY OF THE ARGUMENTS

The last element of the extended analysis is an assessment of the plausibility of the arguments presented in the structured debate and documented in Part II, Section II. This assessment is clearly experimental, since no prior parallel has been identified in the open literature. Any definitive interpretations of the results should therefore only be made with great caution. On the other hand, it is felt that since the decision-maker is ultimately faced with the problem of weighting the arguments (before a decision can be reached on the central issue of further R&D funding of RPV system research), such weighting should also be attempted as an integral part of this study, in a formal (systematic) and open setting.

The plausibility assessment is aimed at the quantification of the strength and relative trustworthiness of the arguments. It responds to the question, "Does the argument hold water?", and helps to pinpoint the areas in need of additional research (i.e., the weaker elements of an argument).

More specifically, the purpose of the plausibility assessment is threefold:

(1) To examine the plausibility of the arguments and their subelements (claim, data, warrant, backing, and rebuttal) as presented by the two teams.

(2) To check the logical consistency of the arguments within each issue.

(3) To determine topics for further study, for the purposes of clarifying the credibility of the arguments.

The rest of this section gives first a brief description of the method used, followed by a presentation and a discussion of the results.

1. Methodology

The assessment procedure consisted of five steps.

The First Step involved the preparation of a set of instructions which defined the argument component concepts and the plausibility measure. A plausibility scale (from 0 to 9) was presented with a brief description of the meaning of each of the numerals, as follows:

0 = Completely implausible, absolutely no assurance or certainty in the truthfulness or reasonableness of the argument

1 = Nearly implausible

2 = Very low plausibility

3 = Low plausibility

4 = Moderate plausibility

5 = Medium plausibility

6 = High plausibility

7 = Very high plausibility

8 = Virtually true and plausible

9 = Maximally plausible, a logical and necessary truth, absolute assurance or certainty in the truthfulness or reasonableness of the argument.

Furthermore, the instructions specified that the ratings be based on the following three factors:

(1) The credentials of the source including its reliability and trustworthiness.

(2) The soundness of the logic and reasoning employed.

(3) The degree to which the argument or its components agree with previous knowledge, experience, and beliefs.

The Second Step involved the preparation of a workbook containing all of the 22 arguments as identified in the debate (see p. 2-23 ff.) interleaved with a plausibility rating form (Figure 2-23) for each argument.

The Third Step was to select the plausibility rating panel. Five individuals (see Appendix A) were selected, all knowledgable in the field but with no direct interest in either side of the issues. The panel was told to review each argument in its entirety before rating the plausibilities of the separate components. The results of these ratings were compiled and the median, mean, and standard deviation computed.

The Fourth Step was to bring the panel together to discuss and possibly revise their initial assessments.

The Fifth Step was to summarize the final results of the plausibility rating. Based on the assumption that an argument is no more plausible than the weakest link (the least plausible element in the chain of reasoning), an aggregate plausibility value was derived for each argument. This value was computed (for each argument) as the median-of-the-minimum of each panelist's subelement ratings within an argument (excluding the rating of the rebuttal). The following example illustrate this medi-min computation:

Issue No. 1: Ratings of the First-Level Claim of the Blue Team

Panelist	A	B	C	D	E
Claim	1	3	3	1	3
Data	2	4	2	2	4
Warrant	1	2	5	0	4
Rebuttal	7	5	4	7	6
Backing	NA				
Minimum	1	2	2	0	3
Ordering	0	1	2	2	3
			Medi-min		

ARGUMENT ____________________

PAGE NO. ____________________

CIRCLE THE APPROPRIATE NUMBER

The plausibility of the claim is:

0 1 2 3 4 5 6 7 8 9

The plausibility of the data is:

0 1 2 3 4 5 6 7 8 9

The plausibility of the warrant is:

0 1 2 3 4 5 6 7 8 9

The plausibility of the rebuttals is:

0 1 2 3 4 5 6 7 8 9

The plausibility of the backing is:

0 1 2 3 4 5 6 7 8 9

Completely Implausible	A Logical Truth

Figure 2-23. Plausibility Rating Form

2. Results

To summarize the results of the plausibility assessment, the medi-min values (discussed above) for each of the first level arguments are presented in Figure 2-24, together with the range and the mean of the corresponding minima.

The detailed results are tabulated at the end of this section (Table 2-8).

The results show that the Blue Team's case for the RPV system is especially weak in two areas (Issues No. 1 and No. 5). Its claims for significant levels of petroleum displacement and consumer acceptance held very little water. In contrast, the Red Team's claims were rated high. This is clearly displayed in Figure 2-24.

It became apparent during the discussion of the results of the plausibility rating that there were at least two critical issues that lowered the believability of the Blue Team. Several of the raters graded it down based on its contention that the RPV system would increase freeway safety due to automation of the system. The raters cited such systems as the San Francisco BART system where automation had not been a factor in improved safety. It was concluded that automation was not effective in improving safety, and in some cases, had an adverse effect.

The second claim that the raters found unsupportable was the complete penetration of the 110 million vehicle fleet by RPV system. By insisting on 100% penetration, the Blue Team decreased the validity of their argument.

Another problem mentioned was the apparent contradiction of some of the claims, especially the Blue Team's. For example, the Blue Team argued that the RPV system will be competitively priced with the alternatives and gave some cost estimates. Then, in some of the later claims, features of the system are illustrated which one rater believed would raise the costs of the system above those that were previously stated. The method employed in the plausibility rating has no standard method to account for the consistency of arguments from issue to issue.

The main conclusion that may be drawn from the outcome of the plausibility rating exercise is that there is more support for the case of the Red Team than for that of the Blue Team. This may be seen graphically in Figure 2-24. Taking the means of the box scores (the derivation of these numbers is described above) the Red Team's arguments scored an average of two points higher that the Blue Team's. The mean of the scores of the Blue Team's claims is 2.5; of its rebuttals is 5.2; the mean of the Red Team's claims' scores is 5.0 and of its rebuttals is 2.2. (Issue No. 5 was not included in this

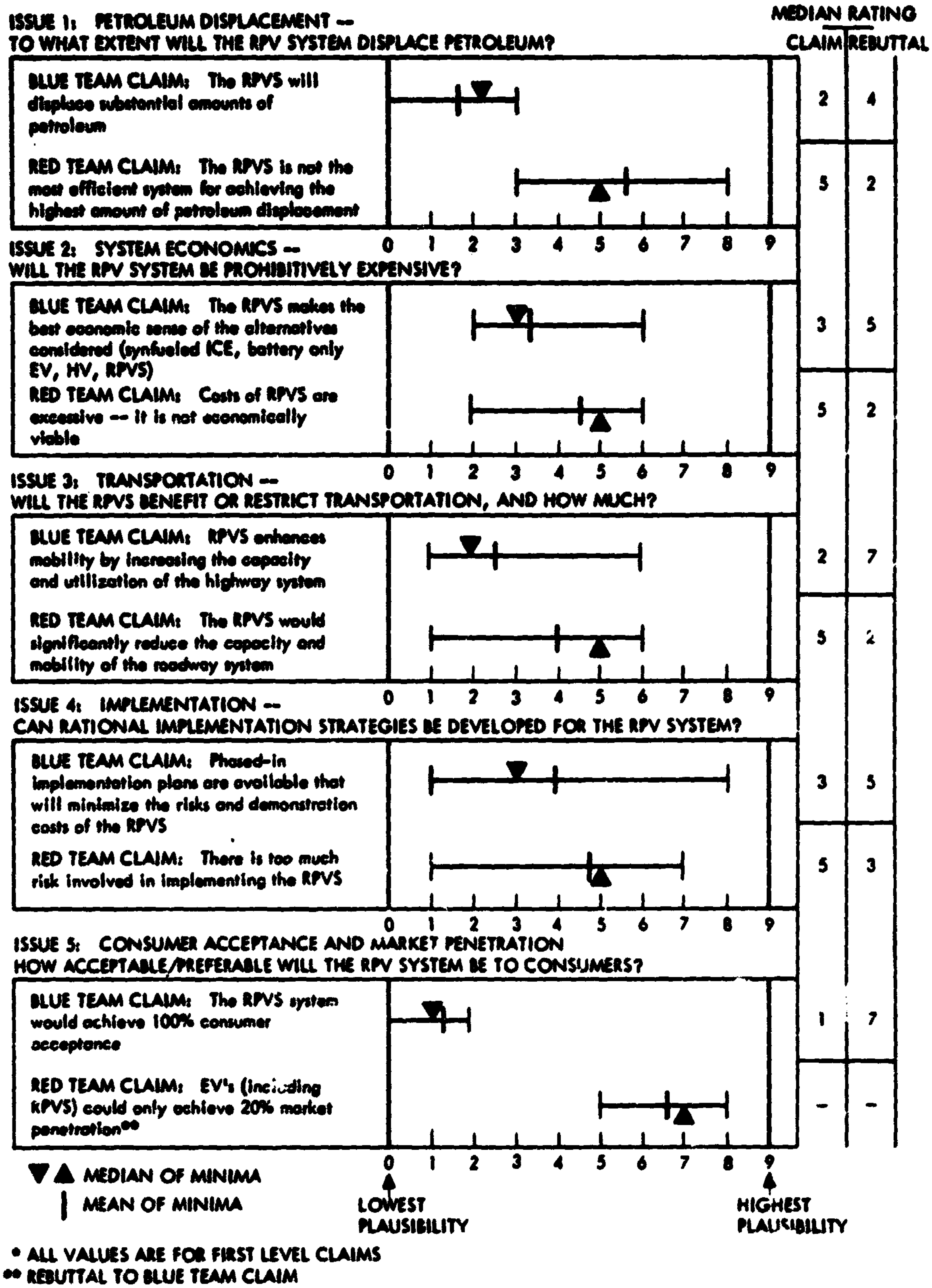


Figure 2-24. Summary of the Plausibility Ratings

calculation because the argument was not completely structured.) Note the reciprocity of the plausibilities as a check for consistency within an issue--the high plausibility of the claims is mirrored by the corresponding low plausibility in the rebuttal (and vice versa). This check is also apparent (to a lesser extent) with the medians for each issue (Figure 2-24).

In addition to finding the weak links in the arguments of both teams through the plausibility analysis, some weaknesses in the process itself were identified. The raters used different strategies to arrive at their plausibility judgements. Several used the "weakest link" method. Where there were multiple items to be considered, the overall number they assigned corresponded to the least believable item. Another rater used the weighted average approach to scoring multiple items.

When raters were uncertain of the validity of a statement, two different approaches to scoring were evident. Some raters split the difference and assigned medium plausibility, while others scored these items at the low end of the scale due to lack of information on specific issues. It was brought up at the meeting that this problem might be alleviated by employing as raters only those people with a higher level of knowledge about the system under investigation.

Discussion of the plausibility rating format led to comments on the success of the dialectic inquiry process as a whole. Everyone present at the meeting thought it was worthwhile to hold the structured debate and the subsequent activities. One member of the Third Party suggested that the debate not be held the day after the selection of the issues for debate. A week should elapse so that the teams would have more time to prepare their arguments. It was also noted that the Red Team had an advantage in this particular debate. Unlike the Blue Team, it did not have to prepare an offense for its claims, but only to rebut the points made by its opponents. The dialectic inquiry process, and specifically, the plausibility rating activity, were seen as valuable tools that policymakers could use in the decision-making process. It is a simple, yet powerful method for discovering the strengths and weaknesses of opposing arguments and the areas where further investigation would be the most useful.

Table 2-8. Results of the Plausibility Assessment

Issue No. 1. Petroleum displacement. To what extent will the RPV displace petroleum?

Argument Components	Distribution[a]	Median	Mean	Standard Deviation
Blue Team (Level 1)	The RPV system will displace substantial amounts of petroleum.			
Claim	1 3 3 1 3	3	2.2	1.0
Data	2 4 2 2 4	2	2.8	1.0
Warrant	1 2 5 0 4	2	2.4	1.9
Rebuttal	7 5 4 7 6	6	5.8	1.2
Backing	NA			
Blue Team (Level 2)	The RPV system will not require petroleum to produce its electrical energy.			
Claim	1 3 4 2 3	3	2.6	1.0
Data	1 2 4 1 3	2	2.2	1.2
Warrant	2 4 6 4 3	4	3.8	1.3
Rebuttal	7 6 3 8 6	6	6.0	1.7
Backing	NA			
Blue Team (Level 3)	Peak load requirements imposed by RPV system are minimal.			
Claim	2 6 1 1 2	2	2.4	1.9
Data	1 6 2 0 3	2	2.4	2.1
Warrant	1 6 5 3 1	3	3.2	2.0
Rebuttal	7 2 3 5 6	5	4.6	1.9
Backing	NA			
Red Team (Level 1)	The RPV system is not the most efficient system for achieving the highest amount of petroleum displacement.			
Claim	8 6 8 7 7	7	7.2	0.7
Data	7 6 8 7 7	7	7.0	0.6
Warrant	6 3 8 6 7	6	6.0	1.7
Rebuttal	2 6 2 2 4	2	3.2	1.6
Backing	5 6 8 7 5	6	6.2	1.2

[a]Each column presents the plausibility ratings elicited from the same individual.

Table 2-8. (contd)

Issue No. 2. Economics. Will RPV system be prohibitively expensive?

Argument Components	Distribution	Median	Mean	Standard Deviation
Blue Team (Level 1)	The RPV system makes the best economic sense of the alternatives considered (synfueled ICE, battery only EV, HV, RPV system).			
Claim	2 7 2 4 3	3	3.6	1.9
Data	3 6 4 4 5	4	4.4	1.0
Warrant	5 7 1 4 4	4	4.2	1.9
Rebuttal	6 3 7 5 5	5	5.2	1.3
Backing	NA			
Blue Team (Level 2)	Major capital costs for converting the 110 million automobile vehicles to the RPV system are similar to or less than alternatives.			
Claim	2 7 4 3 4	4	4.0	1.7
Data	2 6 3 2 2	2	3.0	1.5
Warrant	2 6 3 3 2	3	3.2	1.5
Rebuttal	8 5 8 4 7	7	6.4	1.6
Backing	4 7 4 3 6	4	4.8	1.5
Blue Team (Level 3.1)	Synfueled ICE system capital costs are $300 to $400 billion plus costs of extra coal mining and transportation that are required by energy wasted in manufacture.			
Claim	2 4 5 2 4	4	3.4	1.2
Data	2 2 3 2 4	2	2.6	0.8
Warrant	3 2 4 2 5	3	3.2	1.2
Rebuttal	5 8 5 4 5	5	5.4	1.8
Backing	NA			
Blue Team (Level 3.2)	Marginal capital costs for battery only EV system are $565 billion plus.			
Claim	3 3 3 2 4	3	3.0	0.6
Data	3 3 5 2 4	3	3.4	1.0
Warrant	4 6 2 2 4	4	3.6	1.5
Rebuttal	4 8 3 2 4	4	4.2	2.0
Backing	NA			

Table 2-8. (contd)

Issue No. 2 (cont). Economics. Will the RPV system be prohibitively expensive?

Argument Components	Distribution	Median	Mean	Standard Deviation
Blue Team (Level 3.3)	Marginal capital costs for ICE/battery HV system are $434 billion.			
Claim	2 2 6 2 4	2	3.2	1.6
Data	2 2 6 2 4	2	3.2	1.6
Warrant	2 7[a] 2 2 4	2	3.4	2.0
Rebuttal	6 8 2 1 4	4	4.2	2.6
Backing	NA			
Blue Team (Level 3.4)	Marginal capital costs for RPV system are $400 billion.			
Claim	2 7 4 2 4	4	3.8	1.8
Data	2 7 4 2 4	4	3.8	1.8
Warrant	1 6[b] 5 1 4	4	3.4	2.1
Rebuttal	8 8 5 5 4	5	6.0	1.7
Backing	NA			
Red Team (Level 1)	Costs of RPV system are excessive; it is not economically viable.			
Claim	6 2 6 5 5	5	4.8	1.5
Data	6 6 6 5 3	6	5.2	1.2
Warrant	6 7 6 6 5	6	6.0	0.6
Rebuttal	3 2 2 1 5	2	2.6	1.4
Backing	6 7 6 5 5	6	5.8	0.7
Red Team (Level 2)	Cost of saving one barrel of petroleum with RPV system ranges from $41.75 to $4812.			
Claim	6 7 7 6 5	6	6.2	0.7
Data	6 7 7 6 5	6	6.2	0.7
Warrant	6 7 7 6 5	6	6.2	0.7
Rebuttal	2 7 3 1 4	3	3.4	4.2
Backing	NA			

[a]Weighted (one 2, two 7s, three 8s).

[b]Weighted (one 2, one 3, three 8s).

Table 2-8. (contd)

Issue No. 3. Transportation. Will the RPV system enhance or restrict transportation, and by how much?

Argument Components	Distribution	Median	Mean	Standard Deviation
Blue Team (Level 1)	The RPV system enhances mobility by increasing the capacity and utilization of the highway system.			
Claim	1 7 2 2 2	2	2.8	2.1
Data	1 8 2 3 5	3	3.8	2.5
Warrant	1 6 2 2 5	2	3.2	1.9
Rebuttal	8 2 7 8 6	7	6.2	2.2
Backing	1 7 4 3 5	4	4.0	2.0
Blue Team (Level 2.1)	The RPV system automation will increase the capacity and utilization of roads on which it is installed.			
Claim	1 8 2 1 5	2	3.4	2.7
Data	3 8 3 2 6	3	4.4	2.2
Warrant	6 8 7 7 8	7	7.2	0.7
Rebuttal	8 8 7 8 6	8	7.4	0.8
Backing	8 8 7 1 8	8	6.4	2.7
Blue Team (Level 2.2)	The RPV system is no more vulnerable to adverse weather conditions than the existing roadway/vehicle system.			
Claim	4 1 3 1 5	3	2.8	1.6
Data	4 8 1 1 5	4	7.4	1.4
Warrant	4 8 2 2 6	4	4.4	2.3
Rebuttal	6 9 8 7 8	8	7.6	1.0
Backing	NA			
Red Team (Level 1)	The RPV system will significantly reduce the capacity and mobility of the roadway system.			
Claim	2 2 6 8 5	5	4.6	2.3
Data	6 7 8 9 6	7	7.2	1.2
Warrant	5 1 8 6 7	6	5.4	2.4
Rebuttal	3 7 2 2 5	3	3.8	1.9
Backing	NA			
Red Team (Level 2)	Inclement weather, mainly snow and ice, will interfere with operation of the system.			
Claim	5 8 7 6 5	6	6.2	1.2
Data	5 8 7 6 5	6	6.2	1.2
Warrant	5 8 7 5 5	5	6.0	1.3
Rebuttal	4 2 2 1 4	2	2.6	1.2
Backing	NA			

Table 2-8. (contd)

Issue No. 4. Implementation. Can rational implementation strategies be developed for the RPV system?

Argument Components	Distribution	Median	Mean	Standard Deviation
Blue Team (Level 1)	Phased-in implementation plans are available that will minimize the risks and demonstration costs of the RPV system.			
Claim	4 9 5 3 8	5	5.8	2.3
Data	4 9 6 5 6	6	6.0	1.7
Warrant	3 9 4 3 5	4	4.8	2.2
Rebuttal	5 0 1 6 6	5	3.6	2.6
Backing	5 8 3 1 8	5	5.0	2.8
Blue Team (Level 2)	Comprehensive RPV system implementation on existing roads can be the final program phase.			
Claim	4 7 6 1 8	6	5.2	2.5
Data	3 7 6 1 6	6	4.6	2.2
Warrant	3 8 6 2 5	5	4.8	2.1
Rebuttal	6 3 3 7 4	4	4.6	1.6
Backing	NA			
Red Team (Level 1)	There is too much risk involved in implementing the RPV system.			
Claim	5 1 7 7 7	7	5.4	2.3
Data	6 2 7 8 6	6	5.8	2.0
Warrant	6 1 5 7 7	6	5.2	2.2
Rebuttal	3 8 2 0 3	3	3.2	2.6
Backing	5 6[a] 7 7 6	6	6.2	0.7
Red Team (Level 2)	The RPV system will not be implemented successfully because the scale economies and phase-in economics are not favorable.			
Claim	6 4 7 4 6	6	5.4	1.2
Data	4 4 7 3 6	4	4.8	1.5
Warrant	6 7 7 5 6	6	6.2	0.9
Rebuttal	4 7 3 0 4	4	3.6	2.2
Backing	5 2 7 4 6	5	4.8	1.7

[a]Weighted (one 2, two 8s).

Table 2-8. (contd)

Issue No. 5. Market Penetration and Consumer Acceptance. How acceptable/preferable will the RPV system be to the consumers?

Argument Components	Distribution	Median	Mean	Standard Deviation
Blue Team (Level 1)	The RPV system would achieve 100% consumer acceptance.			
Claim	1 2 2 1 1	1	1.4	0.5
Data	1 7 4 3 6	4	4.2	2.1
Warrant	0 3 4 0 2	2	1.8	1.6
Rebuttal	5 7 6 8 7	7	6.6	1.0
Backing	3 5 2 0 5	3	3.0	1.9

PART III: SUPPORT DOCUMENTATION

SECTION I

DETAILED DESIGN CONSIDERATIONS

A. ELECTRICAL DESIGN

The LBL Feasibility Study /1/ presents calculations for an inductive coupling system that are unassailable from an electrical engineering standpoint. The electrical behavior of the inductive coupling will be essentially as described in the LBL study. The vehicles can be considered plugged into the electrical grid when driving on the electrified roadway. Questions of the cost and desirability of such a transportation system can be addressed using the LBL study as far as electrical parameters are concerned. This conclusion was reached through the examination of the following aspects.

1. Power Losses

The design point calculations on the properties of the source and the pickup, presented in Table 4.1 (/1/ p. 55) and Table 4.2 (/1/ p. 59), are correct. The only problem might be in the core loss predictions which are based on manufacturers' watts per kilogram data. Such data are based on measurements on ideal toroidal cores. Other shapes, such as required in the inductive coupling, can have core losses several times higher because of imperfect alignment of the magnetic field with the laminations. In fact, in the LBL Test Report on the static prototype of the inductive coupling /2/, the core losses for the half-length model were a minimum of 514 W, corresponding to 1028 W for the full size coupling. The predicted core losses in the LBL Feasibility Study were 580 W. The core losses are constant regardless of vehicle power; therefore, an increase of 500 W in constant load might represent 5% to 10% of average vehicle power.

There was a report by General Electric several years ago stating that inductive couplings are not feasible /5/. However, this conclusion only applied to the transfer of 4500 kW into a pickup about the same size as LBL's. The General Electric calculations applied to 20 kW transfer would have agreed with LBL's.

2. Effect of Increased Gap

We are not dealing with electromagnetic power transmission here. The primary (roadway source) and secondary (vehicle pickup) are both parts of the same magnetic circuit. The larger air gap, compared with a transformer, requires that a larger volume of space be filled with magnetic field energy on each half cycle. This is only quantitatively different from an ordinary transformer which has windows which contain space that must be magnetized on each half cycle.

The primary (roadway source) sees the air gap as an inductance that must be filled with magentic field energy each half cycle, but draws no power except for the resistance loss in the roadway conductors. The secondary (vehicle pickup) looks like a resistance in series with the inductance. The effect of increasing the air gap is to lower the vehicle load resistance seen by the source so that more current must flow in the roadway to produce the required vehicle power. The practical limit comes when the roadway conductors and power supply have excessive power losses from the high current.

For the design gap of 2.5 cm the source losses of 12 kW/km (/1/ p. 58) are about equal to the power required to operate one car at half power. Fig. 4.5a (/1/ p. 64) shows that doubling the gap to 5 cm would reduce the resistance of the vehicle load, as seen by the source, by a factor of about 2. Raising the source current a factor of 2 to compensate would raise the source losses to the equivalent of one full-power vehicle per km. This is still small. Gaps up to at least 10 cm would probably be possible without prohibitive losses.

3. Flux Through Large Source Loop

It has been questioned if the return conductor should be closer to the source conductor to avoid excessive magnetic flux in the source loop. The closest distance allowable would be about 1.0 m before the return conductor field would start cancelling the source conductor field. The inductance L of the loop is calculated from Equation (3-1).

$$L = 0.4(\log_e(d/w) + 0.25) \qquad (3\text{-}1)$$

where d is the spacing and w is the conductor width. With w = 20 cm, the inductance of the loop with full lane spacing (d = 3.7 m) is 1.27 H/m, in agreement with Table 4.1 (/1/ p. 55). If the return loop spacing is reduced to 1.0 m the inductance is reduced to 0.75 H/m. The power supply losses would be reduced, but probably not by enough to make up for having two conductors per lane instead of one.

4. Effect of Iron Reinforcing Bars in the Roadway

We can see from the flux plot in Fig. 4.3a (/1/ p. 56), that the maximum field under the source is about half as great as the field 30 cm above the source. If a steel sheet were placed 30 cm under the source it would, therefore, be heated about 25% as much as the steel sheet placed 30 cm above the source in Fig 3.6 (/1/ p. 32). The corresponding loss is 77 W/m^2 (25% of the 0.2 W/in^2 calculated on p. 31). If this loss extends over the 60-cm width of the source the loss would be 46 W/m, or four times the source conductor loss. It is estimated that reinforcing bars would produce only a few percent, at most, of this loss, but this is an area of possible concern.

5. Attraction of Steel Objects

The attraction force on the vehicle pickup is 716 N (161 lbf) from Table 4.2 (/1/ p. 59). This force is distributed over an area of 0.9 m^2. Steel objects would thus be attracted with a force of, very roughly, 800 N/m^2. This is equal to the weight per m^2 of a 10 mm thickness of steel sheet. Thus, we are talking about steel objects being attracted by an amount comparable to their own weight. The behavior of steel objects dropped on the roadway would not be much different than now. The small clearance of the coupling would be the main problem.

6. Noise

The noise from the coupling inside each vehicle should be the same as for a 20 kVA transformer. Knowlton's handbook gives Equation (3-2).

$$\text{decibels} = 10 \log_{10} \text{kVA} + 31 \qquad (3\text{-}2)$$

or 44 dB for 20 kVA. "Average office noise" is 40 to 50 dB. The noise would be less than inside a present car.

In the LBL experiments, higher noise was observed, but this was attributed to factors specific to the experimental setup.

