An Assessment Methodology for Alternative Fuels Technologies

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Through its federal research and development (R&D) policy, the government of Canada has committed itself to active participation in R&D. In the field of road energy technology R&D, the federal government is one of the several players in addition to provincial governments, universities, the private sector, and others. Because of its legislative mandate Transport Canada bears significant responsibility in the area of alternative field technical R&D. Therefore a framework that facilitates coordination of federal expenditures with others and ensures the identification of gaps in R&D so that resources can be focussed on promising research directions was required. Criteria for assessment includes the degree of support for national energy objectives, Canadian commercialization potential, contribution to a more cost-effective transportation system and, from a federal perspective, the contribution to departmental mission objectives. The technology assessments form essential components of a strategic road energy R&D plan aimed at identifying promising research directions and providing a technological success indicator for guiding the allocation of federal energy R&D resources in transportation. Program areas in which federal-provincial joint efforts should be strengthened or initiated in support of national transportation system energy efficiency are highlighted in the paper. The technology assessment exercise, on which this paper is based, is a first step in developing a plan and consensus on strategy for pursuing the most promising road energy R&D within Transport Canada, within the federal government, and between the federal government and nonfederal interests.

Research