7. Magnetic Field Hazards

At worst, without shielding, the passengers would be exposed to a 120-Hz magnetic field of about 1 mT (10 G) rms amplitude (Fig. 3.7a, 9 in. elevation, /1/ p. 33). Lightweight shielding could reduce this by orders of magnitude (Fig. 3.6, /1/ p. 32). Household appliances produce similar fields, 1.0 to 2.5 mT for a hair dryer for example (J. E. Bridges, IEEE Trans. PAS-97, p. 19). On the other hand, someone standing on the source would receive 7 mT immediately at ground level.

Heart pacemakers might be affected. There is no current standard for magnetic field exposure of pacemakers.

B. VEHICLE DESIGN

The success of a RPV system is impossible without the vehicle designed for this system being accepted (and purchased) by the public. For this to occur, the vehicle must offer some advantage over its alternatives, which in this study includes electric, hybrid, and conventional internal combustion engine (ICE) vehicles. The focus of the RPV system vehicle design study has been to evaluate two critical parameters for such comparisons:

(1) Manufacturing cost ratio (MCR)

(2) Life cycle break-even gasoline price (BEGP)

But first, before these parameters can be estimated, a number of key assumptions have to be made concerning mission specifications, performance requirements, and battery characteristics.

1. Assumptions

a. Mission Specifications. The mission was defined with the intention of providing travel patterns, which would be most reasonable for a commuter with a specific work trip in mind (and one that would be reasonable for a vehicle equipped with an inductive coupling). This mission was based on a commuter year of 260 days.

The trips were defined as a combination of EPA Urban and Highway driving cycles (the RPVs were assumed coupled on the EPA Highway cycle). To simplify the evaluation, the commuter travel pattern (home to work) was defined as follows:

1/2 EPA-Urban, X EPA-Highways, 1/2 EPA-Urban

This pattern was assumed to be repeated on the return trip from work. The variable X was determined by the annual vehicle kilometers traveled (AVKT) by the vehicle. Three AVKTs were chosen (10,000, 20,000, and 30,000 km per year) to show the effect of annual mileage and the ratio between Urban Highway driving on the RPV system, as shown in Table 3-1.

Table 3-1. Ratio of Urban to Highway Driving for Three Different AVKTs

Annual Vehicle Kilometers Traveled	Ratio of Urban:Highway
10,000 km	70:30
20,000 km	63:37
30,000 km	36:64

b. Performance Requirements. A generally overriding acceleration requirement of 0-100 km/h in 14 seconds, was determined necessary for passenger cars, in a recent JPL study of hybrid vehicles /6/. This specification, which was derived from an analysis of freeway entrance requirements in California, has been relaxed in the design of RPVs. Since freeway on-ramps theoretically could be coupled just as the rest of the RPV system, the on-board power capability could be reduced substantially. The maximum power capability required of the RPVs is related to the need for freeway lane change and passing maneuvers: 60-90 km/h in 9 seconds.

The resulting performance requirements for the RPVs were as shown in Table 3-2.

Table 3-2. RPV Performance Requirements

Maneuver	Time, s
Low-speed merge (0-50 km/h)	6
Low-speed pass (30-55 km/h)	4
Freeway merge (60-90 km/h)	9
Maximum acceleration (0-100 km/h)	20

The performance requirements for those vehicles incapable of utilizing the RPV system (conventional ICE and pure electric) remained as defined by the JPL Hybrid Vehicle Study /6/ (Table 3-3).

Table 3-3. Non-RPV Performance Requirements

Maneuver	Time, s
Low-speed merge (0-50 km/h)	6
Low-speed pass (30-55 km/h)	4
Freeway merge (60-90 km/h)	9
Freeway entrance (0-100 km/h)	14

The range requirement for the RPV designs were 14 miles (when uncoupled), as originally specified in the LBL Feasibility Study /1/. The comparable pure electric vehicle (EV) was specified in terms of two design ranges (24 mi, and 48 mi).

The lower power requirement for the RPVs (which is just slightly above the peak power requirment of the EPA Urban cycle) greatly affects the battery-powered RPVs; making the economic picture much more attractive compared to RPV designs which also meet the freeway entrance requirement. The difficulty in meeting this requirement is primarily due to the lack of power in a battery pack designed to have only enough energy for a 14-mi range (uncoupled).

c. Battery Characteristics. Another area where key assumptions were made is related to the batteries where the following cycle lives were assumed (all of which are of the upper limit of what can be expected before year 2000):

Lead-acid battery	1500 cycles
Nickel-iron battery	2000 cycles
Nickel-zinc battery	500 cycles

The assumptions on the expected battery specific power capabilities were based on projections made for the early 1980s by Argonne National Laboratory, as shown in Figure 3-1.

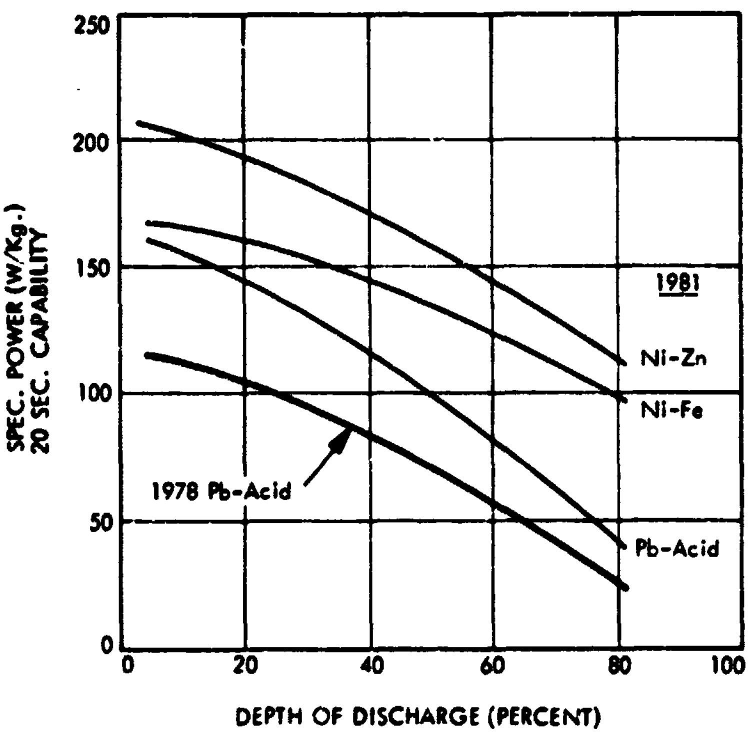


Figure 3-1. Battery Specific Power Capability

d. Other Key Assumptions. First of all it should be noted that roadway construction costs have been excluded from this analysis, which is strictly concerned with the vehicle designs. In essence, most parameters have been identical to those employed previously in the JPL study on hybrid vehicles /6/, including the cost method documented in /7/.

1) Manufacturing Cost Ratio (MCR). Two main categories of vehicles were considered in the MCR and life cycle BEGP calculations:

(1) Limited range vehicles; i.e., electric and flywheel-electric RPVs, as well as pure electrics (ERPV, FRPV, EV).

(2) Unlimited range vehicles; i.e., ICE vehicles and ICE RPVs (ICEV, ICERPV). Though hybrid vehicles would be considered in this category, a more thorough evaluation of these vehicles in comparison to ICE vehicles has been performed in a previous study /6/. The results from this study have hence been used directly concerning the BEGP for hybrids.

Even though the potential mobility of these two categories is divergent per definition, they have been assumed comparable in the eyes of the consumer, in terms of their MCR and life cycle BEGP alone (assuming comparable missions, performance, etc.).

The results of the MCR analysis are tabulated in Table 3-4, together with a more detailed specification of the developed vehicle designs.

In summary, the RPVs are expensive relative to a conventional vehicle in terms of manufacturing cost. The mark-up for conventional vehicles varies from 1.7 to 2.4 times the manufacturing cost, but there is no assurance that the pricing policy would remain the same for this type of vehicle.

At any rate, the RPVs designed for this study would require a manufacturing cost of at least 1.4 times the conventional vehicle, and at the most 2.0.

Table 3-4. Vehicle Design and Manufacturing Cost

	UNLIMITED RANGE			LIMITED RANGE							
	CONV. ICE VEHICLE	CONVENTIONAL (ICE-RPV)		ELECTRIC - 14 MILE (E-RPV)			FLYWHEEL - ELECTRIC - 14 MILE (F-RPV)			Pb-ACID ELECTRIC	
		A	B	Pb-Acid	Ni-Fe	Ni-Zn	Pb-Acid	Ni-Fe	Ni-Zn	24 MI.	48 MI.
Chassis (kg)	$1419 (805)	$1577 (895)	$1580 (897)	$1650 (936)	$1637 (929)	$1625 (922)	$1560 (885)	$1555 (882)	$1538 (878)	$1696 (962)	$1828 (1037)
Engine (kW) or	525 (50)	573 (61)	573 (61)								
Flywheel (kWh)							200 (1)	200 (1)	200 (1)		
Trans (kW)	70 (50)	75 (61)	85 (61)	60 (4)	60 (44)	56 (42)	140 (55)	137 (54)	134 (53)	86 (64)	107 (80)
Motor (kW)		78 (10)	150 (26)	180 (22)	180 (22)	168 (21)	130 (15)	128 (14)	126 (14)	258 (32)	322 (40)
Controller (kW)		140 (10)	460 (52)	403 (44)	403 (44)	390 (42)	220 (15)	210 (14)	204 (14)	518 (64)	601 (80)
Battery (kWh)				596 (14.9)	1510 (15.1)	966 (16.1)	180 (4.5)	450 (4.5)	270 (4.5)	920 (23)	1440 (36)
Charger Acc				20	20	20	20	20	20	20	20
Coupling, etc. (kg)		310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)	310 (115)		
Vehicle Ass, (Curb Weight kg)	125 (995)	160 (1218)	165 (1226)	201 (1521)	196 (1484)	191 (1447)	170 (1320)	165 (1303)	160 (1282)	222 (1678)	278 (2100)
Manufacturing Cost	$2139	$2923	$3323	$3420	$4316	$3726	$2930	$3175	$2972	$3720	$4596
MCR	1.0	1.4	1.6	1.6	2.0	1.7	1.4	1.5	1.4	1.7	2.1

2) <u>Life Cycle Break-Even Gasoline Price (BEGP)</u>. The life cycle cost of each vehicle design was compared to an ICE vehicle, designed specifically for the same mission. The method of comparison chosen uses the break-even gasoline price (BEGP) as the life cycle cost comparator. The BEGP is the necessary price of gasoline to cause the life cycle cost of the conventional vehicle to equal that of the proposed vehicle. The BEGP is intended to be a life cycle cost comparator between vehicles designed for the same purpose.

The resulting break-even gas prices, shown in Figure 3-2, illustrate the advantage of the RPV over the pure electric vehicle for longer AVKT, if the roadway costs are ignored. Also quite evident is the advantage of the flywheel-electric RPV (FRPV) over the electric RPV (ERPV) used in conjunction with any of the advanced batteries. As expected, the RPVs improve economically with more travel on the inductively coupled roadways with any configuration.

It appears from these results that an ICE vehicle equipped with an inductive coupling (ICERPV) would be very costly.

It should be noted that the BEGP of hybrid vehicles with comparable passenger capability, but higher performance, was estimated at approximately $2.50 to $3.00/gal (1978 dollars) in the JPL Hybrid Vehicle Study /6/.

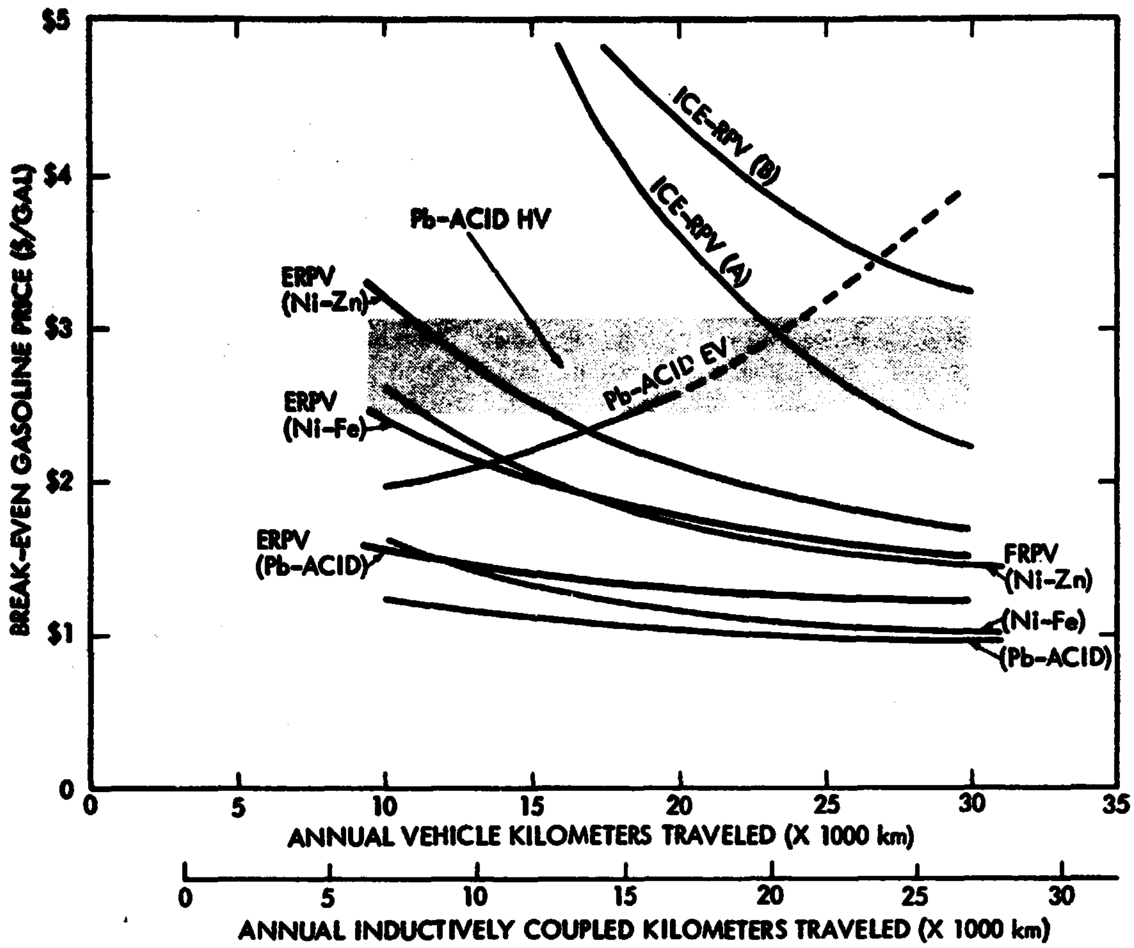


Figure 3-2. Break-even Gasoline Prices vs AVKT

C. ROADWAY DESIGN

The RPV system roadway issues fall into four broad categories, three of which concern the freeway or Interstate Highway System application (installation, operation, and maintenance) and one concerning the non-freeway application.

1. Installation

a. Cost and Timing of Installation. It has been proposed that the cost of installation of the RPV system can be substantially reduced by installation of the system simultaneously with rehabilitation (which includes both resurfacing and reconstruction of differing types of highways) of the existing highway system. This presupposes that substantial portions of the roadway will be rehabilitated at the same time, thereby allowing a substantial stretch of the RPV system power source to be laid at the same time.

However, investigations with the California Department of Transportation (Caltrans), Los Angeles, indicate that such a large-scale rehabilitation of the existing roadways is not planned, nor is it likely. Despite the fact that the highways have a 20-year design lifetime, the roadway surface is rehabilitated only as needed, and then only in short sections as required. Only two such freeway sections are under consideration for imminent rehabilitation in Los Angeles County. This method of freeway rehabilitation is the only system planned for use by Caltrans, for at least the next 30 years. Therefore, the entire cost, or at least a major portion, of any RPV system installation must be borne by the system. Furthermore, all physical parameters of installation must be calculated using this basic assumption.

b. Constraints by Characteristics of the Roadbed. The following four items are considered most important with respect to the roadbed design:

Pavement material. There are two chief materials used for pavement in the nation's highways: Portland cement concrete (PCC) and asphaltic concrete (AC). Portland cement concrete hardens to a rigid solid, while asphaltic concrete hardens only to a semi-fluid, being malleable and flowing under several circumstances. It appears that the characteristics of an RPV system source embedded in the roadway require a rigid roadbed. This would preclude its installation in any material except Portland cement concrete.

Bridges. The structure of bridges and freeway overpasses probably prohibits the use of an RPV system source in these locations. These locations are typically constructed with a 5 cm asphaltic concrete over a steel bed, which prohibits the emplacement of an RPV system source as proposed in the LBL Feasibility Study. Moreover, the laying of additional paving material without removal of original surface is precluded in many instances by such factors as impeded drainage, bridge clearance, and bridge weight loading capacity. Therefore, these locations in the roadway would probably be unpowered sections even in a stretch of powered highway.

Thermal expansion. Some Portland cement concrete highways are installed in slabs of 4 m to 6 m lengths with thermal expansion joints between the slabs. Adjacent slabs move both laterally and vertically relative to each other. This issue has not been addressed in the LBL Feasibility Study /1/. The RPV system source must be designed to successfully withstand many years of such thermally induced motion. Indeed, in roadways with or without thermal expansion joints, the source must be designed to compensate for its thermal expansion coefficient being different from that of concrete.

Strength of roadbed. The installation of the RPV system source in an existing PCC surface appears to have no significant effect on the roadbed structural integrity. The RPV system source would require a slot to be cut in the roadbed surface of approximately 7.5 cm by 60 cm; this does not impair significantly the strength of PCC roadbeds now in place, which have depths of 20 cm or more.

c. Performance of Installation. According to Caltrans, the installation of the RPV system source would probably be done by contractors to Caltrans, not by Caltrans directly. This appears to offer no inherent problems.

2. Operation

a. Obstacles. It is certain that obstacles in the roadway (mufflers, debris, etc.) will be occasionally encountered by the RPV, and other vehicles. The LBL Feasibility Study addresses this subject briefly, but dismisses the possible damage to the vehicle as being no problem, although it recognizes the danger from launched obstacles. This should be addressed more thoroughly, both in the areas of vehicle resistance to damage and roadway resistance to damage from a struck obstacle.

b. Winter Zone Conditions. Substantial geographical regions of this country endure severe winters. This brings up a large group of problems, most of which are maintenance problems. One item pertinent to freeway operation is salt water. During ice and snow conditions, it is common winter zone practice to spread rock salt on the highways to melt the snow and ice. This leaves salt water on the roadway, which poses a possible threat to the RPV system source in two areas: corrosion and electric conduction. Salt water is an excellent conductor of electricity: what is the effect on the RPV system of the roadway being covered with a layer of conductive salt water?

3. Maintenance

a. Jurisdiction. Maintenance of the RPV system source would most probably be done in California by Caltrans itself, not by contractors. Presumably this would be the case in other states as well. This is not seen to pose any problem for the system.

b. Roadway Surface Uneveness. The subject of surface unevenness was seen by the LBL Feasibility Study to be a significant problem, and was investigated in some depth for their report. However, their conclusion, that a 2.5 cm air gap between the source and pick up is sufficient to avoid damage due to surface unevenness, is not conclusively supported by other conversations with Caltrans.

Caltrans officials in Los Angeles state that their preferred limits to high points on pavement surface are 1 cm to 1.3 cm, but that this is only a guide. There is no systematic, comprehensive program by Caltrans to assure that this is the worst unevenness encountered on the highways. In fact, measurements such as those made by the profilograph in the LBL Feasibility Study, are not made in connection with rehabilitation projects. Therefore, surface projections in excess of 2.5 cm are likely to be encountered occasionally.

c. Future Rehabilitation. Rehabilitation of the highway surface at some time in the future may consist of an overlay of 5 cm to 10 cm. The emplacement of a RPV system source which prohibits such future rehabilitation would be undesirable. Some provision is made in the conceptual design of the RPV system for future resurfacing of up to two inches, but the height adjustment not included in that design is unconvincing as to its durability and adequacy of adjustment. Will an emplacement of this design be sufficiently rigid to withstand years of use? Can a design be generated which would enable overlay of more than 5 cm depth to be emplaced in the future?

d. Lane Movement. Because of varying usage patterns or changes in requirements for the level of service of given stretches of highway, Caltrans occasionally moves freeway lanes laterally. Where four lanes plus shoulders may have existed previously, Caltrans may install five lanes of traffic within the same area by narrowing the lanes and moving them laterally. This would clearly be problematic on a RPV system lane.

e. Winter Zone Highways. The corrosion problem due to salt water has been mentioned. Another winter zone problem is the freeze-thaw cycle. The thermal expansions and contractions resulting from repetitive freeze-thaw cycles is a major factor in the deterioration of standard highways. What will it do to an RPV system source emplaced in those highways?

4. Non-Freeway Applications

a. Freeway Problems Intensified. The emplacement of an RPV system in non-freeway roadways entails many of the same problems of freeway emplacements, only intensifed. Roadway surface roughness tolerances are much wider, making air gap clearance requirements larger. The vertical and horizontal alignment of vehicle to source is made more difficult. Obstacles and debris in the roadway are far more often encountered.

b. <u>Surface Materials</u>. In the non-freeway roadways of the United States, ashphaltic concrete is by far the predominant surface material used. This would seem to severely restrict the application of an RPV system.

c. <u>Subsurface Utilities</u>. In non-freeway roadways, there are frequently utility easements below the surface of the roadway. Access to these utilities is needed. These utilities are probably deep enough below the surface to pose no problem to the RPV system emplacement, but this issue should be further investigated.

d. <u>Intersections</u>. Crossing intersections may pose specific problems to an RPV system. These include the geometrical problems of crossing a crowned road and crossing a running stream of drainage water at crowned road intersections. Because of these problems, there would probably be no source laid through such intersections, so RPV's would not be powered by the roadway through these intersections.

e. <u>Lateral Vehicle Movement</u>. On most roadways, weaving maneuvers of vehicles are frequently encountered. Lane changing and avoidance of opening doors on parked cars are examples of such maneuvers. These maneuvers cause brief intervals of unplanned loss of motive power from the source, and vehicle design must take this into account.

D. POWER SUPPLY DESIGN

In the LBL Feasibility Study /1/ it is concluded, in Section 5, that the RPV system would not place unreasonable or unreachable demands upon the electrical generation and distribution system. The review of the LBL analysis indicates no fundamental disagreement with this conclusion, although several qualifications and disagreements with the analysis itself are outlined below.

As a reference case, the authors took the Los Angeles area and assumed the extremely high estimate of 73% of all vehicles being electric and all of these would have inductive coupling capability, and further that 100% of all the freeway lane miles would be inductively coupled. They found that for the period about 1990 to 2000, this number of RPVs would imply approximately a 4% increase in total generation capacity required. Their calculations appear to be reasonable, although they do not seem to have considered the expected increase in regional vehicle miles traveled.

This 4% upward shift in the demand curve is not a uniform 4% increase for all periods of the day but rather represents a 4%

increase in total required capacity during peak periods. Peaking resource is expected to be approximately 14% of total capacity in the Southern California area in the 1990s. The 4% increase in total capacity implies an approximately 30% increase in peaking plant capacity. Estimates made by SCE on total required capacity growth per year is approximately 8%, including a growth in peak capacity of about 10% per year. The addition of the RPV system implies a forward shift of approximately 3 years in the peaking capacity addition schedule. No change to the base or intermediate addition schedule would be required. Due to the lower capital, environmental, siting and permitting requirements, the capacity addition schedule for peaking plants is more flexible than that for baseload plants (nuclear or coal). For a more conservative estimate of the requirements of an RPV system, a 15% of vehicles being electric and inductively coupled, and 50% of the freeway lane miles being electrified would imply approximately a four-month forward schedule change for peaking plants. With a planning horizon of 10 to 15 years for a utility, a four-month forward schedule shift in 10 years in the future does not seem to present an insurmountable barrier.

The calculations of operating cost for the RPV seem to imply an assumption of 6 ¢/kWh for electricity. Large industrial users of electricity in this region pay between 3 to 4 ¢/kWh. Although a negotiated rate schedule could run higher than 6 ¢/kWh due to the higher variable cost of supplying peak electricity, the number is not overly optimistic.

The allocation of the capital cost for capacity addition by the utility to the RPV system is incorrect. Capital requirements for generating capability are the concern of the utility, not that of the users. Rate schedules developed by the utility and approved by the PUC are designed to adequately reflect the cost of capital required for capacity addition. Furthermore, the assumed cost of $360/kW installed is too low for a capital intensive baseload plant, and too high for a peaking plant which an RPV system would require. For such a peaking plant, $200 to $250/kW installed capacity is a more representative number.

Unless relieved by pump storage, hydroelectric or east-west interchange, peak power will in the future continue to be supplied by petroleum and/or natural gas. Because of the coincidence of the demand from the RPV system with the peak demand seen by the utility, this appears to severely limit the petroleum displacement potential of the RPV system.

SECTION II

IMPACT ASSESSMENT

A. TRANSPORTATION IMPACTS

The concept of electric vehicles operating on roadways utilizing an electrical pickup from the roadway via an inductive electromagnetic connector and a 1-in air gap between the pickup and the roadway surface has been proposed. The intent of the system is to extend the range of electric vehicles, thereby making them a more viable contender with internal combustion engine vehicles for use as a general utility passenger vehicle. The task of analyzing this technology and its implications has been divided into several areas of concern and major issues. This section deals with transport elements of the RPV system. In this context, transport means the carrying capability or impediments to the ability of the RPV system to perform its mission. This section does not deal with issues of the roadway by itself, since they are addressed in the previous section. The transport issues that will be considered here are:

(1) Stream dynamics (movement of vehicles in relation to each other).

(2) Availability of the system to perform its mission.

(3) Weather and its implications for system operation.

(4) Capacity on a comparative basis with existing vehicle roadway systems and other competing transport systems, such as high speed rail and bus operations on roadways.

In order to properly assess the capabilities of an RPV on the highway, it is necessary to make several assumptions concerning the capabilities of the vehicle. For purposes of this investigation, it is assumed that the vehicle has enough batteries on board for a range of at least 14 mi. It is further assumed that the vehicle is capable of accelerating to 100 km/h and performing other maneuvers of acceleration, deceleration and lane transition, without being coupled to the roadway power source.

1. Stream Dynamics

This subject deals with the movement of a particular RPV in and among the entire stream of vehicles, whether or not they are inductively coupled. Two scenarios will be employed that deal with situations where the vehicle and the RPV system lane will be positioned at different locations on differing kinds of facilities.

a. <u>Scenario 1: The Urban Freeway</u>. The characteristics of this scenario assume four lanes in each direction with limited access. It is assumed that one lane will be roadway powered, and that this lane will be the outermost lane (Lane 4). It is further assumed in this scenario, that the facility operates at its capacity during the morning and the evening peak periods. Capacity, for purposes of this analysis, is 2000 vehicles per hour per lane. Therefore, this four-lane facility is carrying, during the peak periods, about 8000 vehicles per hour. Operating speed of the total facility is assumed to be approximately 35 to 39 mi/h. Motorists experience extreme difficulty in merging from one lane to another, and effective individual vehicle movement is wholly dictated by the total stream movement.

With these assumptions, Lane 4 becomes an impediment to non-RPVs wishing ingress or egress to the limited access facility. The outermost lane is the one where the merge and weaving section activities are at their highest level of activity. In addition, competition for this lane, between RPVs and non-RPVs, will be at its maximum. The principal reason for placing the roadway powered lane in Lane 4 of a four-lane facility is to ease the transition of the RPVs into the main stream of traffic. However, this logic appears to be defeated when the facility operates at its capacity. If the demand for usage of the facility was in the neighborhood of 2000 vehicles of the RPV variety, then the limited access facility would be completely blocked from ingress and egress movements.

It is unlikely, however, that a total demand of 2000 RPVs could be accomodated by one lane when non-RPVs are vying for the use of that lane. It can be expected that the availability, for RPV system purposes, of Lane 4 would be directly porportional to the number of vehicles entering and exiting in the vicinity of that interchange on a comparative basis, with the total vehicles utilizing the facility at that same point. In most urban freeway situations, the interchange influence area extends from one interchange to another. Therefore, the total lane capacity of 2000 vehicles per hour would never be available for RPVs.

Moving the RPV system lane inward toward Lane 1 increases the acceptability of this kind of operation on the total stream dynamics, where there is a mixed group of RPVs and non-RPVs. It should also increase the availability of such lane for RPVs. It appears, at the same time, to place a heavier demand upon the RPV to gain access to Lane 1. It is in Lane 1 that the RPV is less likely to run into slower moving vehicles, which would impede its continued movement in that lane. Therefore, in a multiple-lane urban freeway experiencing capacity conditions, it appears that the only logical lane for RPVs would be the fast-moving lane (Lane 1). As previously mentioned, this requirement also mandates that the RPV negotiate the traffic, acceleration, weaving, and passing maneuvers required to reach the RPV system lane on battery power only.

If two lanes are roadway powered instead of one lane, in the four-lane urban freeway scenario, certain improvements are realizable in the operation of RPVs. First, the RPV vehicle need only traverse two lanes until finally gaining an RPV system lane. Second, the RPV vehicle can pass slower moving vehicles found in either Lane 1 or Lane 2. Third, should a failure be experienced either in a vehicle or in the RPVs of a lane, the other lane could be available for the RPVs. It can be seen that benefits increase significantly for the RPV as the number of powered lanes increases. It therefore appears logical to conclude that the most desirable operation despite the population of the fleet consisting of ICEs and RPVs would be for all lanes of the four-lane urban freeway to be inductively coupled.

b. Scenario 2: The Urban Arterial. More specifically, Scenario 2 is dealing with the urban arterial at grade facility with traffic signal control and freedom of access from abutting lane uses to the arterial facility. In this configuration, the RPV would operate in mixed traffic. Despite capacity constraints or the particular operational service levels experienced by the facility, the RPV would be subject to, on the inside lane, vehicles wishing to make left turns in either left-turn bays or from that lane itself. The vehicle would therefore, as is commonly found in arterial movement, be subject to considerable lane transitions.

If the RPV were running in the outermost lane, or the lane closest to the curb or parking lane, it would be subject to ingress and egress movements of abutting lanes, door openings, cars parking and unparking, and pedestrian movement. Very little, if any, attention could be paid by the driver of an RPV to maintain a good presence over the powered roadway strip. His attention, as is the case with other motorists on an arterial facility, would have to be directed to the activity around him and the traffic on opposing cross-streets.

An arterial street system is generally not as smooth surfaced as a freeway. This is due mainly to the lower operating speeds, but more importantly surface drainage considerations are more demanding for arterials than for freeways, where the only consideration is roadway surface drainage.

In addition, many types of utilities can be found buried directly beneath the surface or an urban arterial. The presence of, and the need for access to these utilities, mandates intermittent digging up and trenching of the roadway surface and patching. Because of this need to gain access to the roadway surface and immediately beneath the surface by utility companies, it is quite common to find that the roadway driving surface is asphalt (ID 2) as opposed to a concrete surface commonly found on a freeway. This is so simply because the trenching and repair operation is made much easier by that type of fluid building material. That same type of a material, however, does not seem to present itself as a good base to hold down the RPV system source strip.

2. System Availability

An RPV system roadway should possess the same availability for vehicular use as existing highways. Therefore maintenance downtime should be similar. Maintenance will be complicated by the inability to use shoulders, temporary paved surfaces and alternate non-RPV system routes, when road surface or RPV system repair is required.

System availability is a potentially critical issue should an incident (e.g., an accident) occur on an RPV system route, such that the route becomes temporarily unavailable. In this case transport alternatives to the driver of an RPV, with insufficient battery range to complete the intended trip might not exist. In effect the driver/vehicle become stranded unless another RPV system route exists within the battery range of the RPV.

The system availability issue suggests strongly that redundancy must be an inherent part of an RPV system network; therefore multiple lanes of individual freeways and multiple routes available as alternatives should be assumed in any further consideration.

One of the principal effort of traffic engineers, aimed at optimizing traffic flow during peak periods, is distributing traffic flows equally throughout a particular traffic network. Overall maximum system throughput and overall system delay are measures of system efficiency. Traffic Engineers use the term "level of service" to identify relative density on a particular highway facility where the scale A through F is the measure. Level of service A denotes free flow, level of service C denotes design capacity and level of service F indicates total congestion. Ideally a total system (e.g., downtown central business district) should operate at a common level of service to optimize total system transport capability. This requires vehicular diversion capability of automobiles on the system. The RPV system concept runs counter to this philosophy. It promotes constraints to a particular route in some respects similar to fixed guideway transit, but without the high volume capability of that mode.

3. Weather Implications Upon System Operation

The RPV system as proposed will be exposed to the weather. Most of the nation's highways and freeways are located in areas where the freeze-thaw cycle is a major consideration in construction and maintenance. The issue of concern in this subsection is the effect upon system operation at and below the freezing point of water.

While attempts to avoid snow pack on freeways are pursued with much vigor, invariably this condition occurs several times each winter in areas subject to snowfall. The presence of snow on the roadway surface will preclude the operation of RPVs. Therefore the efforts of salt crews and snow removal crews would have to be increased, and/or the system conceded to be unavailable during these periods.

Rain and nighttime driving conditions reduce the operator's ability to identify lane lines. A visual reference to the inductive coupling will be difficult under these conditions and might pose a hazard by distracting the driver from required visual awareness.

4. Capacity Compared to Alternate Transport Modes

At best, within the forseeable future, the application of the RPV system to freeways and private automobiles will carry no more than the present vehicular capacity of a modern freeway, about 2000 vehicles per hour per lane. Assuming the optimistic occupancy of two persons per vehicle, 4000 people per lane per hour. On comparison a single line transit facility can handle 25,000 to 50,000 people per hour and a busway approximately 4000 people per lane per hour.

B. ECONOMIC IMPACTS

The following economic aspects of the RPV system are considered most important for an evaluation of its economic viability:

(1). The question of public acceptance and resultant market penetration is of foremost importance. Other economic issues are highly dependent on this issue.

(2) The question of who pays for the system and the method of payment is crucial. The most obvious options are:

(a) It could be financed by government from general revenues.

(b) It could be financed through a general vehicle tax.

(c) It could be financed by taxing RPVs only.

(3) The question of how to estimate the system cost is of similar importance.

While this section is centered on third aspect only, it should be noted that the first two aspects are at least of equal importance, as realized in the structured debate (see Section II for further detail).

It is felt that the cost method outlined in the LBL Feasibility Study (/1/ p. 101) is too crude, since it:

(1) Internalizes, and fails to parameterize, a number of critical assumptions, such as vehicle penetration and system installation rates.

(2) Neglects the effects of a number of critical factors, such as discount and escalation rates.

(3) Excludes the computation of critical economic measures, such as life-cycle system cost and required governmental expenditure per barrel of oil saved.

The following cost method has therefore been developed to cope with most of these problems. The parametric economic analysis reported in Part II, Section III.B, is based on this method. In essence, it is a present value life-cycle cost method, leading to the estimation of the:

(1) Levelized required revenue per vehicle mile

(2) System cost per barrel of oil saved

(3) Required governmental expenditure per barrel of oil saved.

1. Present Value of System Costs

This subsection presents a methodology for computing the total present value of the future cost to build and operate a RPV system. The present value of the systems life cycle cost (PVLCC) is assumed to be composed of three elements as shown in Equation (3-3).

$$PVLCC = PVCC + PVPC + PVML \quad (3\text{-}3)$$

where PVCC = the present value of construction cost

PVPC = the present value for the cost of of power for the system

PVML = the present value of maintenance labor

The present value of the construction cost is given by Equation (3-4).

$$PVCC = (1+g_{cn})^{\Delta t} * \sum_{t=o}^{T} \left(\frac{1+g_{cr}}{1+i}\right)^{t} * (RWC + RCC + PCC) * LMI_t$$

$$+ (1+g_{cn})^{\Delta t} * \sum_{t=15}^{T} \left(\frac{1+g_{cr}}{1+i}\right)^{t} * (RWC + RCC) * LMI_{t-15} \quad (3-4)$$

The construction costs are composed of two parts. The original cost, and the cost associated with the replacement of the original road coil after its in-use lifetime has ended. The terms in this equation are defined as follows:

g_{cn} = the nominal rate of escalation for highway construction cost

Δt = the number of years between the date of the unit cost estimates and the present

t = the incremental year index

T = the time in years from the present to the beginning of system construction plus the economic lifetime of the system

g_{cr} = the projected real rate of escalation of highway construction cost

i = the real rate of discount for federal expenditures

RWC = the unit cost of roadway construction in dollars per lane mile installed

RCC = the unit cost of the road coil in dollars per lane mile installed

PCC = the unit cost of the power conditioning and distribution system in dollars per lane mile installed

LMI_t = the lane miles of the system installed in time period t

Note: In the second term of the right hand side of the equation, road coil replacement, the road coil is assumed to have an installed lifetime of 15 years and the appropriate unit replacement cost is the sum of the roadway construction cost and the road coil cost. It is recognized that this cost is only an approximation to the replacement cost.

The present value of the power cost for the system is in Equation (3-5).

$$PVPC = (1+g_{pn})^{\Delta t} * \sum_{t=o}^{T} \left(\frac{1+g_{pr}}{1+i}\right)^{t} * \frac{1}{e} * C_p * ICVM_t \qquad (3\text{-}5)$$

Where the symbols not defined previously are:

g_{pn} = the nominal rate of escalation for the cost of utility supplied electricity appropriate for the daily time of demand from the system

g_{pr} = the projected real rate of escalation analogous to the above time

e = the total system efficiency as measured from utility electricity into the power conditioning system to the output of miles driven on the roadway in units of miles per kilowatt-hour[a]

c_p = the unit cost for utility supplied electricity appropriate for the time period of the system demand in units of dollars per kilowatt-hour

$ICVM_t$ = the number of inductively coupled vehicle miles driven on the inductively coupled roadway system in year t

The number of inductively coupled vehicle miles on the RPV system in year t is defined by Equation (3-6).

$$ICVM_t = FFIC * \frac{VM}{LM\text{-}year} * \sum_{k=t}^{t-TS} * (LMI)_k * Z(k - t) \qquad (3\text{-}6)$$

The new variables are defined as follows:

FFIC = the final fraction which is ultimately reached of inductively coupled vehicles to total vehicles on the inductively coupled way

VM/LM-year = the average vehicle miles per lane mile year for the type of freeway being inductively coupled

---

[a]System efficiency may change over time due to vehicle population changes.

TS = the number of years required from first installation for a lane mile to reach full saturation of inductively coupled vehicles

Note: The sum in the above equation is a decrementing sum going from the time period in question backwards TS steps

Z(k-t) = a step function of TS steps going from zero to one describing the rate at which a newly installed lane mile of inductive way reaches saturation of inductive vehicles.

The remaining cost for the system are assumed to be <u>maintenance labor</u> and are given in Equation (3-7).

$$PVML = (1+g_{ln})^{\Delta t} * \sum_{t=o}^{T} \left(\frac{1+g_{lr}}{1+i}\right)^{t} * LMC * TLMI_t \qquad (3\text{-}7)$$

Where the new variables not previously described are defined as follows:

g_{ln} = the nominal rate of escalation of system labor cost

g_{lr} = the projected real rate of escalation of system labor cost

LMC = the unit cost of maintenance labor in terms of dollars per lane mile

$TLMI_t$ = the total number of lane miles installed by period t

2. Levelized Required Revenue per Vehicle Mile

To find the cost associated with one vehicle mile traveled on the system by a user of the system, we assume that there exists a future stream cf revenues which is equal to the present value of the life cycle cost as shown in Equation (3-8). This assumes that the RPV system roadway is a publicly owned facility analogous to a toll road, not a private venture.

$$PVLCC = \sum_{t=o}^{T} \frac{Rev_t}{(1+i)^t} \qquad (3\text{-}8)$$

where Rev_t is the system revenue income in year t. We now assert that the revenue will be assessed from the users of the system on a per vehicle mile basis, hence Equation (3-9):

$$Rev_t = RRVM * ICVM_t \tag{3-9}$$

where, RRVM is the required revenue per inductively coupled vehicle mile traveled on the RPV roadway (constant in real dollar terms).

Hence Equation (3-10)

$$RRVM = PVLCC * \sum_{t=o}^{T} * \frac{ICVM_t}{(1+i)^t} \tag{3-10}$$

3. System Cost per Barrel of Oil Saved

We define the amount of petroleum saved by one inductively coupled mile driven as shown in Equation (3-11).

$$Oil = \frac{1}{mi/gal_{BL}} - \frac{1}{mi/gal_{IC}} \tag{3-11}$$

where the mi/gal is the effective miles per gallon of petroleum, not gasoline, of the inductively coupled vehicle and the baseline comparator vehicle respectively. The effective miles per gallon of petroleum for the RPV is given in Equation (3-12).

$$mi/gal_{IC} = \frac{\text{Btus total}}{\text{Btus oil}} * \frac{\text{Btus}}{\text{gal oil}} * \frac{\text{kWh out}}{\text{Btus in}} * \frac{\text{miles}}{\text{kWh in}} \tag{3-12}$$

where the first term is the ratio of the utility companies total Btus and the Btus of petroleum into the utility. The second term is the number of Btus in a gallon of petroleum. The third term is the ratio of the total kilowatt-hour output of utility versus the total energy input in Btus. The last term is the system efficiency of the RPV system as previously defined in terms of vehicle miles per kilowatt-hour delivered at the roadway.

The effective miles per gallon of petroleum of the baseline comparator vehicle is defined in Equation (3-13).

$$mi/gal_{BL} = \frac{\text{miles}}{\text{gal gas}} * \frac{\text{gal gas}}{\text{gal oil}} \tag{3-13}$$

where the first term after the equal sign is the conventional miles per gallon of the vehicle measured in miles per gallon of gasoline, and the second term is the resource-(i.e., wellhead)-to-gas-pump efficiency going from oil to gasoline. The total system cost for a barrel of oil conserved by the system can now be defined as shown in Equation (3-14).

$$\frac{COST}{Bbl} = 42 * \frac{RRVM}{\Delta oil} \tag{3-14}$$

where the "42" represents the 42 gallons in a standard barrel of oil and RRVM is the previously defined required revenue per vehicle mile.

4. Required Governmental Expenditures per Barrel of Oil Saved

The above methodology does not provide an accurate measure of the viability of the system in terms of a cost effective oil conservation method since it does not include the difference in cash flows which would be experienced by a user of the inductively coupled system vs. a user of a baseline vehicle. To compute the difference in the present value of such cash flows requires the use of a procedure outside of this methodology. One such procedure is described in the JPL Electric and Hybrid Vehicle Cost Handbook /7/. In terms of Equation (3-15)

$$\Delta APV_c = PV_{IC} - PV_{BL} \tag{3-15}$$

where PV_{IC} is the present value of the future cash flows to a user of the inductively coupled system and PV_{BL} is the present value of cash flows for a user of the baseline comparator vehicle. The PV_c is the present value difference of some stream of subsidies which must be provided for the consumer to be economically indifferent (assuming he is a present value purchaser) between the two systems. The present value of a stream of subsidies paid to a consumer is not the same as the present value of the same stream of subsidies provided by the government since the rate of discount presumably is different. Hence, the present value to the government of such a stream of subsidies is given by Equation (3-16).

$$\Delta PV_g = \Delta PV_c * \frac{\text{USPWF (Government 10\%)}}{\text{USPWF (Consumer 2\%)}} \tag{3-16}$$

where the ratio in the second term of the right hand side of the equation is the ratio of the uniform series present worth factor for governmental expenditures at a 10% rate of discount vs. the uniform series present worth factor for the consumer at a 2% rate of discount. This equation will hold if the rate of subsidies provided is approximately uniform. Finally the amount of dollars the government must spend to conserve a barrel of oil in this fashion is given in Equation (3-17).

$$\frac{\text{PV of Government costs}}{\text{Bbl of oil saved}} = \frac{PV_g}{Oil} \qquad (3\text{-}17)$$

where oil is as defined in the above section. If this number is 0, it would mean that no net present value of government expenditures would be required for this system to be economically viable. It may mean there are positive and negative expenditures in the future but their present value would be zero.

C. ENERGY IMPACTS

Two critical elements of the RPV system energy impacts are analyzed in this section:

(1) System efficiency

(2) Total resource demand

The analysis of the system efficiency is based on the RPV system design specifications in the LBL Feasibility Study /1/, and concentrated on the effect of kilowatt-load per car, RPV market penetration, and traffic density. The resource demand is analyzed in terms of the installation and operating demands, as well as a comparison of the total resource demand to the electric, hybrid and ICE vehicle alternatives considered in this study.

1. RPV System Efficiency

The system efficiency characteristics tabulated in the LBL Feasibility Study (/1/ p. 60) are based on two critical assumptions in particular:

(1) A full design load of 20 kW per car

(2) All cars are inductively coupled

This subsection is a parametric analysis of the system efficiency (kilowatt-load/kilowatt-input) as a function of vehicle density (cars/lane mile), for cases with loads less than 20 kW per car and at various ratios between coupled and uncoupled cars on the roadway.

The challenge of assumption (1) is primarily based on the observation that vehicle speed and hence kilowatt-load per car decreases with an increase in density (see Figures 3-7 and 3-8). The challenge of assumption (2) is based on a concern for the consequences (the risk) of a situation where only portions of the vehicle purchasers have chosen to buy RPV.

The principal parameters which this parametric analysis is based on are described in the following paragraphs.

a. Traffic Flow Parameters. The relationship in Equation (3-16) between the average speed and the vehicle density has been assumed, and is commonly used by transportation planners (/8/ p. 291):

$$u = u_f \, e^{-1/2(k/k_o)^2} \qquad (3\text{-}16)$$

where u = average speed, mi/h

u_f = free speed = 60 mi/h

k = density (cars/lane-mi)

k_o = optimal density (cars/lane-mi), i.e., at maximum

b. Vehicle Power Requirement. The commonly used roadload Equation (3-17) is furthermore assumed:

$$P_R = (0.0123\ W_v + 0.004826\ \bar{C}_D A\ u^2)\ 2.7245 * 10^{-3}\ u \qquad (3\text{-}17)$$

$$P_L = P_R/\xi$$

where P_R = roadload power, kW

W_v = vehicle weight, kg

C_D = air drag coefficient

A = frontal area, m^2

P_c = power load at pick-up, kW

ξ = power train efficiency

c. RPV System Losses. Finally, Equation (3-18) for RPV system system losses is assumed, primarily based on the LBL Feasibility Study /1/, is assumed:

$$L_s = L_c \, k \, F_c + L_v \, k \, (1 - F_c) + L_o(1 - k(3 - 2F_c) \frac{1.52}{1609} \quad (3\text{-}18)$$

where L_s = total system losses, kW/lane-mi

L_c = losses per coupled car (kW/car)
= 1.3 kW + 0.005 P_c, kW

L_v = losses per uncoupled car, kW/car
= 1.0 kW (15 feet car)

L_o = losses when no car present, kW/lane-mi = 19.1 kW

F_c = coupled/uncoupled vehicle ratio

It should be noted here, that more optimistic assumptions about L_c could be envisioned as a result of further design trade-off studies. The extended analysis of the system efficiency, described in Part III, Section III.C, is based on such assumptions, involving a direct scaling of L_c as a function of P_c; L_c (kW/car) = 0.07 P_c(kW).

d. Results. Figures 3-3 through 3-6 shows the efficiency drop with lower kilowatt-loads per car (P_c = 2, 5, 10, 20 kW) at various ratios between coupled and uncoupled car on the system (F_c = 0.1, 0.2, 0.5, 1.0).

Figure 3-7 shows Case A, where the speed and power load per car drops with increased density, assuming a vehicle design which require 20 kW at 60 mi/h (including 4 kW for recharging). The traffic parameters are characteristic for an excellent roadway installation (u_f = 60 mi/h; k_o = 70 veh/lane-mi).

Figure 3-8 shows Case B, which is as Case A, except for traffic parameters characteristic for a poorer roadway installation (u_f = 60 mi/h; k_o = 50 veh/lane-mi).

It is seen that the difference between Case A and B are not all that great. The key factors resulting in a variation in system efficiency are clearly the power loads per car and the ratio between coupled and uncoupled vehicles. Other contributing factors than speed, which would result in lower kilowatt-loads per car, and hence lower system efficiency, are: (1) offset from centerline and (2) no charging of the batteries.

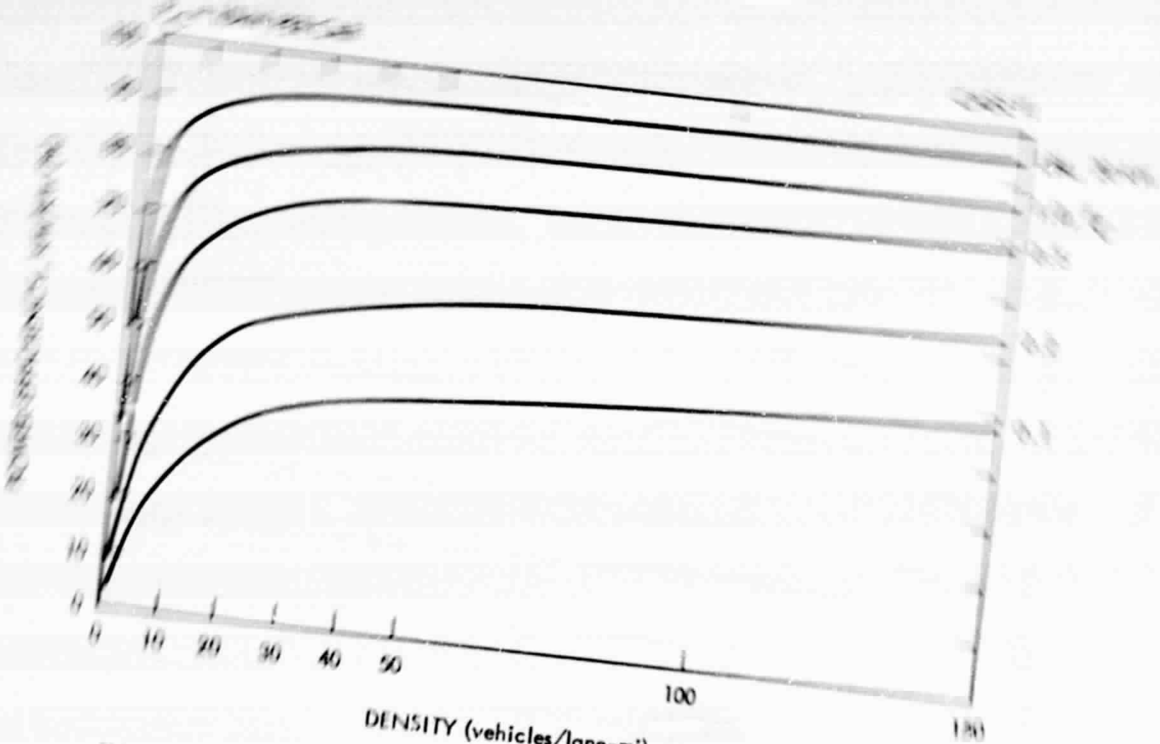


Figure 3-4. System Efficiency with 10-kW Load per RPV

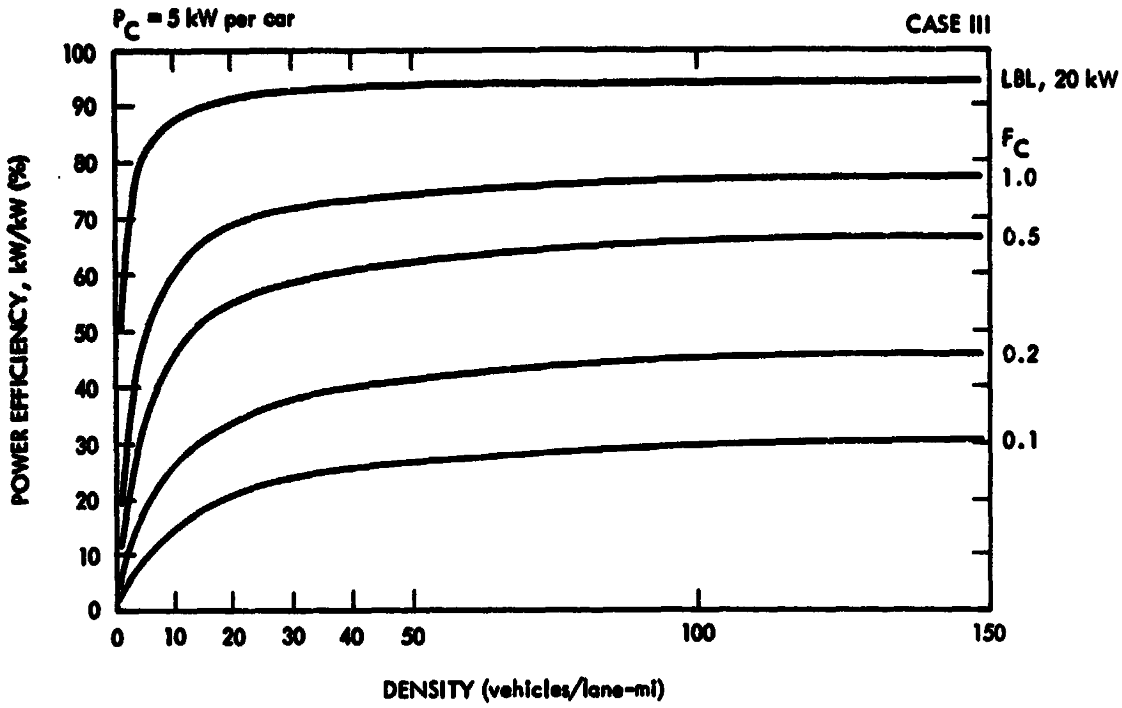


Figure 3-5. System Efficiency with 5-kW Load per RPV

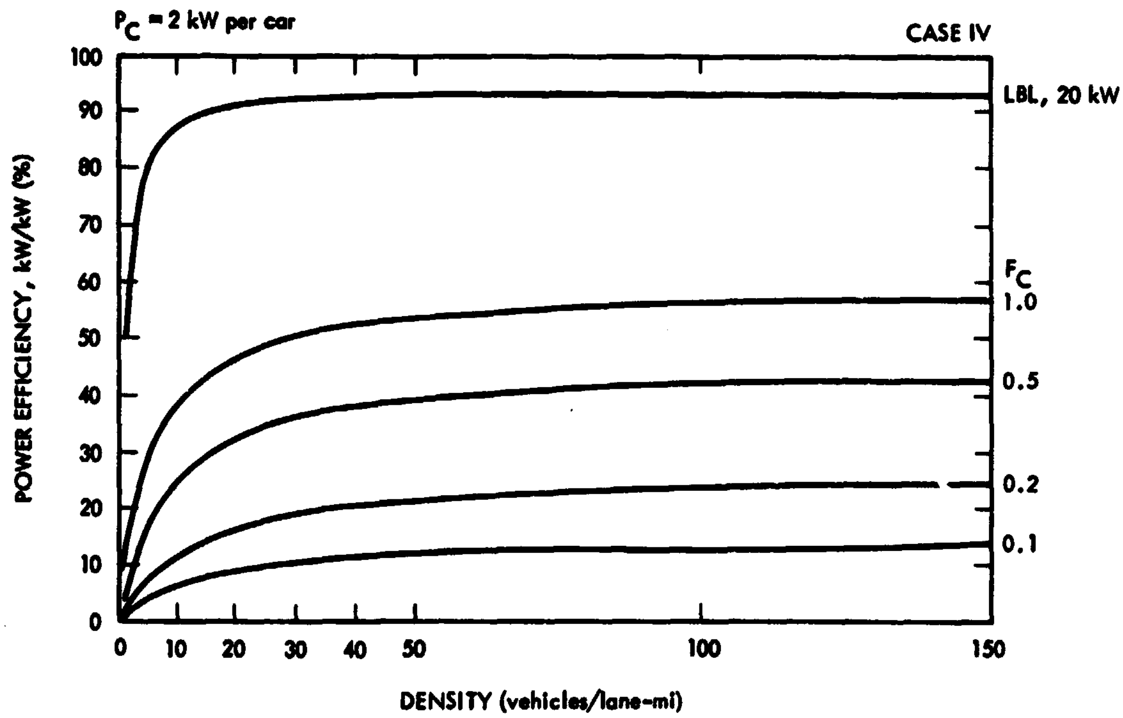


Figure 3-6. System Efficiency with 2-kW Load per RPV

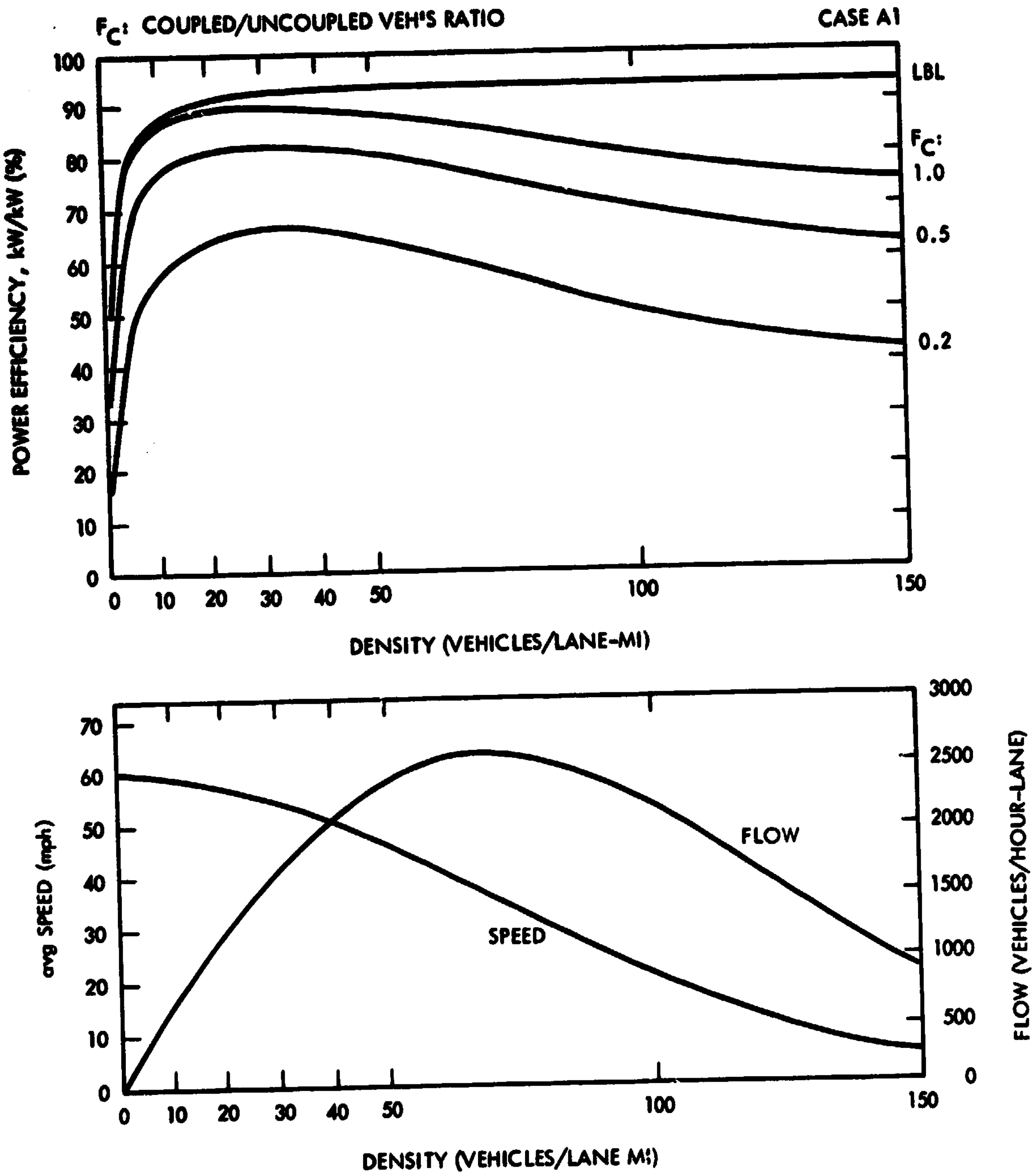


Figure 3-7. System Efficiency on an Excellent Roadway Installation

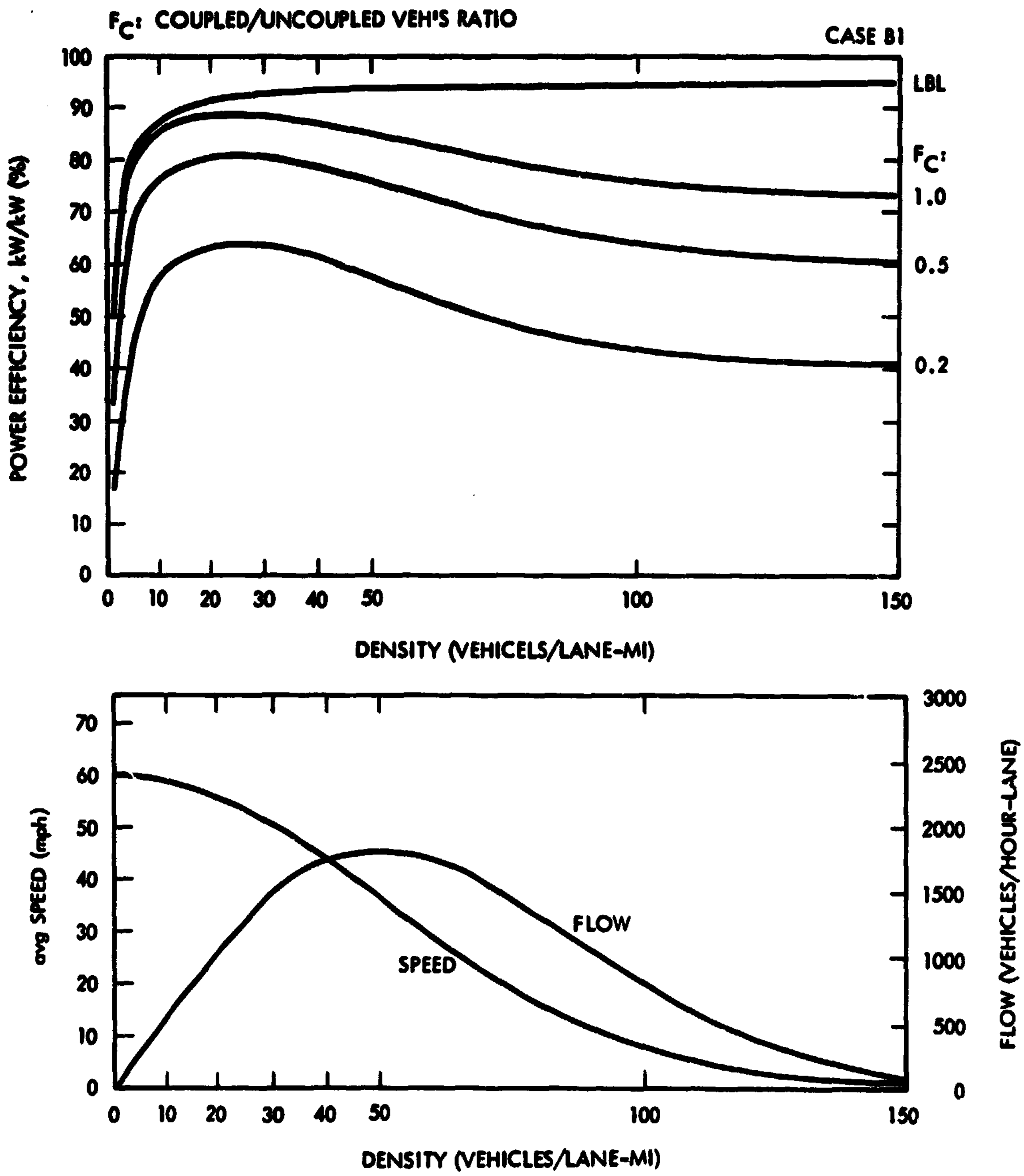


Figure 3-8. System Efficiency on a Fair Roadway Installation

2. RPV System Energy Resource Demand

a. System Operating Energy Resource Demand. Presumably, the policy objective that an inductively coupled system attempts to satisfy is the displacement of petroleum from transportation. Questions have been raised on the viability of the system to achieve this objective, since it requires electrical energy during the peak to intermediate demand period. To examine this issue, a possible electrical generation system for the year 2000 is presented in Figure 3-9. This is based upon the Brookhaven National Laboratories Reference Energy System with several modifications /15/ /16/: (1) a small amount of nuclear base capacity is utilized for pumped storage which is then used to meet peak demands; (2) a small amount (approximately 5%) of coal is routed to liquefaction and gasification.

Before any numbers are put to paper, several caveats should be made. First, this is just one of an infinite number of possible year 2000 generation systems. Secondly, there exist no generalized national electrical generation systems, as they are all highly regional. Thirdly, the distinction between base, intermediate, and peak is arbitrary and the split of technologies used to supply them represents an oversimplification of the real system. Table 3-5 presents the wellhead or mine mouth resource demand (in Btus) resulting from a 1 kWh demand for each of the three demand periods.

Table 3-5. Resource Sensors of 1-kWh Demand in Year 2000 in British Thermal Units

1 kWh of	Coal	Requires Oil	Gas
Peak	1250	3536	2968
Intermediate	7610	1890	1590
Base	2760	0	0

The rows do not sum to approximately the same number of British thermal units since the contribution from hydroelectric and from nuclear sources is not accrued here.

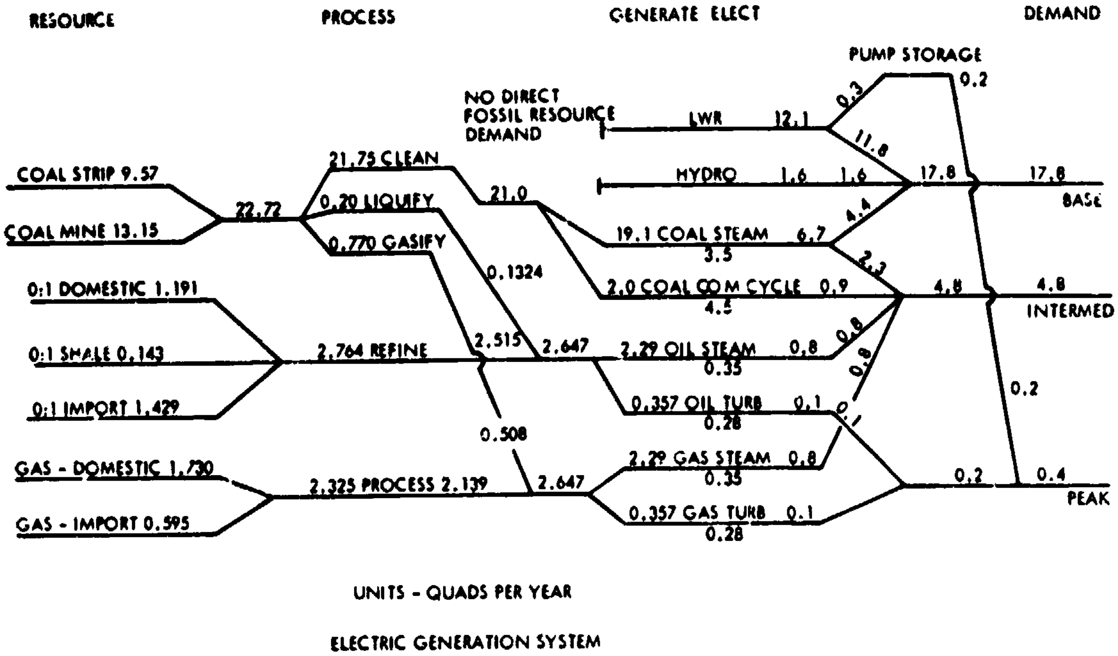


Figure 3-9. Year 2000 Electric Energy Flow

b. Energy Embodied in Inductive Supply and Generation Facilities. Unlike other transportation petroleum displacement technology options, the inductively coupled system requires a large initial investment in fixed way hardware. Such large investment implies a concomitant energy investment.

Tables 3-6 and 3-7 present a breakdown of the road coil and the power distribution facilities in terms of cost and energy. The energy impact of the capital investments are derived from work done by the Center for Advanced Computation at the University of Illinois, and devoted to the examination of energy input/output analysis /17/ /18/.

There are several criticisms that can be pointed at energy input/output analysis but the one of greatest concern here is that the coefficients which represent British thermal units of energy per dollar spent were for 1967. One can assume that technology remains static from 1967 to the present time, and hence reduce the energy impact simply by the ratio of the wholesale price indices for the two respective time periods. However, several have argued that the energy input into construction has been escalating faster than the dollar has been inflating; hence, the results given in Tables 3-6 and 3-7 represent an underestimate, not an overestimate.

The second major area of concern is the percentage of petroleum going into the construction energy. Since the basic motivation for an inductively coupled system is scarcity of petroleum, one would assume that the petroleum going into construction during the year 2000 time frame would be proportionately less than that which was going into the year 1967. In other words, even if the energy coefficient is basically correct, one can still argue that the petroleum coefficient is a overestimate, not an underestimate.

With the above caveats in mind, the results of this analysis imply 50×10^9 Btu/lane-mi from all sources and approximately 29×10^9 Btu/lane-mi from petroleum.

c. Comparative Resource Demand. The results of the two previous sections can now be put together to derive a comparative measure of the RPV system versus the alternatives of the hybrid and the all-electric vehicle.

Table 3-8 presents the wellhead petroleum only resource demand resulting from one vehicle mile of travel. The petroleum consumption of the conventional vehicle is calculated assuming 30 mi/gal yearly average and that all transportation fuel is derived from petroleum, not from coal. The petroleum demand for the electric vehicle is calculated assuming that it is recharged wholly from baseload sources. The petroleum demand for the hybrid system is calculated assuming approximately 0.5 kWh from baseload in addition to 90 mi/gal from gasoline (this is a conservative hybrid - it could be much better). The inductively coupled electric vehicle system petroleum demand is calculated assuming that one-half of a load is from intermediate sources, one-fourth is from the peak, and the remaining one-fourth is from baseload.

Contrary to some allegations, these assumptions imply a petroleum displacement of up to 80% for the inductively coupled system compared with the efficient conventional vehicle. Since the all-electric vehicle is assumed to be recharged from baseload, its petroleum displacement is 100%.

The foregoing results along with the embodied energy analysis can now be used to provide a comparative measure for the several options. Figure 3-10 presents the petroleum energy saved vs. time or total miles driven for the various options. The vertical scale is total cumulative wellhead petroleum saved in units of 10^9 Btu for each lane-mile. The horizontal scale is the total accrued miles traveled on the lane-mile (including conventional, not just alternative vehicles). The dotted lines are the savings in wellhead petroleum assuming that all vehicles were instantly and totally replaced with the alternative vehicle. The solid line represents the savings assuming a 10-year replacement scenario (10% more is replaced each year, i.e., 10% in the first year, and 90% in the ninth year would be

Table 3-6. Embodied Energy (Road Coil)

Description	Quantity Per Lane Mile	Cost Per Unit	Cost $	BEA Sector	KBTU Unit	KBTU $	WPI (67) WPJ (78)	Total KBTU
(1) CORE - Laminated Silicon Steel Sheet	100 tons		100K			267		26700K
- Magnitite Filler & Bouding	200 tons		(?) 10K	500		147		1470K
(2) Conductor - Stranded Aluminum	12 tons		21.3K			-244		519/K
- Insulation Support	8 tons		23.9K			110		2629K
(3) Fittings/Connectors/Fastener	1000 sets		?					
(4) Assembly	528		(?) 10K					
(5) Transport	-320 tons		0					
(6) Installation			20K					
(7) Road Work			39.6K			76		3010K
TOTALS								39006K

40×10^9 Btus/lane mile
60% Petro 24×10^9 Btus Petro

Table 3-7. Embodied Energy (Power Supply System)

	Cost	BEA Sector	KBTU $	KBTUS
(1) 3000 KVA Transformers	$27,000	53.02	82.7	223K
(2) 2400 KVAR Capacitors	16,000	57.03	59.0	896K
(3) Cyclo Inverter (SCRS)	20,000	57.02	58.5	1170K
(4) 60 Hz Switch Gear	20,000	53.03	52.2	1050K
(5) Line Filters	20,000	57.03	59.0	1180K
(6) Controls	15,000	53.05	43.4	651K
(7) Installation, Housing	20,000	40.09	153.9	3073K
	138K			10,253K

Table 3-8. Wellhead Demand from One Vehicle Mile, Year 2000

Vehicle Type	Gasoline Fuel Equivalent, mi/gal	Electricity	Petroleum Resource, Btu/mi
ICE Vehicle	30	-	4760
Electric Vehicle	-	Baseload only	0
Hybrid Vehicle	90	Baseload only	1587
Roadway Powered Vehicle	-	1/4 Baseload 1/2 Intermediate 1/4 Peak	915

alternative vehicles). The petroleum British thermal units saved are computed from Table 3-8 with the savings relative to a 30 mi/gal conventional car. Only one-half of the original petroleum net energy investment for each lane-mile of the RPV system roadway has been assessed since the inductive to non-inductive split was assumed to be approximately 50-50.

The following tentative conclusions can now be drawn: (1) the petroleum payback period for the RPV system appears to be on the order of 5 years, (2) the petroleum displacement for the various alternatives are all of the same order of magnitude with the all-electric ranking the highest, and (3) for the first 10 to 15 years after the establishment of the system, the hybrid vehicle option would present more petroleum savings than the RPV system.

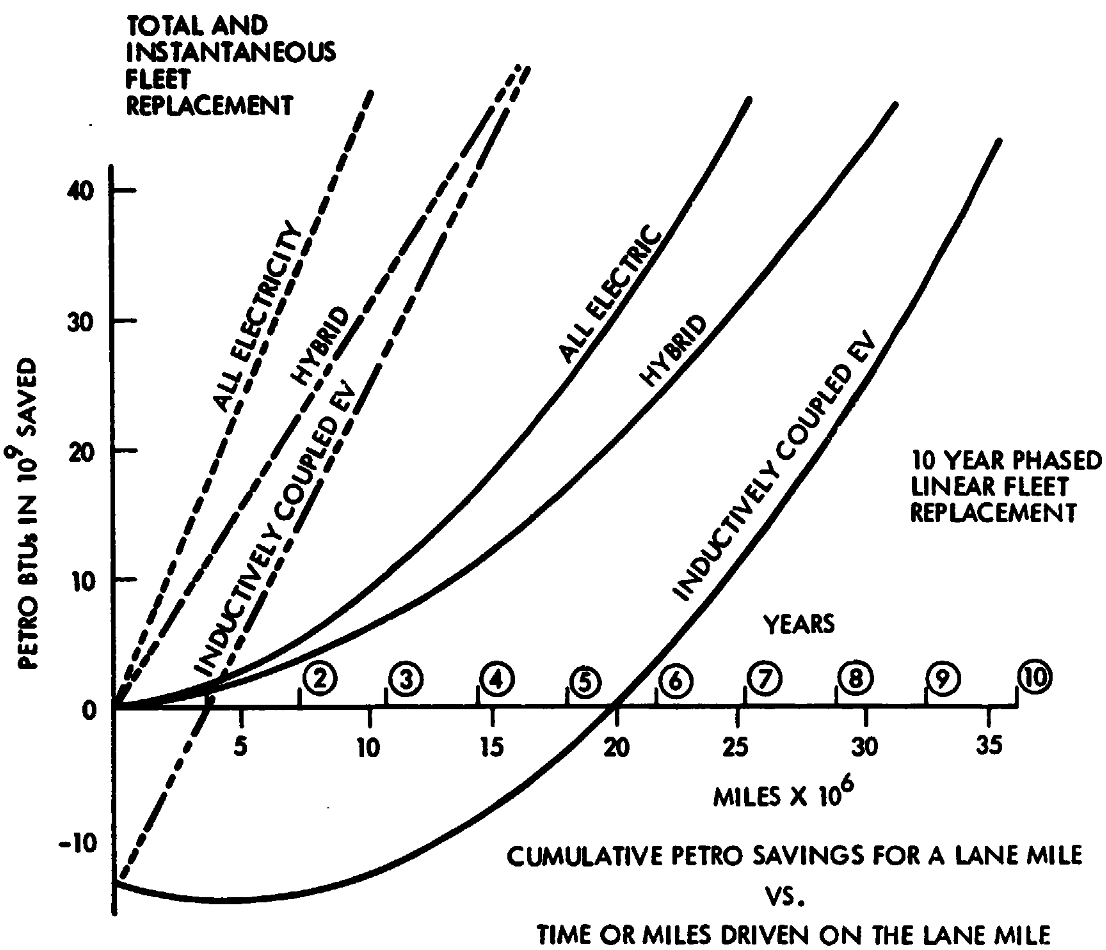


Figure 3-10. Cumulative Comparative Petroleum Savings per Lane-Mile

SECTION III

STUDY APPROACH

A. PROPOSED INQUIRY SYSTEM

The overall purpose of this study is to help DOE in its effort to establish an R&D policy concerning further funding of RPV research. This subsection deals first with the relevance of the selected study approach to such cases of real policy-making, then provides an attempt to clarify the broader philosophical background of this particular approach (or inquiry system).

1. Policy-Making and Dialectical Inquiry

The method used for studying the major issue of whether R&D funding for the roadway powered vehicle system should be continued is an application of dialectical inquiry. It proceeds from the assumption that policy is ultimately based on the relative weight of arguments presented for and against a policy option. The method augments detailed scientific analyses by showing where they fit into the structure of the arguments which either support or deny the viability of a policy option. The method further assumes that actively involving representatives of the parties of interest in the process yields dimensions of argument, beliefs, and insights beyond those normally captured by other methods.

A dialectical inquiry analyzes an issue from two or more points of view. Dialectical inquiry explicitly acknowledges the role of purpose in securing information for policy-making and for problem solving concerning complex social issues. In the scientific ideal, data are considered to be impersonal, impartial and unbiased and therefore replicatible by anyone else qualified to undertake the investigation. The idea of dialectical inquiry, on the other hand, assumes that data may be gathered, or if necessary, created for a specific purpose (it is frequently one-sided, interested, misleading and incomplete). Consequently, dialectical inquiry contends that all data and conclusions should be opposed by countervailing data and conclusions collected with roughly similar degrees of intensity.

Policy-making requires both scientific and dialectical data as an input. Failure to understand and therefore to take account of the essential differences between them creates problems. It frequently results in scientific conclusions being unimplemented or unused and in dialectical conclusions being misunderstood or misinterpreted. Dialectical inquiry treats any statement as being comprised of two components - a factual part called data (which may be scientific data) and a belief and value part called a warrant which derives from the experience and intention of the source making the statement. Since all complex policy-making involves the merger of conflicting interests, dialectical inquiry provides information and insights for policy-making that other methods do not provide.

The purpose of applying dialectical inquiry to policy issues is to inform the decision-maker as to the breadth and the depth of the case being made for each side. It is assumed that the decision-maker will review the strength of the case on each side and arrive at a final conclusion. The analysis helps the decision-maker in the following ways:

(1) It provides an overview of the critical elements involved in the case for each alternative.

(2) It provides a sense of the strength or plausibility of the argument being made by each side.

(3) It highlights the discrepancies, differences and gaps in the arguments and procedures of the opposing parties.

(4) It helps identify the critical elements in the path of argumentation leading to a final conclusion.

(5) It pinpoints exactly where various data sources or detailed studies lie in the chain of the policy argument.

(6) Because it reveals weaknesses in arguments on one or more sides of an issue it identifies topics for further research or study. That is, it indicates what additional data, analysis or experiments would be useful to improve the quality of the argument.

(7) Coupled with methods for formally weighing the arguments and assessing their plausibility, it can be used as a decision support aid for the decision-maker.

The specific procedure employed by JPL was first to conduct a structured debate. The formal framework of this debate is described in later in this section. Four individuals were chosen to represent the RPV system position and four individuals were chosen to represent the counter position. Individuals were chosen, to the extent possible, who had done research in the area and who generally favored the position they argued. This insured the active participation of several parties with an interest in the outcome of the policy decision. Further, four individuals were chosen to serve as a third party. The primary functions of the third party are to clarify arguments during the debate and to summarize arguments using argumentation analysis following the debate. Third party members were chosen who were rather neutral with respect to the outcome. The members of each team are identified in Appendix A of this report.

It should be pointed out that whereas the members of the RPV system team shared a common view about the advantages of RPV system, the opposing EHV team was more fragmented, each having expertise in either battery-operated, hybrid, or synthetic fuel alternatives, but not all. Consequently their position was less cohesive.

2. Inquiry Systems

A number of distinct and radically different inquiry systems have been developed during the past three centuries. Some of the historically famous inquiry systems - those of Leibniz, Locke, Kant, Hegel, and Singer - have been discussed in a modern context by Churchman /21/. Models for these inquiry systems have been described and their use for technological forecasting assessed by Mitroff and Turoff /22/, who have succinctly provided the sense of each of the five inquiry systems (IS) cited above.

a. Leibnizian Inquiry System

"The philosophical mood underlying the major part of theoretical science is that of Leibniz. The sense of Leibnizian inquiry can be rather quickly and generally captured in terms of the following characteristics.

(1) Truth is analytic, i.e., the truth content of a system is associated entirely with its formal content. A model of a system is a formal model and the truth of the model is measured in terms of its ability to offer a theoretical explanation of a wide range of general phenomena and in our ability as model-builders to state clearly the formal conditions under which the model holds.

(2) A corollary to (1) is that the truth of the model does not rest upon any external considerations, i.e., upon the raw data of the external world. Leibnizian inquirers regard empirical data as an inherently risky base upon which to found universal conclusions of any kind since from a finite data set one is never justified in inferring any general proposition. The only general propositions that are accepted are those that can be justified through purely rational models and/or arguments. Through a series of similar arguments, Leibnizian IS not only regard the formal model component as separate from the data input component but prior to it as well. Another way to put this is to say that the whole of the Leibnizian IS is contained in the formal sector and thus it has priority over all the other components."

b. Lockean Inquiry System

"The philosophical mood underlying the major part of empirical science is that of Locke. The sense of Lockean IS can be rather quickly and generally grasped in terms of the following characteristics.

(1) Truth is experimental, i.e., the truth content of a system is associated entirely with its empirical content. A model of a system is an empirical model and the truth of the model is measured in terms of our ability (a) to reduce every complex proposition down to its simple empirical referents (i.e., simple observations) and (b) to insure the validity of each of the simple referents by means of the widespread, freely obtained agreement between different human observers.

(2) A corollary to (1) is that the truth of the model does not rest upon any theoretical considerations, i.e., upon the prior assumption of any theory (this is the equivalent of Locke's Tabula Rasa). Lockean inquirers are opposed to the prior presumption of theory, since in their view this exactly reverses the justifiable order of things. Data is that which is prior to and justifies theory, not the other way around. The only general propositions which are accepted are those which can be justified through "direct observation" or have already been so justified previously. In sum, the data input sector is not only prior to the formal model or theory sector but it is separate from it as well. The whole of the Lockean IS built up from the data input sector."

c. Kantian Inquiry System

"The Kantian Inquiry System incorporates the philosophies of both Locke and Leibniz. The sense of Kantian inquiry can be rather quickly grasped through the following set of general characteristics.

(1) Truth is synthetic, i.e., the truth content of a system is not located in either its theoretical or its empirical components, but in both. A model of a system is a synthetic model in the sense that the truth of the model is measured in terms of the model's ability (a) to associate every theoretical term of the model with some empirical reference and (b) to show that (how) underlying the collection of every empirical observation related to the phenomenon under investigation there is an associated theoretical referent.

(2) A corollary to (1) is that neither the data input sector nor the theory sector have priority over one another. Theories or general propositons are built up from data, and in this sense theories are dependent on data, but data cannot be collected without the prior presumption of some theory of data collection (i.e., a theory of "how to make observations," "what to observe," etc.) and in this sense data are dependent on theories. Theory and data are inseparable. In other words, Kantian IS require some coordinated image or plan of the system as a whole before any sector of the system can be worked on or function properly."

d. Hegelian or Dialectical Inquiry System

"Hegelian or Dialectical IS is the epitome of systems involving conflict and synthesis. The idea of the Hegelian or Dialectical IS can be conveyed as follows.

(1) Truth is conflictual, i.e. the truth content of a system is the result of a highly complicated process which depends on the existence of a plan and a diametrically opposed counterplan. The plan and the counterplan represent strongly divergent and opposing conceptions of the whole system. The function of the plan and the counterplan is to engage each other in an unremitting debate over the "true" nature of the whole system, in order to draw forth a new plan that will be hopefully reconcile (synthesize, encompass) the plan and the counterplan.

(2) A corollary to (1) is that by itself the data input sector is totally meaningless and only becomes meaningful, i.e. "information," by being coupled to the plan and the counterplan. Further, it is postulated that there is a particular input data set which can be shown to be consistent with both the plan and counterplan, i.e., by itself this data set supports neither naturally, but that there is an interpretation of the data such that it is consistent with both the plan and counterplan. It is also postulated that without both the plan and the counterplan the meaning of the data is incomplete, i.e., partial. Thus, under this system of inquiry, the plan and the counterplan, which constitute the theory sector, are prior to the input sector and indeed constitute opposing conceptions of the whole system. Finally, it is also assumed that on EVERY issue of importance, there can be found or constructed a plan and a counterplan, i.e. a dialectical debate can be formulated with respect to ANY issue. On any issue of importance there will be an intense division of opinion, feeling."

e. Singerian Inquiry System

Singerian IS are synthetic, multimodel, interdisciplinary systems. Actually, the Singerian IS is a meta IS in that it constitutes a theory about other IS.

"Singerian IS are the most complicated of all the inquirers encountered thus far and hence the most difficult to describe fully. Nevertheless, we can still give a brief indication of their main features as follows.

(1) Truth is pragmatic, i.e. the truth content of a system is relative to the overall goals and objectives of the inquiry. A model of a system is teleological or explicitly goal-oriented, in the sense that the truth of the model is measured with respect to its ability to define (articulate) certain systems objectives, to propose (create) several alternate means for securing these objectives, and finally, at the "end" of the inquiry, to specify new goals (discovered only as a result of the inquiry) that remain to be accomplished by some future inquiry. Singerian inquiry is thus in a very fundamental sense nonterminating, though it is response-oriented at any particular point in time, i.e. Singerian inquirers never give final answers to any question although at any point they seek to give a highly refined and specific response.

(2) As a corollary to (1), Singerian IS are the most strongly coupled of all the inquirers. No single aspect of the system has any fundamental priority over any of the other aspects. The system forms an inseparable whole. Indeed, Singerian IS take holistic thinking so seriously that they constantly attempt to sweep in new variables and additional components to broaden their base of concern. For example, it is an explicit postulate of Singerian inquiry that the systems designer is a fundamental part of the system, and as a result he must be explicitly considered in the systems representation, i.e. as one of the systems components. The designer's psychology and sociology is inseparable from the system's physical representation."

It is not too difficult to agree with Mitroff and Turoff's /22/ conclusion that the Hegelian and Singerian IS offer the greatest prospects for the analysis of ill-structured problems.

Mason /23/ has incorporated several aspects of the Hegelian and Singerian IS in a form he terms "Counterplanning and Structured Debate." The decision-maker and the investigator are both part of the inquiry system. The decision-maker responds to the structured debate by forming a new "weltanschauung," i.e., a synthesis that is a more general and expanded view of the problem.

The inquiry system selected to answer the basic question of further research of the RPV system is diagrammed in Figure 3-11. The first phase ends with a structured debate while the second phase concludes with the formation of recommendations. The design of this inquiry system is philosophically founded on the ideas of the Hegelian and Singerian inquiry systems, and from Mason's /23/ adaptation.

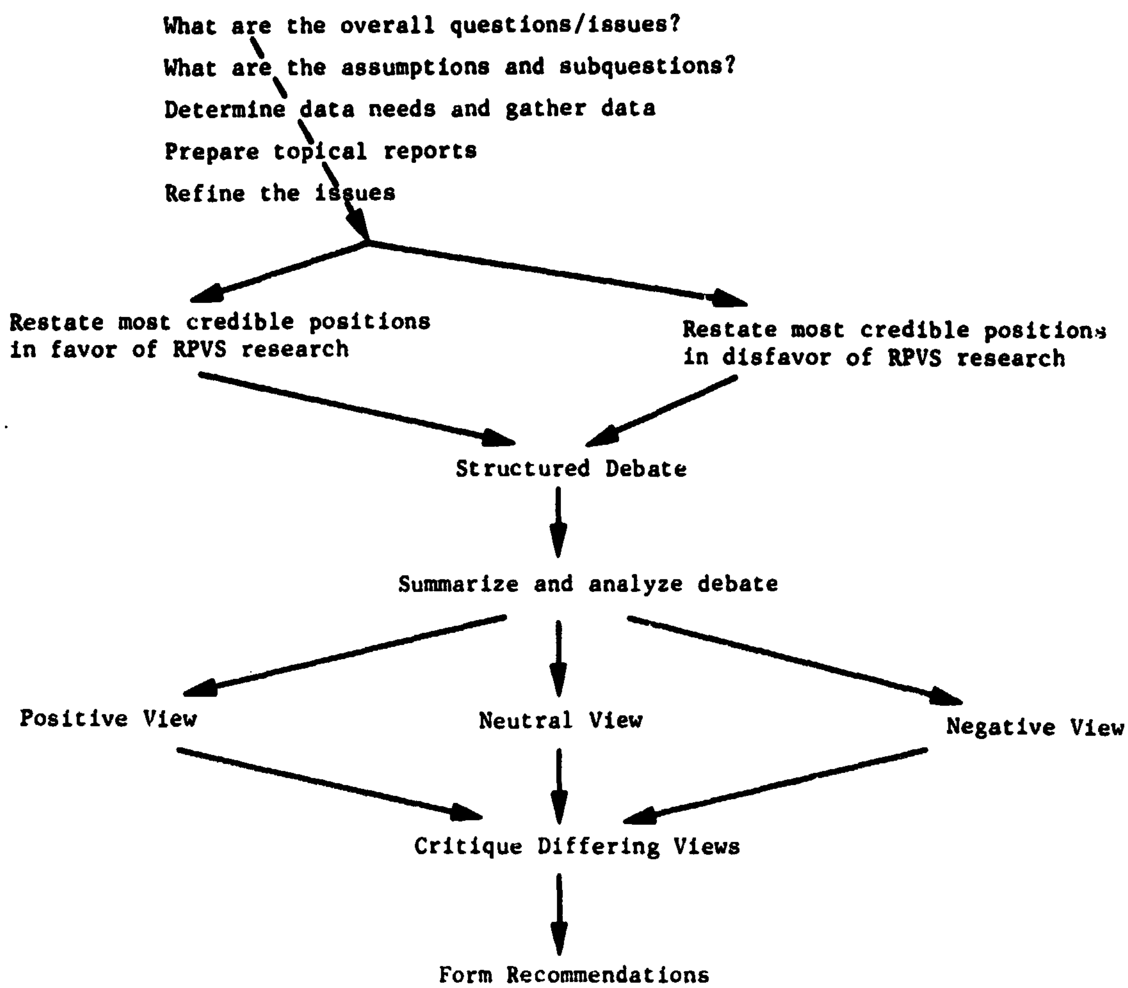


Figure 3-11. Diagram of the Selected Inquiry System

B. FRAMEWORK OF THE STRUCTURED DEBATE

1. Preparation for Debate (Monday Afternoon, July 16, 1979)

Identify and rank the issues in order of importance, and select the six most important issues to be debated the following day.

2. Debate of Issues (Tuesday, July 17, 1979)

The specific time allocation for each of the following elements of the debate is shown in Figure 3-12.

a. Opening of the Debate.

The moderator opens the debate by presenting:

(1) The basic question addressed. In this case, it is whether or not there should be further R&D funding of the RPV system within the DOE EHV Program.

(2) The base, that which is taken as given or common assumption of all parties. For this debate, it would minimally include the conceptual design of the RPV system.

(3) The issue areas and the six issues selected the previous day.

(4) The format and any necessary ground rules for the debate.

(5) The principal rationale for the debate.

b. Opening Arguments on the Basic Question.

(1) The RPV team presents the arguments supporting further R&D funding of the RPV system, in a summarized form (about 20 min).

(2) The EHV team presents the arguments supporting no further R&D funding of the RPV system, in a summarized form (about 20 min).

c. Debate on the First Issue.

(1) Issue No.1:

The most important (first) issue and its boundaries are presented and defined by the moderator.

ORIGINAL PAGE IS
OF POOR QUALITY

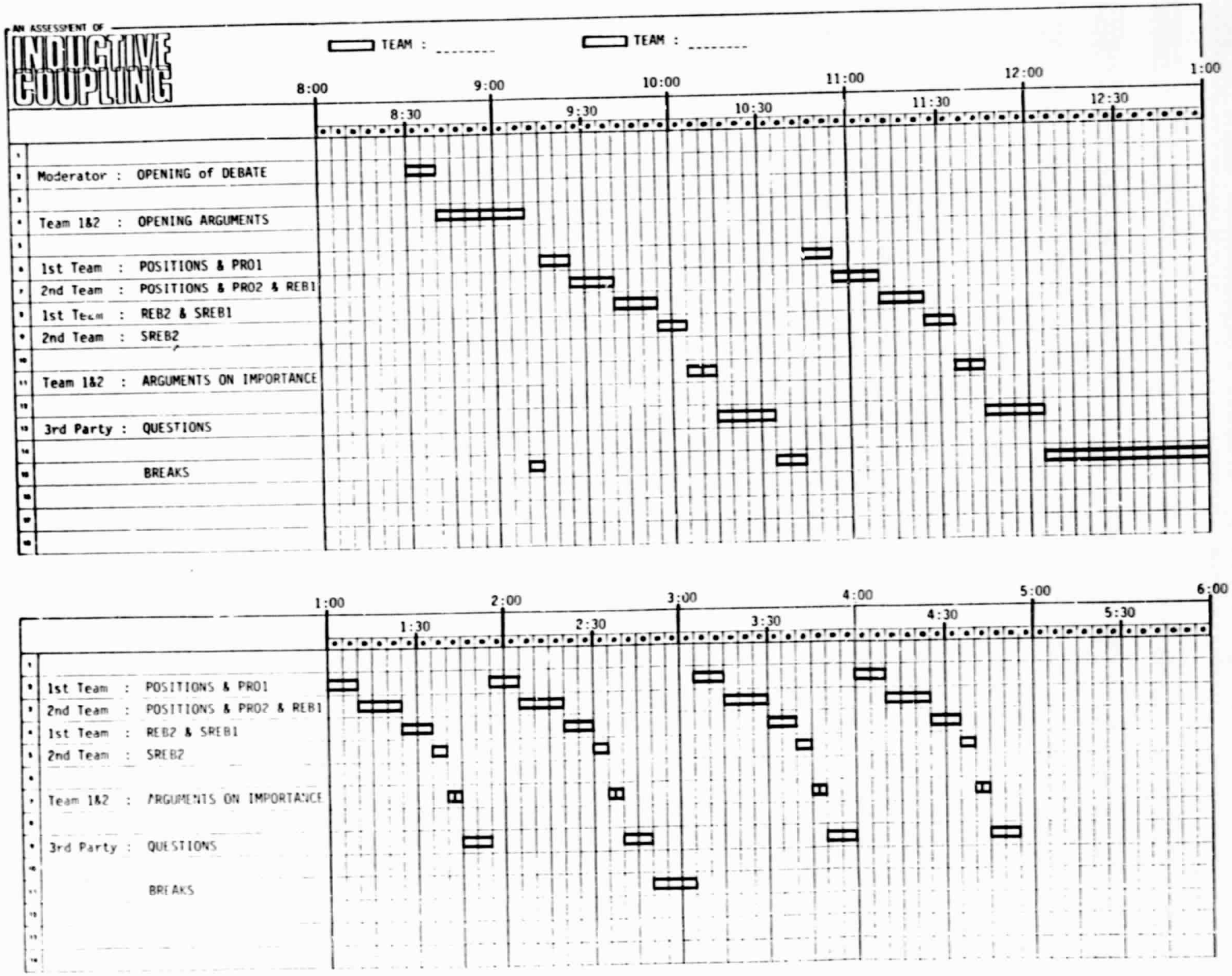


Figure 3-12. Time Schedules of Structured Debate

(2) Position A, and Pro-A:

The RPV Team presents its position on the issue in question, and argues it as an inescapable conclusion of the data, logic, premises, and warrants.

(3) Position B, Pro-B, and Reb-A:

The EHV Team presents its position on the same issue, and argues it. The EHV Team then rebuts the position of the RPV Team; by presenting an alternate warrant, invalidating the premises, and/or attacking the soundness of the logic and the relevancy of the data.

(4) Reb-B, and Sreb-A (Pro A):

The RPV Team rebuts the position of the EHV Team, and may then present a surrebuttal to the EHV Team's rebuttal of the position of the RPV Team (and hence expand their Pro-A argument).

(5) Sreb-B (Pro-B):

The EHV Team may then present a surrebuttal to the RPV Team's rebuttal of the position of the EHV Team (and hence expand their Pro-B arguments).

(6) Arguments on the importance:

The moderator may call for arguments from both sides on the importance of the positions.

(7) The third party may ask questions for clarification.

d. Remaining Issues in Order of Importance

This sequence (1) through (7) is then repeated for each of the remaining issues with the lead for each issue alternating between the RPV team and the EHV team.

3. Reflections on Debate (Wednesday Morning, July 18, 1979)

a. Third Party Questioning. The third party asks questions for clarification of the debate issues, their importance, consistency, and underlying assumptions. This session should allow for a more open discussion than the previous day.

b. Closing Arguments. After reflecting on the debate that has taken place, and the third party questioning, both the RPV and EHV teams then present their closing arguments supporting the two sides of the basic question: "Should there be further R&D funding ..."

4. Third Party Reporting (The Following Week)

The third party, reflecting on the debate, prepares a list of the apparent warrants of each side and those premises which are not truly warrants but could be validated or refuted through analysis.

BIBLIOGRAPHY

Concerning the Subject:

/1/ Bolger, John G., and Frederick A. Kirsten, Investigation of the Feasibility of a Dual Mode Electric Transportation System, Lawrence Berkeley Laboratory, University of California, May 1977 (LBL-6301). Prepared for U.S. Department of Energy.

/2/ Bolger, J. G., and M. I. Green, L. S. Ng, R. I. Wallace, Test of the Performance and Characteristics of a Prototype Inductive Power Coupling for Electric Highway Systems, Lawrence Berkeley Laboratory, University of California, July 1978 (LBL-7522). Prepared for U.S. Department of Energy.

/3/ Bolger, J. G., and L. S. Ng, D. B. Turner, R. I. Wallace, Testing a Prototype Inductive Power Coupling for an Electric Highway System, Lawrence Berkeley Laboratory, University of California, December 1978 (LBL-8634). Prepared for U.S. Department of Energy. Paper presented at the IEEE 29th Annual Vehicle Technology Conference, Chicago, March 1979.

/4/ The Congress Needs to Redirect the Federal Electric Vehicle Program, Report to the Congress of the United States by the Comptroller General, U.S. General Accounting Office, April 1979 (EMD-79-6).

/5/ Nonfrictional Power Collection for Guided High-Speed Ground Vehicles, General Electric Co., Schenectady, April 1968.

/6/ Surber, Frank T., Hybrid Vehicle Potential Assessment, Volume I - Summary, JPL Publication 80-13, Jet Propulsion Laboratory, California Institute of Technology, July 1979. Prepared for U.S. Department of Energy.

/7/ Heft, Ronald C., and Heller, Stuart C., Electric and Hybrid Vehicle Cost Handbook (Review Draft), JPL Document 5030-182 (Rev. A), Jet Propulsion Laboratory, California Institute of Technology, January 1979. Prepared for U.S. Department of Energy.

/8/ Transportation and Traffic Engineering Handbook, Institute of Transportation Engineers, Prentice Hall Inc., 1976.

/9/ Highway Capacity Manual 1965, Highway Research Board Special Report 87, National Academy of Sciences Publication 1328.

/10/ Baker, L. E. and D. W. Humphreys, Vehicle Operations on Roadways: A Systems Optimization Issue, Compendium of Technical Papers, 48th Annual ITE Meeting 1978.

/11/ Automatic Train Control in Rail Rapid Transit, Office of Technology Assessment, U.S. Congress, May 1976.

/12/ Frailey, Fred W., America's Highways: Going to Pot, U.S. News and World Report, July 24, 1978, pp. 36-38.

/13/ Fales, E.D. Jr., Our Crumbling Interstates: A National Dilemma, Popular Mechanics, July 1978, pp. 66-69, 118.

/14/ Heft, R. C., and C. S. Borden, Costs and Energy Efficiency of a Dual-Mode System, Jet Propulsion Laboratory, California Institute of Technology, April 1977. Prepared for U.S. Department of Transportation, UMTA-RD-CA-06-0088-76-2.

/15/ Cherniavsky, E.A., Brookhaven Energy System Optimization Model, Department of Applied Science, Brookhaven National Laboratory, December 1974 (BNL-19569). Prepared for the U.S. Atomic Energy Commission.

/16/ Beller, M., Sourcebook for Energy Assessment, National Center for Analysis of Energy Systems, Brookhaven National Laboratory, December 1975 (BNL-50483). Prepared for U.S. Department of Energy.

/17/ Hannor, R. M., et al., Energy Use for Building Construction, Center for Advanced Computation, Illinois University, Urbana (ERDA 77-61). Prepared for U.S. Department of Energy.

/18/ Bullard, et al., Energy Analysis Handbook for Combining Process and Input-Output Analysis, Center for Advanced Computation, Illinois University, Urbana (ERDA COO-2791-3). Prepared for U.S. Department of Energy.

/19/ Synthetic Electric Utility Systems for Evaluating Advanced Technologies, Power Technologies, Inc., EPRI-EM-285, February 1977. Prepared for Electric Power Research Institute, Palo Alto, CA.

Concerning the Method:

/21/ Churchman, C. West, The Design of Inquiry Systems, Basic Books, New York, 1971.

/22/ Mitroff, Ian I., and Murray Turoff, Technological Forecasting and Assessment: Science and/or Mythology, Technological Forecasting and Social Change, Vol. 5, pp. 113-134, 1973.

/23/ Mason, Richard O., Dialectics in Decision-Making: A Study in the Use of Counter-Planning and Structured Debate, Ph.D. Dissertation, University of California, Berkeley, 1968.

/24/ Mason, Richard O., A Dialectical Approach to Strategic Planning, Management Science, Vol. 15, No. 8, pp. 403-414, April 1969.

/25/ Majone, Giandomenico, Technology Assessment in a Dialectic Key, Public Administration Review, January/February 1978.

/26/ Pierce, Burton B., The Nature and Extent of Long Range Planning in Transportation Regulatory Agencies, Unpublished Ph.D. Dissertation, Stanford University, June 1971.

/27/ Davidoff, Paul, Advocacy and Pluralism in Planning, Journal of the American Institute of Planners, pp. 331-338, November 1965.

/28/ Vickers, Sir Geoffrey, The Art of Judgment, New York, Basic Books, 1965.

/29/ Toulmin, Stephan, The Uses of Argument, Cambridge, Cambridge University Press, 1958.

/30/ Toulmin, Stephan, and Richard Rieke, Allan Janik, An Introduction to Reasoning, New York, Macmillan Publishing Co., 1979.

/31/ Simmons, William W., The Consensor - a New Tool for Decision-Makers, The Futurist, April 1979.

APPENDIX A

STUDY TEAM AND DEBATE ROLES

JPL Study Team Members

Principal Investigator	Kim Leschly
Study Process	Abe Feinberg
Electrical Design	Dave G. Elliott
Roadway Design	John Howe
Vehicle Design	Keith Hardy
Power Supply Design	Ron Heft
Transportation Impacts	Dave W. Humphreys and Steve Volz
Economic Impacts	Ron Heft and Gene Warren
Energy Impact	Ron Heft and Sue Jones
Plausibility Analysis	Jeff H. Smith

Debate Participants and Roles

Moderator:	Frank Surber (JPL)	RPVS Team: (Blue Team)	Jack Bolger (BE)[c] Howard Ross (HRA)[d] Dave Turner (WED)[e] Mike Wenstrom (CR)[f]
Secretary:	Kim Leschly (JPL)		
Third Party:	Abe Feinberg (JPL) John Howe (JPL) Dick Mason (USC)[a] Ann Wilson (UCLA)[b]	EHV Team: (Red Team)	Keith Hardy (JPL) Ron Heft (JPL) Dave Humphreys (JPL) Gene Warren (JPL)

Plausibility Rating Panel

Abe Feinberg (JPL)
Barry Harrow (JPL)
Frank Surber (JPL)
Amy Walton (JPL)
Ann Wilson (UCLA)[b]

---

[a]University of Southern California, Los Angeles, CA
[b]University of California, Los Angeles, CA
[c]Bolger Engineering, Orinda, CA
[d]Howard R. Ross Associates, Palo Alto, CA
[e]Walt Disney Enterprises, Glendale, CA
[f]California Research, Sacramento, CA

APPENDIX B

COMMENTS ON THE METHOD

The following comments, concerning the usefulness of the structured debate approach, were received from three of the RPVS-team members:

(1) Mike Wenstrom, California Research. Letter of July 24, 1979.

(2) Howard R. Ross, Howard R. Ross Associates. Letter of July 30, 1979.

(3) Jack G. Bolger, Bolger Engineering. Review note of August 12, 1979.

July 24, 1979

Kim Leschly
Jet Propulsion Laboratory
510 - 250
4800 Oak Grove Drive
Pasadena, California 91103

Dear Kim:

At the close of our discussion on the viability of the inductively coupled vehicle system you asked for reactions to the debate format. This letter is an attempt to lay out my reactions. The reason I say 'attempt to' is because those reactions are still evolving and will probably become clearer at some future point in time. However, I feel a responsibility to share my present feelings with you.

Let me first say that I enjoyed the opportunity to participate in the debate. I learned a great deal; both about the substance of the issue and the efficacy of such a process in technology assessment. I believe that an approach such as this has a future role in the assessment of technology.

I would further add that, while the enforced discipline of the debate format is useful to a point, if carried out too strictly it is unnecessarily inhibiting. Debates rarely are conclusive. Rather, they provide a mechanism for focusing on critical issues. I believe that you were successful in accomplishing that objective. Moreover, the exposition of issues revealed a number of heretofore hidden (or imperfectly understood) strengths and weaknesses. While the final decision to proceed or not with a technology is essentially a value judgement, you should be able to increase the intelligence with which that decision is taken.

With this as background, I would modify the debate process in any subsequent application. First, I would construct an inter-team dialogue at the close of each issue, but prior to third party questioning. This would permit direct confrontation on the critical components of the issue. Hopefully this would assist the third party to more effectively balance the weight of the opposing arguments. It would also give the third party some added direction for its questions. To avoid this dialogue's degenerating into name-calling, the moderator could exercise some decretion in directing the discussion.

Second, the Questions on the Importance appeared to me to be of marginal assistance. In fact, they seemed more to confuse than to clarify the issue. Questions of importance might more appropriately be addressed by the third party in a more dispassionate mode.

Finally, there appeared to be some confusion as to whether the opposing team was in fact making affirmative arguments for something other than an ICV system. Given the question under discussion, it would be useful to focus on an affirmative/negative dialogue with only secondary consideration given to alternative technologies.

On balance, I came away less skeptical about the process than when I began the process. I believe that with some continued work and experimentation this approach could evolve into a useful tool in assessment processes.

If you would like to discuss this issue further, please feel free to give me a call.

Regards,

Mike

Mike Wenstrom

MW/jlb

July 30, 1979

Mr. Kim Leschly
Transportation Systems Analysis
JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

Subject: Debates on Inductive Coupling Technology

Dear Kim:

The purpose of my letter is to comment on the debate organized by JPL on the inductive coupling technique in which I participated.

I think that the debate format is a reasonable way to explore the implications of the idea, and to present opposing views. JPL's handling of this process was good, and the efforts on your part, the moderator and the third party group to be evenhanded were quite successful. The principal advantages of this approach are as follows:

- Issues are identified rather quickly, as opposed to the rate at which they are uncovered in a normal research process, and it appeared relatively easy for the opposing groups to quickly agree on the key issues. Thus this may be a fast way to get the key issues identified on some technical subject.

- The number of people involved and the catholicity of the interests and views guaranteed that all of the important issues were on the table: I don't think we overlooked anything significant.

- The debate provided an important learning process for all of us.

There are a number of drawbacks to the process that are structural in nature, but they are not so fundamental that they could not be corrected in a replay on a different subject. These include the following:

- It would be desirable to know the people on the opposing team a little better in advance by a certain amount of informal discussion prior to the formal debate. This suggests that the first meeting to agree on critical issues might profitably occupy a full day, preferably with a social hour afterward.

- After the issues are defined it would be desirable to have a time allowance adequate for both teams to prepare, say a week, and written material ought to be given out representing each team's position. As it was we did not have enough time to respond to specific issues, although we did have quite a fair idea in advance because of the JPL papers.

- I found the formality of the debate process a barrier to communication with people whom I would consider to be my professional colleagues in any other setting. I am uncomfortable in an adversarial confrontation on technical issues because it is precisely at moments when we are confronted with the most difficult systems problems that we have the greatest need to communicate ideas.

  Perhaps the third party question session could be expanded at the expense of the debate time to allow more informal communication. But that still does not remove the adversarial process.

- There is some problem of convergence of opposing views, principally because it is difficult in the debate process to examine and reach agreement with the opponent on the assumptions being made and the analyses carried out. This might be mitigated by the advance distribution of position papers, in which assumptions would have to be made clear.

The principal problem with the debate mode has to do with the question of whether the adversarial process (which we generally accept in our judicial system) is really appropriate for technical questions. The objective of an analytical inquiry is to arrive at the truth and to determine how to proceed; it is not simply to win the case. There is a risk that in an attempt to win the case the opposing teams might sacrifice the truth, i.e., not reveal a significant weakness in their own argument (much as a trial lawyer conceals anything prejudicial to his case). I found myself wondering just what the JPL people really thought about this idea. And I wondered if the JPL evaluation team might not, in its role as opponent of the idea, compromise its objectivity in making its evaluation. If so the debate approach would be fundamentally flawed as a method of recommending a course of action to DOE on this technology.

There is also the issue of fairness in this process. JPL has had a substantially greater amount of funding to analyze and evaluate this technology than all of the people on our team have had in the aggregate. I mean that Wenstrom, Turner and Ross have had only minor funding to analyze this technology (our efforts have been made as part of the EPRI study, where it is a key but not dominant issue; we have, of course given a lot of thought to implementation strategies which are as much institutional as technical. But these were not funded efforts). Bolger has had more funding, of course, but most of the DOE funding went for hardware development, not system analysis. Thus one could argue that the pro side of the argument did not have the same level of resources as the con side for analysis.

Having said all of these things I am very grateful for having had the opportunity to participate in the debate because it was highly educational for me, and I think I was able to get my most useful ideas across during the process.

Best regards

Yours sincerely,

Howard

Howard R. Ross

HRR/sh

cc: JPL File (2)
J.G. Bolger
M. Wenstrom
D. Turner
Chrono. File

8/12/79

REVIEW OF ROUGH DRAFT OF 8/3/79 - J. G. BOLGER

'Inductive Coupling Technology Assessment Task
Preliminary Third Party Report of Debate
Held July 16-18, 1979'

- -

On the Method and Its Use -

The argument analysis method was chosen to study the advisability of continuing funding of R&D on the technology. The third party reports cites seven ways in which the analysis will help the decision maker. A subjective evaluation of the effectiveness of the method in achieving those benefits follows:

1) The method did provide an overview of some, possibly most critical elements in each debate issue.

2) It probably provided a sense of the strength of the arguments made. The reliability of this 'sense' may have been compromised to some degree by two factors:

   a) Rhetorical and logical skills of debaters were non-uniform.

   b) The choice of issues to be debated was made just before beginning the debate. This probably resulted in an unequal state of preparedness of the two teams on particular issues.

3) It highlighted some discrepancies and differences in arguments. Because of the limited state of preparedness mentioned above, and the primitive state of the development and analysis of the technology, arguments generally revolved around postulations rather than facts or proofs. Discrepancies and differences in postulations necessarily have much less value than would be the case with facts or proofs.

4) It probably showed that there were no rigorous arguments made that would prove the lack of viability of the technology. Whether the method actually identified the argumentation elements that will lead to a competent final conclusion is not certain.

5) Also because of the shallow state of preparedness, the identification of data sources was limited.

6) It did reveal many arguments as being subjective or of limited basis, and illuminated some important topics for further research.

7) The output of this exercise of the method may not constitute a reliable support aid for the decision maker at this stage.

After some consideration of the theory of the method, I have concluded that it is probably an excellent tool if it is applied carefully in such a way as to avoid bias. We may not have applied the method well in this initial exercise. The whole effort of the JPL technical staff involved was devoted to developing negative positions with respect to the RPVS technology, consisting of some ten working papers. The decision maker will use the output of this debate that revolved around those negative positions to aid in choosing between supporting the RPVS and competitive technologies. Obviously then, the treatment of competitive technologies should have paralleled that of the RPVS in order to support rational, unbiased comparisons.

Most existing technologies would have been discarded at a similar state of development as a result of this kind of application of the method. Consider for example today's flammable (even explosive), toxin-emitting, inefficient, complicated, noisy, wear-prone automobile that requires massive investments in tooling and fuel and repair infrastructure. Would it have survived this evaluative process? I think not.

There were many worthwhile outputs of this attempt to apply the method. Because adequate comparisons to alternate technologies were not developed, I believe that the output of the work cannot be used as the basis for choosing between them. The work has provided considerable new perspective that will be of value, however.

APPENDIX C

REVIEW COMMENTS

This appendix contains the review comments of two of the RPV system team members: Howard R. Ross and John G. Bolger. Howard Ross' comments (of August 15, 1979) were written as a general response to the draft of the third party report (of August 3, 1979), whereas John Bolger's comment (of November 26, 1979) reflect his review of the draft of the full study report (of October 20, 1979).

Technical Notes

ROADWAY ELECTRIFICATION SYSTEM USING INDUCTIVE COUPLING TECHNOLOGY

Howard R. Ross

August 15, 1979

INTRODUCTION

These technical notes were prepared by Howard R. Ross Associates to assist in the Jet Propulsion Laboratory (JPL) evaluation of the roadway electrification system using the inductive coupling technology, which is being carried out for the U.S. Department of Energy (DOE). As part of this evaluation a formal discussion of the inductive coupling technology was conducted July 16-18, 1979 at JPL, in which the principal technical issues were raised and debated; these technical notes were prepared to comment in more detail on the issues raised and various positions taken regarding this system.

BACKGROUND

Overview

The transportation of people and goods accounts for about 25 percent of all U.S. energy consumption. Because automotive/highway and aviation technology provide over 96 percent of all passenger miles of travel, and diesel trucks, railroads and ships over 75 percent of goods movement, about 53 percent of the petroleum consumed in this country goes to transportation.

Thus the transportation sector is particularly vulnerable to higher prices for oil and oil embargos, and in fact the whole of western industrialized society is jeopardized by the OPEC cartel.

Need for Mobility

U.S. transportation is a fundamental economic activity totalling in excess of $400 billion annually, an amount which exceeds the gross national product of most of the remaining nations of the world. Almost precisely half of the total goes for passenger transportation, the remainder for goods. Although some of the personal transportation is frivolous, mobility is a basic concomitant of an advanced industrialized society; large-scale curtailment would mean not merely drastic changes in the way in which we live, but could presage severe and painful economic dislocation and perhaps collapse. The structure of our entire society is based on an extraordinarily high standard of mobility, and because of this extraordinary measures may be required to create the technologies to sustain mobility.

Mobility Alternatives are Limited

A limited number of technological alternatives for mobility are being considered, in which the objective is to diminish or eliminate the use of petroleum. These include more fuel efficient ICF vehicles, battery vehicles, hybrids, synthetic fuels and hydrogen fuels. A shift of trips to public transit is also being advocated as a means of reducing petroleum dependence. It is important to realize just how limited this range of alternatives really is, and to recognize that all of these are flawed concepts that may, if fully implemented out of necessity, result in inordinately high costs for U.S. mobility or drastic curtailment on account of costs.

Roadway electrification with inductive coupling is an additional technological alternative for future mobility. We assert that it is an alternative because from an engineering standpoint its technical efficacy has been fairly well established by laboratory tests and analyses, which have shown that the behavior of the power coupling technique obeys well-known electrical engineering principles. Thus there is little to debate on the subject of whether it works. The real question is: should DOE continue research and development on the inductive coupling technology? The question is not whether to deploy roadway electrification on a large scale, because that question is premature until more information on the technology is available.

SUMMARY OF ARGUMENTS IN FAVOR OF CONTINUING R & D

The principal arguments in favor of continuing research and development on the inductive coupling technology, which we will address in more detail, can be summarized as follows:

- U.S. mobility system is gravely threatened, and any alternative with no fundamental technical flaws should continue to be explored.
- The inductive coupling system, on which only the most rudimentary research and development has been carried out, has potentially a very high payoff with a low-risk low-cost front-end cost for R & D.
- It is premature to make a decision about a technology on which so little R & D has been carried out, since even the most basic system-level questions cannot be adequately answered.
- The annualized capital costs of the system, which we assume would be funded like any other highway improvement (by taxes on all vehicles, electric or otherwise, as a matter of public policy) are extremely modest, typically less than annual license fees, or 1 to 2 percent of total annual operating costs for the typical automobile.
- Plausible strategies for gradual highway implementation can be visualized in which the extent of the electrified lanes matches the number of electric vehicles ready to use the system; for example, a lane-by-lane implementation on freeways and boulevards.
- Public transit systems using buses provide an almost ideal means of demonstrating the technology on a small scale; on a larger scale bus transit networks offer an opportunity for initial HOV operation (buses, vans and jitneys) with evolutionary transition to private automobiles over a period of several years.
- Inductive coupling systems are inherently a public/private technology mix, i.e., public highway and power supply on which operate privately owned vehicles. Thus implementation is innately a system problem, and only through government intervention can such a system be realized. This is not the case with battery and hybrid vehicle, where the private sectors should take the lead.
- Opportunities for highway automation are inherently better with the coupling system, which is a natural sensing and positioning device. Automation has a very large payoff in terms of higher productivity, safety and reliability of the highway system, and considerable potential for energy savings through ride sharing.

- Significant near term potential exists for small scale demonstration projects with the inductive coupling technology, as previously noted, in which small bus systems of limited scale and low technical risk are utilized. However, the interest of other public and private agencies in carrying out such projects, and in developing this technology will be dampened if DOE does not continue a program of R & D. Even a modest DOE program can act as a catalyst to encourage other public agencies on a regional, state and national level to fund research studies, feasibility studies, demonstration projects and the like; without DOE support this will be more difficult to achieve.

DISCUSSION

Payoff from Continued R & D

To date only a few hundred thousand dollars have been spent on research and development efforts on the inductive coupling technology. This is miniscule in comparison with the overall electric and hybrid vehicle program, and suggests some reordering of priorities. Only a few million dollars on R & D would answer most of the questions as to costs and feasibility, but the potential payoff is very great. If R & D reveals costs and performance that are not as expected the work can be discontinued, and thus the risk is low.

Thus far the most basic system-level questions have not been addressed except in the most superficial way. On an area-wide system of electrified highways, for example, one would want to address the following major questions:

- The extent of electrification necessary to an urban area to serve all of the vehicles, i.e., how many lane miles of freeways, boulevards, and other arterials would have to be electrified? Since vehicles have onboard storage with this concept, an urban area of, say, 1 million population might have a few hundred miles electrified. There is an important system tradeoff between onboard storage capacity and extent of roadway electrification.

- The appropriate staging of such a system, starting with the most promising arterials for bus transit and leading to a complete freeway and arterial network.

- The costs to install a system, by stage, and the operating costs of a bus transit network alone; the costs to users of a full network.

- Methods of metering energy use and plausible ways for users to pay for energy consumed.

- Identification of key technical problems associated with the system and definition of R & D efforts to resolve.

- Net energy savings for a given urban area, as it appears that an electric vehicle based on this principle would have about one half the equivalent fuel consumption of an I.C.E. vehicle (reckoned at the source).

- Net petroleum savings potential as a result of shifting to central generating plant power, where the fuel could be coal or nuclear, or hydroelectric, fusion or solar in lieu of petroleum.

- Effects on utility loads such as peaking characteristics, base load peak shifting, and load management.

- Net effect on air pollution and noise in the urban area.

- The implications of this, both technical and institutional, for the technology of automation.

- Estimates as to a plausible rate of introduction of such a system, from initial demonstration stages to fully deployed.

Such studies could ascertain the benefits and costs of inductively coupled vehicle systems provided enough hardware development work were carried on in parallel to provide costs and appropriate engineering approaches.

Annualized Costs

Economic feasibility determinations on the inductive coupling scheme can yield misleading results if the costs are allocated in certain ways. If, for example, a complete highway network is electrified and then a few electric vehicles are introduced, it is obvious that if all of the annualized capital costs are assigned to those few vehicles the amounts will be inordinately high. Some of the analyses JPL did took this approach, which yielded misleading results. Much more likely is that the electrification will simply be considered a highway improvement, and all vehicle owners will pay for it out of license fees, gasoline taxes or whatever. Perhaps property taxes will be used. It is possible that for some of the initial installations general revenue funds will be used to electrify so that the capital costs do not show up on the ledger books at all. This is done with Capital Grants for transit under Section 3 of UMTA.

While we recognize that in the long run someone has to pay for whatever is built, it confuses the issue by allocating all of the capital costs to the electric vehicles in a start-up condition. It is much more appropriate to consider a steady-state condition where electrification is in place and the fleet is dominated by electric vehicles. The transitional costs in getting to the inductive coupling technology, or to any of the other alternative technologies for that matter, are the price that our society will have to pay if it wishes to preserve its mobility.

When the capital costs are annualized on a per vehicle, or per capita, or passenger mile basis, they work out to be surprisingly modest.

A cursory analysis of the Los Angeles region supports this argument. If one assumes a 32 x 32 mile area with electrified streets and highways on a grid spaced an average of 4 miles apart, the total miles involved are 576; with an average of 5 lanes this works out to 2880 lane miles for the region. At a cost of \$0.5 million per lane mile, the cost is $\$1.440 \times 10^9$. The annual costs to retire the debt (payback of original costs plus interest) at 10% interest over 25 years are \$152 million. For 3.5 million vehicles the costs per vehicle per year is \$43.5; per capita about \$22 per year. Per vehicle mile, at 10,000 miles, per vehicle per year, it is 0.4¢.

We have examined other U.S. cities on the same basis and have found similar results. My subjective reaction is that \$1.4 billion is a small price to pay to preserve mobility in a large region like Los Angeles - it is a fraction of the costs of a rail transit network which might still carry only a few percent of the daily trips. And surely public policy mandates will move in that direction if it is what is required to prevent economic collapse.

Implementation Strategies

The surest way to defeat the electrified highway concept is to insist that an "all at once" conversion be made of the requisite lanes in an urban area. By definition this implies staggering start-up costs and gross underutilization in the early years. No politician would agree to such a program, and indeed it is not a rational approach anyway.

As with most transportation systems electrification will probably be implemented gradually in steps, with important corridors first, and then by adding more links and lanes as demand increases.

Another possibility involving electric buses for transit also offers an evolutionary strategy for implementation. We examined the Denver region as one example of an urbanized area where one might consider an electrified arterial system:

Population:	1.3 million
No. of vehicles:	825,000
No. of buses:	700
Route miles:	300
Cost:	$300 million
Bus Cost:	$100 million *

*Note that existing buses have a resale value

We assume that the annualized costs of the roadway are paid for by the automobile owners. There are approximately 8×10^9 vehicle miles per year in the Denver region and 1.5×10^9 passenger trips. The rough costs work out to be 0.4¢ vehicle mile, or 2¢ per passenger trip, or $37 per registered vehicle per year. This does not include the costs of extra generating capacity, which would be paid for out of operating charges for electricity.

As an implementation strategy we have suggested that the bus arterials be electrified and the bus fleet be converted to electric vehicles. If the bus system bore the entire costs of the roadway electrification, the annualized costs would be about 50 percent more than all diesel fleet. However, transit operators do not reckon their costs on an assumption of paying off capital costs, which are typically paid for either by bond issue with UMTA Capital Grants. Thus, to the operator, his annual costs would drop because of longer vehicle life, decreased maintenance, and lower energy charges.

It might, therefore, make sense to electrify an urban area for the bus system, and then provide tax incentives for the purchase of private electric vehicles. In this fashion the transition to electric vehicles could take place in an evolutionary way and I.C.E. vehicles could use the same facilities during the transition; thus it would be institutionally feasible.

Technical Uncertainties

The principal technical uncertainties with the inductive coupling do not relate to its electromagnetic behavior, as there is no reason why a roadway and vehicle could not be built to inductively couple power between the two.

The real uncertainties relate to the capital costs of building electrified roadways and electric vehicles to operate on them, and, put another way, the cost-effectiveness of the resulting system compared to other alternatives. At the present time we simply do not know what the eventual costs will be to produce a continuous roadway element that can withstand the vehicle traffic of a freeway lane and the effects of weather; and we do not know what an optimized vehicle will cost when this technology is fully exploited. What we do know looks encouraging, but no certainty will exist until further hardware development takes place.

We would like to emphasize that the technical uncertainties with roadway electrification are much less than those associated with, for example, the linear induction motor, or in an even more extreme case the personal rapid transit (PRT) systems. In these cases system behavior is not readily predictable, and only full scale testing has provided the basis for accurate projections of performance and costs. With roadway electrification by contrast, the device is so much simpler in concept that the main uncertainties relate to just how certain design problems are resolved, and thus, the eventual cost of a fully engineered system, and the resulting cost-effectiveness. We also point out that all of these engineering design problems probably have several solutions, even though the most cost-effective ones are not readily apparent at the outset. Some of these design problems are as follows:

- The structural design of the roadway element. It is desireable that the element be a solid, integral part of the road, impervious to weather, resistant to the pounding of traffic, surfaced with something like the surrounding road surface, amenable to repaving of the road at intervals, and susceptible to repair in the case of failure.
- Design for automated installation. Clearly the initial installation must be emplaced by hand; any extensive installation must rely on the equivalent of the Barber-Greene automated paving machines.
- Vehicle design. A vehicle designed from the ground up is essential to fully exploit the electric vehicle potential without the weight constraints of the battery powered vehicle.

To fully resolve these technical uncertainties requires engineering, development, test and demonstartion that have thus far not been carried out, and because of this most statements about costs are speculative. But we would like to observe that it does not necessarily follow that the costs will be higher than those currently forseen: the present designs are analogous to the earliest automobiles in terms of engineering refinement, and cost reductions are still a possibility.

Automation

The inductive coupling technology has one distinctive feature that does not exist with any of the other alternatives to the ICE vehicle, and this is its potential for automation. The roadbed element may provide a powerful catalyst for automation of the highway.

Once the highway is rebuilt for electrification the incremental costs to provide for automation may be not too great. Automation, moreover, may be phased in on an evolutionary basis to minimize the trauma of the transition, for example, as follows:

- Lateral guidance through sensing of the roadbed element and servo control of steering.
- Position sensing and speed profile control (acceleration, running, braking and stopping).
- Longitudinal spacing control, starting with the equivalent of "automatic train protection" (ATP), and leading to the equivalent of "automatic train operation" (ATO). In the long run, the technology of automated guideway transit (AGT) systems will be exploited for these systems.
- Vehicle management, exploiting concepts for routing strategies and trip time minimization algorithms.

The ultimate goal, perhaps achievable in 20 to 30 years, is an automated highway system, with only minor segments under manual control.

The possibility of automatic control is an important factor in evaluating the inductive coupling potential. It is highly significant in terms of system through-put, performance, safety and reliability, to be sure, but it also has a strong relationship to energy savings through ride sharing. The simplest systems of transit using inductive coupling can have some degree of automatic control, for example, lateral guidance. The same evolutionary strategies for implementation of electrification can be used for automatic control.

<u>Near-Term Demonstration Potential</u>

Application of electrification on an urban scale must be preceded by near term projects of much more modest scale.

Small scale public transit applications of this technology, rather than automobile systems, make a great deal of sense for initial applications.

These could be, for example, a downtown circulation system using small buses, a pedestrian/transit oriented mall with special vehicles, or a busway. The advantages of such systems are as follows:

- The applications can be limited in scale with reasonable technical objectives. Thus technical risk is manageable. At the same time they offer meaningful demonstration of the technology in a public environment in, say, four years from now for malls and 6 to 8 years for busways.
- They offer a way to break out of the "chicken-egg" problem of applying the technology to freeways and private automobiles.
- The public agencies provide a good institutional framework for collecting data on operations, and for controlling the way in which the vehicles are used.
- Busways provide an evolutionary means of exploiting the technology, with public transit vehicles the first user followed by gradual introduction of other HOVs over time so as to test the system with automobiles.

It is important that the hardware inductive coupling continue to be developed so that it is available for these simple applications in the time frame envisaged. If it is not, however, we think that the programs that are developed can include a prototyping and test phase to try out equipment in non-revenue service. Although this is an approach that is technically feasible it may be much harder to implement these projects if there is no support from DOE and DOT for the development of the technology.

CONCLUSION

Shifting the U.S. transportation system from petroleum and other fossil derived fuels to electricity in the next decades, on some cost-effective basis, may be one of the most important technical challenges facing this country in the next two or three decades. To the extent that this challenge can be met U.S. trade deficits and inflation can be reduced, order can be restored to the world monetary system, and the western industrialized nations and Japan can avoid being hostages to the oil cartel.

In the long run, of course, say in the next 40 years, transition to some alternative prime mover is essential even assuming the fullest cooperation of OPEC, since petroleum will become increasingly scarce and fuel costs will become prohibitively high for transportation.

Under the best of circumstances this transition is going to be difficult. Given the uncertainties as to the future all plausible avenues must be explored. The roadway electrification technology discussed in these notes is an important alternative that has not been adequately researched and developed thus far, and we recommend that DOE continues with a strong R & D program.

J. G. BOLGER
CONSULTING ENGINEER
RESEARCH • DEVELOPMENT • DESIGN • ANALYSIS
469 TAHOS ROAD ORINDA, CA 94563 415/254-4504

FILE:

November 26, 1979

Mr. Kim Leschly
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, Ca. 91103

Dear Kim:

Enclosed is a copy of a rough draft of my critique of the assessment report. I will call you later this week, after you've had a chance to read it, to discuss it. If you would like to have the originals, I will be glad to send them.

I appreciate the opportunity to make the critique, Kim, and hope that the effort was productive.

Very truly yours,

Jack

J. G. Bolger

JGB:gb

MINORITY CRITIQUE

of the

ASSESSMENT OF ROADWAY POWERED VEHICLES

By: John G. Bolger
November, 1979

Contents | Page

INTRODUCTION

This report presents a balancing critique of the assessment of the roadway powered vehicle system (RPVS) prepared by staff of the Jet Propulsion Laboratory (JPL). The necessity for and importance of this critique stems from the unusual circumstances surrounding the assessment and the ongoing RPVS research and development program.

The assignment of the assessment to JPL posed some inherent problems. The large ongoing programs at that laboratory that are devoted to the advancement of conventional electric and hybrid vehicles have created a familiarity with and understandable institutional bias for them. Those who were assigned the management of the assessment have undoubtedly striven to avoid this bias. The role of many of the participating analysts, however, was schismatic in that they served as debating opponents of the RPVS technology, for which role they prepared supposedly dispassionate technical analyses. The result is evident in the adversary nature of many of those analyses.

The minority debating panel provided the only active positive input for the RPVS technology. The views expressed in this critique in the main reflect the views of that panel. The panel's effort consisted of a few man days for each panelist in preparation for the three-day debate process. The perspective of the panel was designed to provide a broad and experienced perspective in the technology, implementation, and operation of transportation systems. This perspective was developed by:

- J. G. Bolger, the engineer/inventor of the technology, and driving force behind its development.
- H. R. Ross, a transportation analyst with a wealth of experience in the planning of transportation systems of many modes.
- D. B. Turner, a senior electronic engineer experienced in the design and operation of transit automation systems.

M. A. Wenstrom, a principal in a research firm that specializes in matters relating to industrial/government interfaces.

The managers of this work faced the difficult task of assessing a technology in its infancy. The full dimension of its technical competences and applicational utility are not yet clearly defined. The method chosen to make this assessment brought into play many subjective or judgmental processes. The results can only be regarded as 'soft' and of short term value at best.

New technologies typically must struggle to penetrate an inherent resistance to new concepts and change that we all exhibit to some degree. This assessment is an outgrowth of this resistance in that it seeks to find a rationale for diverting support from it to alternative programs. While the assessment includes a spectrum of opinions, analyses, and miscellanea, one basic theme has come thru the process unscathed:

The roadway powered vehicle system has the potential to achieve major beneficial impacts on the nation's energy supply, transportation system, and economy.

I. STRUCTURE AND NATURE OF THE CRITIQUE

The organization of the assessment is somewhat fragmented. Discussions relating to a particular topic are frequently dispersed among more than one section. The critiques that follow have attempted to collect and treat topics in a less fragmented way.

Altho this critique is a product only of the author, it is intended to reflect in general the viewpoints of the 'advocate' debating panel. The primary objective of the critique is to balance, challenge, and/or correct the assessments presented by the JPL analysts. The bulk of the material on which critiques are based is included among the assessment reference material, and valuable expanded treatments of particular topics may be found among that material.

While it was the intent of the author to present a critique rather than a minority report, a 'minority overview' is included that departs from the objective described above. It is hoped that this overview will suggest a more positive and productive course of action with regard to what has to be recognized as a highly significant new technology.

The methodology of the assessment including that of 'dialectical inquiry' is not critiqued. The reader may be better able, from a position of non-involvement, to form his own more accurate opinion.

The results of the structured debate are comprehensively reported and are not critiqued. Expanding on that argumentative process would serve little purpose.

II. MINORITY OVERVIEW

A) The Transportation Energy Problem and the Place of the RPVS

The incentives to shift the U.S. transportation system to non-petroleum energy supplies become more powerful by the day. Sources of imported petroleum are increasingly jeopardized by political instabilities and restrictive economic policies of middle eastern countries. The economic damage from huge outflows of American capital for petroleum is becoming intolerable.

After a period of high hope, the Congress and the public have come to realize that neither conventional electric and hybrid vehicle technologies nor synthetic fuel production can be relied upon to resolve this problem in a timely and acceptable way. It is clear that even major advances in these old technologies cannot wipe away their fundamental limitations. In the case of battery vehicles, it is the need to haul and statically recharge a large and inefficient supply of stored energy. In the case of hybrid vehicles, it is the continued marriage to liquid fuels and the need for a dual propulsion system and energy supply. In the case of synthetic fuels it is terrible environmental penalties, inefficient use of feedstock energy, and irrational economics.

It is in this technological environment that the RPVS must fight for life. This technology is all electric. It makes use of the advances that have been achieved in the development of battery-powered vehicles in providing unconstrained mobility in city use. By constructing RPVS power systems on freeways, this mobility is expanded to match the full capabilities of today's automobiles in range and performance. Two factors are of vital importance; this full performance is achieved within the bounds of decreased operating cost to the consumer. For this reason rapid, large scale implementation is possible with attendant shifts away from petroleum use. A second major factor is that trucks and buses, which will use almost as much energy as cars will in two decades, also be able to be electrically powered by the RPVS system. Thus the potential for petroleum displacement in transportation by this technology is massive.

B) The Transportation Service Problem and the Place of the RPVS

The transportation network in the U.S. faces some serious and worsening problems. The capacity of the network has kept pace neither with the increase in population and automobiles nor the shifts in population in urban areas.

DOT projections show that traffic on interstate freeways and other principal arterials in urban areas will have nearly doubled between 1970 and 1990. Freeway construction is currently at a near standstill and is unlikely to increase significantly. A large fraction of urban freeways are operating with traffic loads that are far above optimum capacity. How then is this increasing transportation demand to be met?

The RPVS offers two competences that could signifantly impact this problem. One is the system's high degree of compatability with automation. The well recognized condition for maximum traffic flow on highways is with speeds of 40 mph and vehicle headways of about 100 feet (i.e., 2,000 vehicles per hour per lane). Above this speed, the instabilities introduced by human reactions require larger vehicle separations. If traffic demand exceeds 2,000 vehicles per hour, then, the increased headways are not possible, and traffic slows and thruput drops. Modest automation techniques, including coordinated traffic sensors and ramp metering for incoming traffic, advisory indicators in vehicles for headway control, and automatic guidance assistance are readily achieved in conjunction with the RPVS inductive power coupling system. If one could improve traffic flow with these modest techniques to achieve, for example, average speeds of 55 mph instead of 40, and headways of about 70 feet instead of 100, the traffic capacity of the freeway would have been doubled.

The cost of highway accidents in the U.S. is 50,000 lives and 50 billion dollars each year. RPVS automation systems have the potential for significantly reducing this terrible toll. Even if there were no other reason for its development, this incentive alone is sufficient to warrant a vigorous RPVS development effort.

A second competence is the RPVS's utility in serving urban buses. Recent rapid rail construction programs have demonstrated clearly that only the buses can provide new transit systems with reasonable cost effectiveness. Bus systems are doubly advantageous in that they can provide both pickup and distribution as well as line haul service with one vehicle. Busways on freeways have demonstrated their viability. The RPVS could impact this transit technology in two ways. First, the automation techniques described above could allow high speeds to be maintained in busways that are shared with other traffic. This is very important to acquiring the acceptance of the busways by the motoring public. Secondly, the RPVS bus would be acceptable on feeder routes in business districts and urban neighborhoods where diesel and trolley buses are not. The smell and noise of diesels, and the visual intrusion of overhead wires and supports are often resisted in these environments.

The RPVS in many ways represents a significant new transportation mode.

C) Implementation - Is It a Major Barrier to RPVS?

Several practical implementation strategies are suggested in this assessment. These strategies reflect the thinking of those of us who have a commitment to the success of the RPVS technology. To date, no funded, organized work has been done to thoroughly explore the whole spectrum of possible strategies that may be available. What is known then, is that there are strategies of much promise to first demonstrate, evaluate, and then expand the implementation of the RPVS in processes that rigorously constrain the financial and technological risks. What is not known is whether these are the optimum strategies.

If one compares the risks and procedures associated with initial implementation of RPVS with those of transportation technologies in the past, it is immediately obvious that the RPVS is a much more tractable technology in this respect. Compare an RPVS busway, for example, with the Morgantown project, or BART. The construction of the busway involves no significant risk, since it can be used by any vehicle in addition to the RPVS bus. The capital investment in the RPVS power system and buses would be a small fraction of the busway cost, as is usual in electric transit systems. The construction of BART and Morgantown on the other hand, involved very large commitments of resources to systems whose efficiency was not proved (and to some degree still is not).

The implementation process for the RPVS is a problem of tractable dimensions that should be addressed soon by competent planners and innovators.

D) The Development Program

The technical basis for the RPVS has been proved with prototype tests and confirming analyses. The transition to a competent development program now needs to be accomplished.

The momentum in the RPVS technology resides in three areas. The author conceived and developed the technology to the point that it could be demonstrated and patented. He canvassed a cross section of appropriate industries, government agencies, and politicians until a small amount of initial support for a feasibility study and continuing development was acquired from ERDA. After he had led a vigorous development program at Lawrence Berkeley Laboratory for two years, the program was interrupted by internal politics at that laboratory. He has now resumed the development of RPVS for smaller commercial applications.

The ERDA work, now DOE, is to continue at Lawrence Livermore Laboratory, This laboratory will install a dynamic prototype consisting of a 50 meter section of powered road and a skeletal vehicle next year after a program interruption of more than a year. Additional support is being solicited by that laboratory from transportation agencies to supplement DOE funding.

The third area is the work of Howard Ross Associates. Mr. Ross has contracted with the California Dept. of Transportation to make a feasibility study of an RPVS street bus system for the city of Santa Barbara. Mr. Ross has also been active in soliciting support for studies relating to RPVS from a number of federal agencies and municipalities.

A revitalization of the RPVS development program is badly needed. Above all, a determined program leader with the spectrum of needed skills is essential. The present leadership structure is not achieving the needed results. Rather than attempting to fit the program to perceived congressional and bureaucratic preferences, the effort must be made to educate the appropriate political infrastructure to the incentives for and needs of the program. If this is not done, the program may continue on its unsatisfactory course. While the truths of the RPVS will eventually prevail, it is not in the interests of any of the actors in the technology nor the public at large to countenance the limitations of the present program.

It was pointed out in the course of the structured debate that there is currently a very high payout available in knowledge and technology for each dollar spent on RPVS. This is not true of alternate, older technologies on which those dollars might otherwise be spent.

The application of RPVS on highways involves the government; this underlying premise inherently denies the technology support from industry. For this reason, only the government can assume responsibility for the successful development of the RPVS. A well planned and directed, adequately supported program is the only rational path for this significant new technology.

III. GENERAL CRITIQUES

A) 'Reflections and Recommendations'

The inference is made that the alternate technologies to the RPVS are responsive to market economics while the RPVS cannot be. This is nearly an exact reversal of the most likely circumstances.

The development and deployment of battery/electric highway vehicles since their renaissance has become largely a heavily subsidized government program. It is clear that any major penetration by this technology will continue to require heavy subsidies to offset the poor functional characteristics and high costs of these vehicles. While mature hybrid vehicles may provide better functional characteristics, they also can be expected to be economically disadvantageous and will continue to beg the issue of the use of liquid fuels. The use of liquid fuel in the long term must involve synthetic fuels; this is an area of heavy government intervention and subsidy.

RPVS power systems are closely analogous to existing utility power systems. This infrastructure should be managed and supplied, if not owned, by the utility industry. Government is demonstrably incapable of effectively accomplishing such roles. The remaining system element, i.e., the RPVS vehicle fleet, will in all probability represent a commodity that is much better able to make its way in the arena of commercial economics than is the case with either battery or hybrid EV's. The RPVS system, then, has much more of the character of a 'free market' entity than do the 'alternate' technologies.

B) <u>'Principal Conclusions'</u>

The 'Findings' as recited by the analysts are felt to be generally correct, and reasonably complete.

The conclusion that electric, hybrid, and synfueled-ICE vehicles seem, at the present, to have a higher potential for meeting these (transportation and energy conservation) needs is not supported by the work of the assessment. Comparative analyses vis-a-vis the major issues were not made for those technologies in the work. This conclusion must be regarded as subjective and inappropriate to the assessment.

The conclusion is drawn that small commercial transportation systems 'provide a valuable (but not sufficient) R & D base'. This conclusion is only vaguely supported by the work of the assessment, and while it is undoubtedly true, tends to distract from the underlying motivation for the assessment. Ongoing commercial R & D will not hand over to the government a set of developed equipment that will achieve the major impacts in transportation and energy that are so desperately needed, Government officials must not be distracted from the gut issues and decisions that are required with respect to this new technology. The conclusion should be regarded as tangential to the purposes of the assessment.

C) 'Recommendations'

The recommendation is made that DOE should weigh the RPVS assessment against similar treatments of the present EHV technologies.

The RPVS technology has been proved to be functionally sound and to offer many potential payouts of large value. Piling another layer of paper on the technology will in no way serve to advance it to the point where clearcut and meaningful decisions can be made with respect to its place in the domain of the public interest.

A second recommendation is that a joint DOE/DOT research program, focused on smaller scale public transit applications should be explored. The analysts apparently are not aware of the continuing communications between the various actors in the technology and in DOT. These communications were begun in 1976 by the inventor and the Federal Highway Administration. Other communications have occurred with UMTA personnel, the director and others in Transportation Systems Center and the director of the Research and Special Programs Administration. These communications have not been focused only on small public transit systems.

Studies are ongoing that relate to an RPVS bus system in Santa Barbara, Ca., and a truck 'booster' system for grades on highway 5 in California. It is apparent that there currently is a more receptive and vigorous climate for productive R & D among transportation officials who interface with operating systems, as opposed to the more insulated officials at the federal level.

V. TOPICAL CRITIQUES AND DISCUSSIONS

A) Petroleum Displacement

Summary of major viability determinants, and comparisons to other technologies

- The roadway powered vehicle system offers many attributes that contribute to receptivity by the consumer - good performance and low operating cost, unrestricted range, enhanced safety, and environmental cleanliness. This enhances the prospects for large scale implementation and consequent major displaements of petroleum.

  Comparisons:

  Battery powered vehicles will always suffer from high operating cost and range limitations, even if 'advanced' batteries are successfully developed. These factors will severely constrain their marketability and potential for petroleum displacement.

  Hybrid vehicles will always suffer from increased complexity and dependence on liquid fuels. Both of these factors mitigate against their marketability and potential for petroleum displacement.

- Energy for the RPVS need include no content of petroleum. The analyses pointed up the fact that the utilities' choice of fuel is one based primarily on economics. The increment of peak load required by RPVS can exclude the use of petroleum if a small fraction of the operating cost savings are used to support other types of generating facilities.

  Comparisons:

  Battery powered vehicles typically require no energy derived from petroleum, but Hybrid vehicles will require petroleum or synthetic fuels.

- The RPVS is well suited to use by trucks and buses. This transportation sector now uses 40% as much fuel as automobiles do; this proportion is projected to rise to 80% by the year 2000. The potential for petroleum displacement is massive.

  Comparisons:

  Battery powered trucks and buses are not feasible except in very limited duty cycles because of range and performance limitation and high operating cost.

  Hybrid vehicles are not well suited to most truck and bus applications because of their inherent complexity and limited performance. A full performance hybrid truck or bus becomes a close equivalent to a conventional ICE powered vehicle.

Topical Discussions

Regarding the discussion of pivotal issues, the extent to which the RPVS will displace petroleum does not, as the analysts suggest, depend critically on assumptions relative to load leveling strategies, interties, and baseload storage. It is shown in the analyses and this critique that the displacement of petroleum in electrical power generation is primarily an economic decision. The economics of RPVS will support the shift away from petroleum with no penalty to the consumer.

While the ratio between coupled and uncoupled vehicles on an RPVS system affects the parasitic losses in the system, it is far from being a critical factor in the displacement of petroleum by the system.

An analysis is presented in Chapter III that attempts to quantify the effect of the RPVS on a utility system's generating capacity and petroleum consumption. The analysis predicts a peak load increase of 13.25% that is met by petroleum use in proportions ranging from 3% to 100%, depending on the characteristics of the particular utility system. Two factors are responsible for a considerable overestimation of this effect.

The assumed vehicular energy consumption is 0.5 KWH/VM. The 'road energy' required for electric vehicles at average freeway speeds is known from test data to be on the order of .22 KWH/VM.* (This data was for a vehicle with curb weight of 3400 pounds). An RPVS vehicle of the same passenger capacity would weigh much less, and thus consume even less energy. The maximum battery charging load for the RPVS vehicles would be about 3 KW, assuming a typical state of charge of 50% for their batteries. Thus the total energy per mile would be less than:

$$.22 \frac{\text{KWH}}{\text{Mile}} + 3 \text{ KW} \times \frac{1}{40} \text{ HR} = .30 \frac{\text{KWH}}{\text{Mile}}$$

The overestimation by the analyst is $\frac{0.5 - 0.3}{.5} = 40\%$.

A second factor that distorts the results to a lesser degree is that the assumed daily vehicle miles are inconsistent with the number of lane miles of RPVS. Caltrans data shows that the average traffic on urban freeways exceeds 11,000 vehicles per lane-day. While the apparent error is on the order of 9%, it could in actuality be much greater. This is because even modest implementations of ramp metering and other automated and advisory functions that are available in the RPVS can increase a lane's traffic capability substantially. The result of this discrepancy is that the fixed loss component of the RPVS is overestimated. The effect of the combination of these factors then is an overstatement of peak load requirements by 50% or more.

The analysis indicated correctly that the type of generating capacity

---

* 'Baseline Tests of the EVA Metro Electric Passenger Vehicle' DOE report CONS/0421-1

i.e., base, intermediate, or peak, that is chosen for use by a utility is basically an economic decision. Given the incentive of an incremental increase in revenue per KWH for doing so, the use of petroleum in meeting an increase in peak load could be totally avoided. The RPVS vehicle enjoys a significant operating cost advantage over other vehicle technologies for a very fundamental reason. The RPVS vehicle can use electrical energy in real time that costs typically from 4 to 6 cents per KWH. Energy obtained from a battery typically costs from 20 to 30 cents per KWH because of battery replacement and battery inefficiencies. The cost of energy at the output shaft of a typical automobile's engine is also approximately 20 to 30 cents per equivalent KWH; this cost can be expected to multiply if it comes from synthetic fuels. It is apparent that the economic advantage of the RPVS vehicle will not be significantly affected if a cost increment for non-petroleum based electrical capacity is added to support the system.

The JPL analysts prejudge the consumer's acceptance of the RPVS as low. The RPVS vehicle can be a full performance, durable vehicle with unrestricted range, low operating cost, and ready access to energy supplies. Until the public has the opportunity to assess vehicles that offer these characteristics, the analysts' opinions must be regarded as specious.

Altho a case is not developed by the analysts for the comparative petroleum displacements available from the implementation of EV's or hybrid EV's, there are substantive factors that mitigate against large petroleum displacements by them. Battery EV's will always suffer from some combination of range, performance, and operating cost constraints, even if the continually promised 'advanced' battery should materialize. The conclusions of many respected investigators and the development policies of automobile manufacturers vis-a-vis battery powered EV's indicate clearly that the potential market penetration of these vehicles is severaly limited.

Hybrid vehicles also suffer from some fundamental problems that could cripple any opportunity for wide scale usage. The claim by the JPL analyst that the cost of two small propulsion systems is less than a large one is highly suspect. The costs of emission controls, engines, electric motors, and controllers all can be shown to decrease less than linearly with size. The cost of hybrid vehicles with two propulsion systems and complex controls is likely to be higher than other vehicles. It is very unlikely that the public would welcome the necessity of maintaining both an electric and heat engine propulsion system and two energy supplies on an automobile. Thus any major petroleum displacement by this technology is unlikely.

Synthetic fuels are often cited as a potential replacement for petroleum. This has been shown to be irrational for several reasons:

These fuels entail very high production costs, and massive capital investments.

These fuels would continue to be used in ICE vehicles that typically deliver about 10% efficiency in actual use.

The production of these fuels would impose severe environmental damage at the production sites.

The emissions from these fuels may be much more hazardous than is the case with fuels derived from petroleum.

From a third to a half of the feedstock energy is wasted in manufacture. This means that more coal must be mined and transported and that large additional thermal and CO_2 emissions result.

The analysts have ignored the potential of the RPVS to displace the petroleum used by trucks and buses. This use is now 40% as much as that of automobiles. More importantly, this proportion is projected to increase to 80% within the next two decades. The RPVS can supply the necessary electric propulsion power to these vehicles by making use of long or multiple power pickups.

An interesting additional energy and cost saving is possible by implementing RPVS 'booster' units for trucks on long grades. The booster can supply extra propulsion power to trucks on uphill grades, increasing the speed of the truck. On the down grade the booster would serve as a regenerative retarder that would return much of the hill climbing energy to the system. Preliminary studies indicate that significant energy and travel time savings are likely.

Neither battery powered nor ICE/battery hybrid vehicles are well suited to these applications. The large amounts of energy that are required quickly eliminate the use of batteries from serious consideration in long range, heavy vehicles.

The high cost of synthetic fuels would be a severe handicap to this very competitive industry.

B) Economics

Summary of major viability determinants, and comparisons to other technologies

- The major capital costs of implementing RPVS are similar to or less than those of alternative technologies. An RPVS lane can be expected to serve more than four million vehicles annually, hence the amortization of its cost of about .5 million dollars represents a very small fraction of a cent per vehicle mile.

  Comparisons:

  The capital cost of the inventory of batteries on battery-powered electric vehicles that would travel on one freeway lane mile each day is approximately $300,000. [a)]

  The capital cost of the heavy duty battery chargers required by battery EV's is approximately $2,000. per vehicle.[b)]

  The capital cost of manufacturing and distribution facilities for synthetic fuels has been estimated at 300 to 400 billion dollars, or approximately $3,000. per vehicle.[c)]

- The operating cost of an RPVS vehicle will be less than alternate technologies; electrical energy supplied in real time costs less than stored energy from batteries, and less than energy from gasoline or synthetic fuel.

  Comparisons:

  Battery replacement, costs and electrical energy costs for battery EV's typically exceed seven cents per vehicle mile.

  Gasoline costs typically exceed five cents per vehicle mile; synthetic fuel costs may be twice that of gasoline.

  The averaged total cost of energy and battery replacement for

---

a), b) and c) see reference calculations, page 23.

an RPVS vehicle would approximate four cents per vehicle mile.

- With rational input data assumptions, the 'break even' analysis predicts RPVS costs, including capital cost amortization, that are competitive with present vehicle operating costs.

  Comparisons:

  Comparative analyses of battery powered and hybrid vehicles were not provided.

- Automated RPVS have the potential to reduce the incidence of highway accidents; the attendant savings in dollars and lives are potentially very large.

  Comparisons:

  Alternate technologies cannot improve the status quo.

Topical Critiques

The analysis of the economic viability of the RPVS used mathematical model into which were inserted sets of assumed values for cost and performance parameters. While it is not possible to derive a single, clear evaluation from this work, some interesting effects can be deduced.

Rational sets of assumed parameters are shown to result in very favorable RPVS economics. An inspection of the table on pages 3-17 reveals that the data inserted by advocates is generally not grossly dissimilar to the skeptic's data, in fact some advocates' data is more disfavorable to the RPVS. Major differences lie in the fraction of vehicles that are inductively coupled, the MDG of the 'baseline' (non-RPVS) vehicle, and the utilities' 'petroleum fraction'.

The fraction of RPVS vehicles on the typical freeway lane can rationally be postulated to be near unity, since lanes on typical multiple lane freeways would not be added until existing lanes were near saturation.

The MPG of the vehicle fleet has historically been much less than mandated federal standards; this is unlikely to change in the future. The advocates' choice of MPG were taken from reasonable projections made by a JPL investigator that reflect this fact.

The utilities''petroleum fraction' should approach zero, since the peak load added by the RPVS is small, and generating capacity added to supply it in the future almost certainly will not use petroleum. This topic was addressed in the previous section.

A comparative economic case for battery-only EV's, hybrid vehicles, and synthetic fuels was not made by the investigators. It was shown by the advocates, however, that on the basis of identifiable major capital cost elements for the various alternatives, the RPVS system's capital requirements are competitive with or less than the alternatives. The system's critics are prone to cite the large investment in roadway power systems while ignoring the very large distributed costs of the alternate technologies. These costs include the (first) large battery packs and heavy duty battery chargers required for EV's, and the investment in plant and distribution systems required to supply synfuels to ICE or ICE/electric hybrid vehicles.

A pragmatic treatment of this topic is found in the appended 'Technical Notes' of H. R. Ross. These notes provide an interesting and useful perspective relative to the workings of the economics of transportation systems as they really occur. Clearly, analytical tools such as break even oil (or gas) price are unlikely to be recognized policy determinants in the 'real world' arena.

One major economic factor that must be considered in any transportation system is the cost of accidents that occur within it. Existing automated transit systems typically exhibit accident rates that are lower than non-automated systems by a very large margin. The RPVS, when adapted to increasing levels of automation, can be expected to reduce the number of highway accidents. The cpst of motor vehicle accidents in 1977 was estimated to be 48 billion dollars, five and a half million injuries, and forty-nine thousand deaths. These statistics alone provide powerful economic and humanistic incentives to develop and deploy the RPVS.

Reference Calculations:

a) $11{,}000 \text{ VEHICLES/LANE DAY} \times (220 \frac{\text{WH}}{\text{VM}} \div 0.65 \text{ EFF}) \div 12 \frac{\text{WH}}{\text{LB}} \times 1\$/\text{LB}$

$= \underline{\$310{,}000/\text{MILE}}$

b) $75 \text{ MILE (RANGE)} \times (220 \frac{\text{WH}}{\text{VM}} \div 0.65 \text{ EFF}) \times 0.35 \frac{\text{KW}}{\text{KWH}} \times 250\$/\text{KW}$

$= \underline{2220\ \$/\text{VEHICLE}}$

c) $\$350 \times 10^9 \text{ CAP COST} \div 120 \times 10^6 \text{ VEHICLES}$

$= 2920\ \$/\text{VEHICLE}$

C) Transportation

Summary of major viability determinants, and comparisons with other technologies

- The roadway powered vehicle system offers a clear opportunity to preserve the nation's mobility in the face of diminishing supplies of liquid fuels and limited financial resources for new transportation systems.

  Comparisons:

  Battery powered vehicles are too limited in their capabilities to significantly impact the transportation system.

  Hybrid vehicles offer no new transport capabilities; at best they would have a minor impact on energy supplies.

  The increased cost of synfuels would have a negative effect on mobility.

- The RPVS electric bus will have many characteristics of a new transit mode:

  - adaptability to automation with capacity and operating safety.
  - environmentally benign, visually, acoustically, and emission free.

  Comparisons:

  Other technologies do not provide these characteristics.

- The RPVS provides the option of a new energy supply for trucks and buses. This transportation sector will otherwise have to compete with an increasingly large number of diesel automobiles for energy.

  Comparisons:

  Battery powered and hybrid vehicles cannot serve this sector well.

  Synthetic fuels would be a severe economic problem for this competitive transportation sector.

Topical Critique

Many of the analyses and opinions presented in chapters 3 and 5 are deserving of comment. The 'four primary transport issues' unilaterally selected by the analyst for extended analysis are not consistent with the major transportation issues selected by the debating panels.

With respect to 'availability', the analyst's assumption that the RPVS is constrained to feasibility only on limited access highways is in error. An ongoing feasibility study for a city street system has been funded by California state transportation professionals, who are probably more familiar in detail with the system than the analyst. This fact provides a clear indication that there is a strong possibility or probability that the system is well suited to this use.

A second error is the contention that an RPVS vehicle suffers from the same lack of availability as a battery powered EV because of the need to recharge. Two factors are involved. The RPVS vehicle needs only to reach a freeway to become capable of unlimited range. This distance in urban areas seldom exceeds 10 miles. The recharge energy that would have to be put into a fully discharged battery to travel those ten miles is approximately 2 to 3 KWH, which can be achieved with a light duty charger in about an hour. In very few cases will the battery be fully discharged, so that this scenario represents a worst case. The analyst's projection of 8-12 hour unavailability is grossly overstated.

With respect to 'mobility', the analyst attempted to make the case that the government will control the availability of energy to the RPVS system, and that as a result a constraint upon vehicle operation will result. The weaknesses in this postulation are apparent when one considers the close analogy of the electric utility systems. The consumer is not arbitrarily denied the service of these utilities in his home, nor will he be if he uses this service on the highways. It has been shown that a modest inventory of freeway power systems provides comprehensive availability of electrical service to vehicles thruout an urban area. The percentage of off-system trips has little significance to the issue, since these trips involve modest ranges and speeds that can be well served by the RPVS vehicle's supply of stored energy. One of the most striking advantages of the RPVS is the high degree of mobility that it provides, i.e., closely approaching the present automobile, in an all electric vehicle.

Liquid fueled automobiles face an almost certain energy shortage at best, and rationing in all probability. The constraints on mobility that result will be certain and severe.

With respect to 'model optimization', the analyst's assertion that the RPVS somehow injects a new confinement to vehicular traffic on freeways is not rational. In the postulated case of a freeway accident, the traffic response would remain exactly as it is now, i.e., vehicles will wait until the accident is cleared or creep past it in congested traffic. If traffic must bypass the congestion on city streets, that option also still exists.

Electrical failures will occur on the RPVS with a frequency similar to present utility outages. RPVS vehicles will have the capability of continuing to travel at reduced speed for a half hour or longer. Power outages seldom exceed this duration.

The assumption of a doubling of freeway traffic capacity thru the addition of automatic vehicle and traffic control systems to the RPVS power system would be considered conservative by most investigators of the subject. While non-RPVS highways can be automated, the cost of doing so would be much higher than the incremental cost of doing so with an RPVS.

With respect to 'modal utilization', it should be noted that 'Urban sprawl' was initiated by the electric street railway, not the automobile, as might be inferred from the analyst's comments. The severe traffic peaking characteristic during commuting hours tends to be equally bad, if not worse, on transit systems as is the case on freeways. Figures 1 and 2 illustrate this. Figure 1 shows the peak to average traffic ratio on BART; while Figure 2 shows the traffic pattern on a freeway that parallels BART. While the ratio exceeds 3 for the morning traffic on BART, the ratio is less than 2.5 on the freeway.

A detailed comparison was made of BART and a hypothetical freeway of the same capacity.*) That comparison showed a near equivalence of the systems in most respects. However that comparison included the cost of building a new freeway. Since the freeway network now exists, a freeway based transit system such as an RPVS bus system would enjoy a large cost advantage over other transit systems.

The analyst critically points to the 'double storage' requirements of the automobile. In the case of most American cities, any attempt to substitute line-haul commuting transit systems for freeways will quickly find, as BART did, that the storage requirements are not removed. The commuter typically drives to and parks in the transit system's parking lot. In the process his car operates with a cold engine that consumes a prodigious amount of fuel per mile traveled (ref. Figure 3), and spews out large amounts of pollution because of the enriched fuel mixture and because the catalytic converter doesn't function when cold.

The case of energy efficiency is also not particularly favorable to mass transit. BART uses less energy per car mile than most other rail transit systems. It delivers about 27 passenger miles per gallon in terms

*) 'A Comparison of the Capital Costs of Building BART and Freeway and Bus Alternative', Wayne English, Proceedings of the Fourth Intersociety Conference on Transportation, 1976.

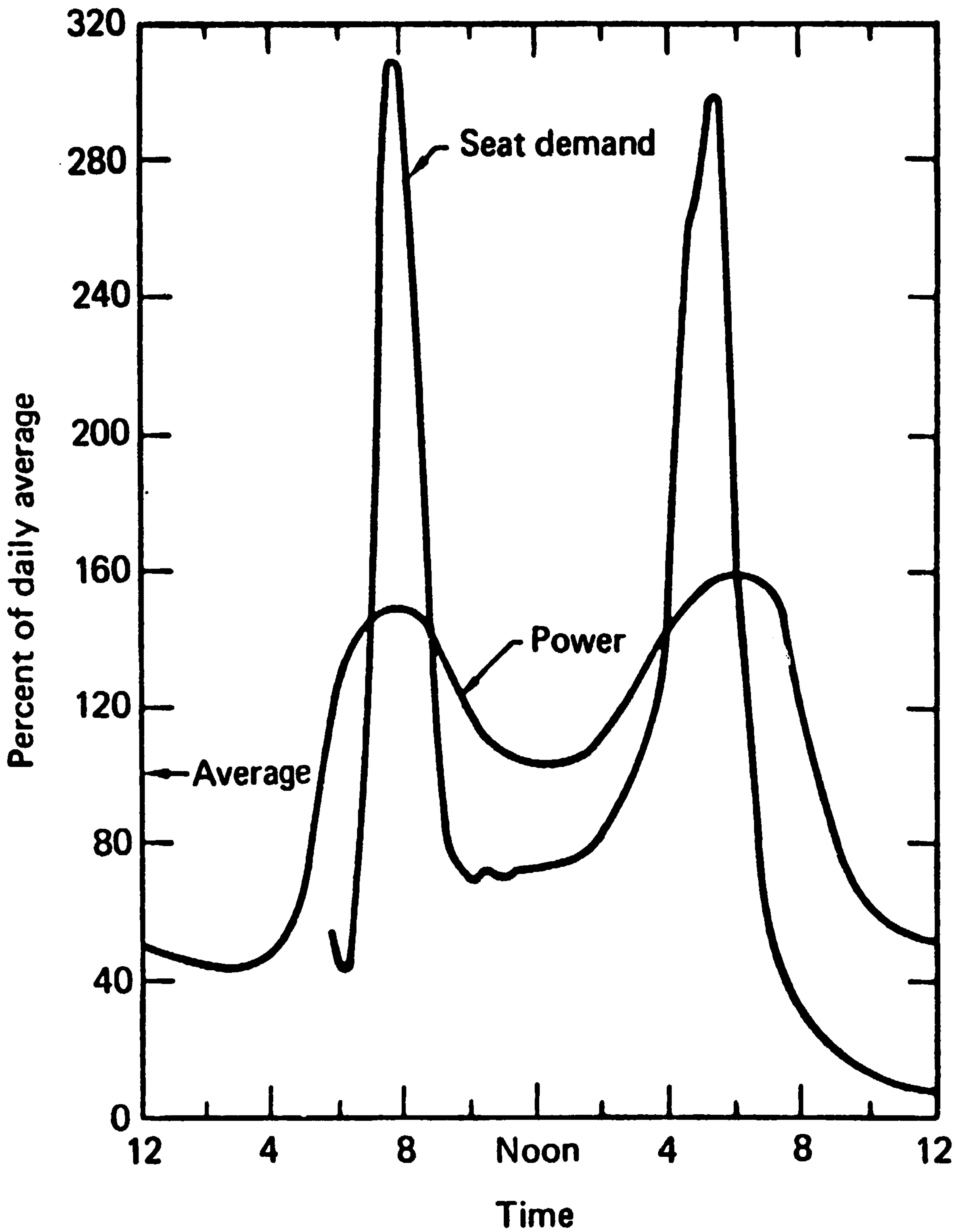


Fig. 1. Typical rapid transit passenger loads and system power profiles. Source: BARTD operating data.

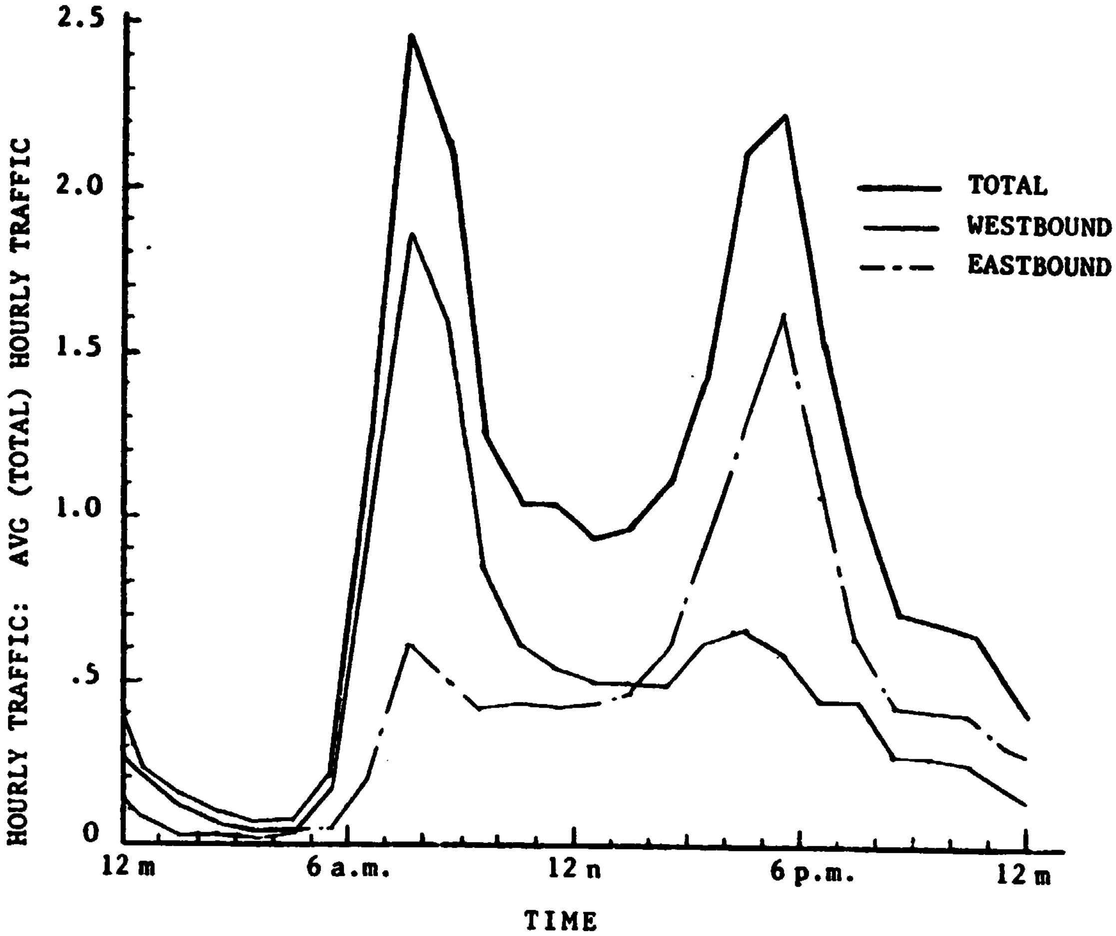


Fig. 2. CALIFORNIA HIGHWAY 24 (SAN FRANCISCO BAY AREA)

ORIGINAL PAGE IS
OF POOR QUALITY

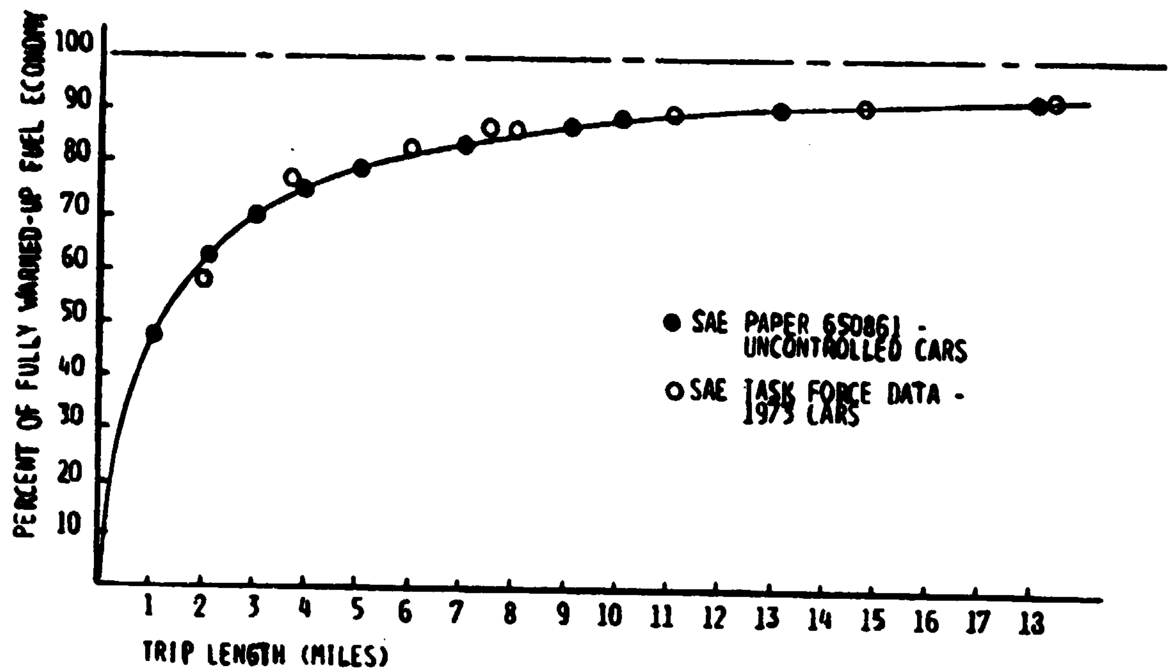


Fig. 3a. Relative cold start fuel economy vs. trip length

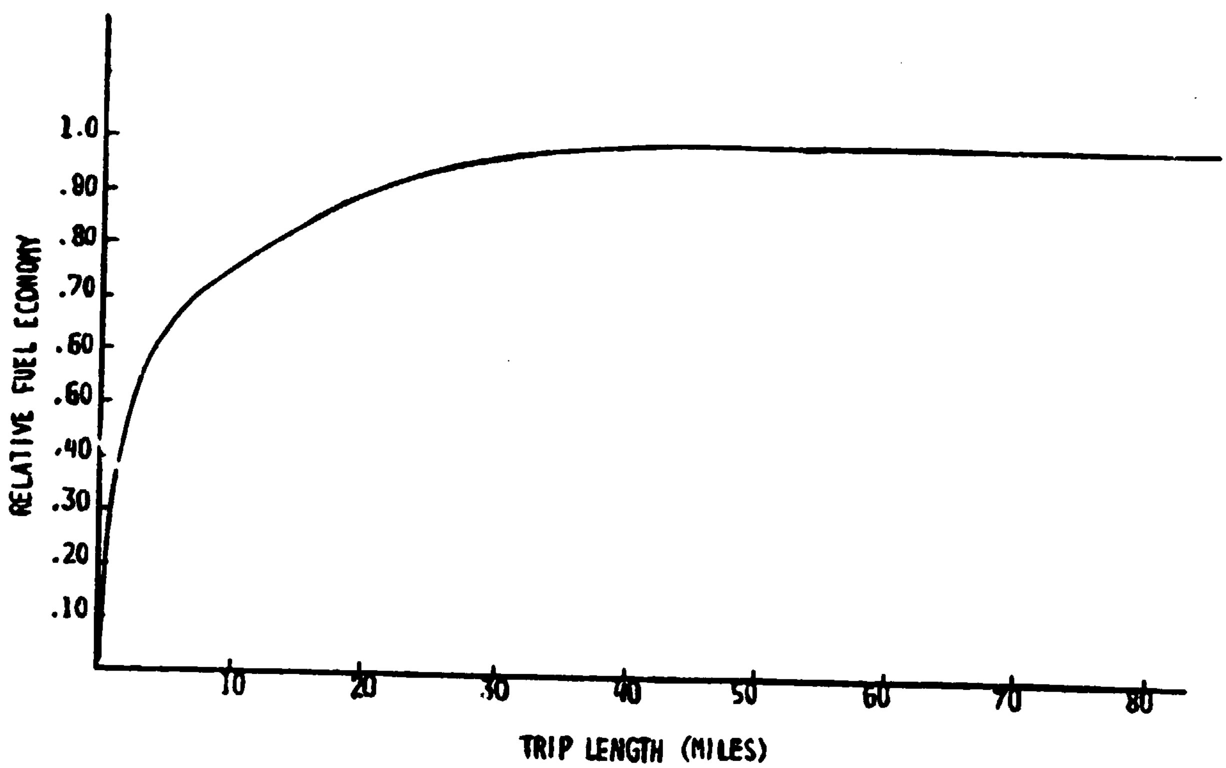


Fig. 3b. Relative cold-hot weighted fuel economy vs. trip length

of equivalent petroleum gross energy input. (This figure is derived from total energy used by the system divided by the passenger miles delivered by it). This can be matched by automobiles with a typical average passenger load of 1.4 that achieve a fuel economy of 19 MPG, or an electric car that consumes less than .5 KWH/mile.

A strong case can be made for RPVS electric bus systems. But systems are the least capital intensive and most flexible of the transit modes. Implementing these bus systems on freeways and urban arterials would provide feeder service at both ends of routes in addition to line haul service on freeways. This type of system would displace automobile trips and reduce freeway congestion. The implementation of the BART system, on the other hand, proved that rail transit systems tend to displace buses on parallel routes but do not displace significant numbers of automobiles. The RPVS electric bus will be acceptable in urban neighborhoods that now object strongly to diesel and trolley buses. Thus the RPVS bus may represent the best possible use of available resources for transit.

With respect to 'transportation impacts', the analyst has considered the installation of RPVS on freeways and arterials and has reached some conclusions relative to the choice of lanes. One conclusion is that placing the first RPVS lanes on an eight lane freeway in lanes one (the outer lanes called 'lane #4' by the analyst) is not feasible because of constraints imposed on ingress and egress of non-RPVS vehicles. The most feasible lane is concluded to be lane four (called 'lane #1' by the analyst).

These conclusions should be regarded as extremely tenuous because of the shallow depth of the supporting analysis. Many factors have not been considered that could have a large bearing on such decisions. A few factors included in a very cursory compilation include:

- Coordinated vehicle detection in lane one and ramp metering might significantly enhance the ability of vehicles to pass thru lane one without constraint.

- The efficacy of mature automatic vehicle and traffic controls in an RPVS as a means of increasing traffic capacity has not been quantified even as an estimate. These control systems may remove the need for equipping all lanes with power systems because of the attendant increase in lane capacity. They also may create regular vehicle spacings that provide continuous, safe pass-thru capability.
- The cost effectiveness of RPVS systems in serving trucks and buses could provide a powerful incentive to initially equip either lane one or lane two, with installations in other lanes following as the first lanes approach saturation by RPVS automobiles.

The analysis of the utility of RPVS on urban arterials is primarily a recitation of potential problems rather than a balanced evaluation of problems and available solutions. The kinds of solutions to the cited problems that should be considered include:

- Automatic vehicle guidance assistance from the roadway can increase rather than degrade the driver's ability to perceive traffic hazards.
- Typical asphalt paving provides a surface quality that is compatible with the needs of an RPVS. This was determined from experimental data. While considerable unevenness is encountered in street and on-ramp surfaces, the magnitude of this unevenness in the length of a vehicle's wheelbase was found to be well within acceptable limits.
- The development of hardware for the RPVS is ongoing. This work has uncovered some design options that may provide RPVS source structures that will be readily removed and reinstalled whenever road or utility service work might require it.

- The clearance airgap between vehicle power pickups and the roadway source can vary considerably without impeding the necessary power transfer. It should be noted that the power needed on urban arterials is less than is the case at higher speeds on freeways. This will allow vehicles to operate with increased airgap (clearances) on the arterials should it be desirable to do so.

With regard to 'weather implications' the analyst erroneously assumed that an RPVS would be rendered unserviceable by snow accumulations. The presence of snow, water, or ice will have no effect on the magnetic properties of the coupling. The power pickup suspended below vehicles will be capable of maintaining a scraped surface above the power source in the road, and the power dissipated in the pickup will be sufficient to prevent the accumulation of ice or snow on it.

The magnetic field from the power source will supply guidance to vehicles either as an advisory function (indicator) or as an automated function. Driving safety cannot fail to be enhanced by this guidance under inclement conditions.

The analyst discussed the 'capacity compared to alternate transportation modes'.

The RPVS electric bus represents a new transit mode that differs from ordinary buses in some important ways:

- Being electric, it is acceptable in neighborhoods where diesel noise and smell are objectionable.
- It is acceptable in neighborhoods where the visual intrusion of trolley wires is not.
- It is the only electric bus that could provide high speed travel in mixed traffic on freeways and expressways.
- It is adaptable to automation on RPVD routes, with attendant potential

tor increased safety, average speed, and route capacity.

The Highway Capacity Manual (Highway Research Board Special Report 87) indicates that the passenger car equivalent of buses on a bus lane is 1.6. The capacity of a lane operating at capacity (2,000 passenger cars per hour, equivalent) would thus be 1,250 buses per hour. With 40 passengers per bus, the passenger capacity is 50,000 passengers per lane-hour. This approximages the upper limit cited by the analyst for a 'single line transit facility'. Important differences are the greatly improved route flexibility (especially collection and distribution) that the bus provides, and the large reduction in capital and operating costs compared to rail systems.

D) Implementation

Summary of viability determinants re implementation

- Several implementation strategies have been identified that constrain risks while achieving important demonstrations of the RPVS technology. Street bus systems, freeway busways, people movers, and truck grade boosters all are options in limited demonstration systems.
- The design of the RPVS power coupling provides considerable tolerance for guidance errors and (clearance) airgap variations. These features ensure a high degree of compatability with ordinary roadways and vehicles.
- The RPVS power couplings are not affected by the presence of rain, snow, or ice. The roadway power source will provide guidance to vehicles even if hidden by surface contaminants or snow.
- The desirable characteristics of the RPVS may serve to accelerate consumer acceptance of the system and its implementation. These characteristics include the long-term availability of energy, low vehicle operating cost, and environmental improvements.

Topical Critiques

Large scale impacts with respect to automobiles may well grow out of initially modest RPVS busway implementations on freeways. Such strategies effectively address any concerns relative to consumer acceptance and functional characteristics while constraining risks to low levels.

In the discussion of 'pivotal issues' the analysts assert that the implementation of the RPVS would be too risky 'because breakthroughs in battery and other 'EV technologies would make EV's more attractive, and hence RPV's obsolete'. This is not correct. A successful advanced battery would benefit the RPVS vehicle just as much as any other, since typically 60% of its travel will make use of stored energy (tho in modest duty cycles). The advanced battery would still leave the battery powered vehicle in the form of a very costly vehicle to purchase and operate, one that requires heavy duty chargers in garages, whose aggregate cost exceeds that of the RPVS, and one that is unavailable for use for 8 to 12 hours after trips of a hundred miles or so. The extra energy wasted in battery charging losses and in continuously transporting the heavy battery and its support structure is also of concern. Thus major breakthrus would in no major way change the battery EV from its status as an inferior technology.

With respect to discussions of the 'roadway installation', the analyst suggests that cutting a slot in freeway lanes in order to install the power source is a 'key question' with respect to technical feasibility of the system. The assertion is made that it is not feasible to concurrently 'rehabilitate' (i.e. resurface) the roadways and install the RPVS in order to avoid cutting a slot into roadways. A special report on highways (U.S. News and World Report, 7/24/78) noted that as far back as 1975, 42% of all paved highways and 27% of interstate pavement were in fair to poor condition. It was also noted that the rate of deterioration, once begun, accelerated. The average annual cost to maintain 1975 road quality standards was estimated to be 21.8 billion dollars a year until 1990.

The analyst overlooks the obvious opportunity to coordinate this maintenance with the RPVS construction program. The fact that roadway repairs are now done in short sections indicates only the existence of budgetary and priority constraints, not that large sections of the freeway network do not need resurfacing.

Looking ahead, such developments as the use of sulphur for a resurfacing material with controllable physical properties (ref. Industrial Research &

Development, 10/79), or the automated road resurfacing (or slot cutting) machinery that was identified in this work indicate that there will be many options available in achieving cost effective RPVS installation methods.

The analyst has contended that typical pavement quality of concrete and asphalt roads is not adequate for the RPVS, and that the presence of the system precludes the rehabilitation or reorientation of lanes. Test data and design studies indicate that these contentions are suspect. RPVS vehicles have the onboard, electronic capability to compensate for guidance errors and airgap variations; this in turn allows the RPVS to tolerate sloppy alignment and surface quality in roadway installations. The analyst's statement that surface projections in excess of an inch are likely to be encountered occasionally on freeways is an exaggeration.

The analyst's statement that the RPVS installation would prohibit the rehabilitation of roadways is also in error. The installation of the roadway source as it will be developed will consist of mechanically fastening the source to the road. This technique will allow the source to be loosened and replaced at a new elevation.

With respect to 'Maintenance', the RPVS installation process, almost by definition, will have the roadway surface in good repair. As the analyst points out, there is no identifiable reason to expect that the presence of the RPVS would accelerate the deterioration of roads. On the other hand, the presence of the RPVS does introduce a (normally small) thermal input to the roadway that could reduce freezing damage to the adjacent pavement. This thermal input is controllable and would be increased if it is found to be economic to do so.

Chuck holes will rarely be present in RPVS roadways, as noted above, and the vehicles' power pickups and their supports can be designed to be sufficiently rugged to withstand occasional 'bottoming out' without damage.

E) <u>Plausibility Assessment</u>

This assessment has some fatal flaws. The analysts cite 'two critical issues that lowered the believability of the Blue Team' (advocates of the RPVS).

The 'raters' asserted that automation in systems such as BART has not been a factor in improved safety, and in some cases have had an adverse effect. The automated systems that are in use have, in fact, displayed system safety records that are typically far beyond the capabilities of non-automated systems. The raters should survey the reliability and safety of such systems as the Seattle-Tacoma airport, Dallas-Fort Worth Airport, Morgantown, and BART. Accidents on BART, other than one during the 'shakedown' period, have invariably involved manual operations or equipment problems other than the automation systems. There is no way that this system could continue to safely operate its high speed trains at close headways thru merges and route changes under manual control. The assertion of the raters is grossly in error.

The second fallacious premise of the raters was the supposed insistence by the 'Blue Team' on a 100% penetration of the 110 million vehicle fleet by the RPVS. This penetration number for RPVS (<u>and</u> battery powered, hybrid, and synfueled ICE) vehicles was used as the basis for an even-handed comparison of capital input requirements for the technologies. The results of those comparisons would have been exactly the same had a penetration of 11 million or 1 million been used.

The credibility of the 'plausibility assessment' was effectively destroyed because of the major role that the above error and misrepresentation played in it.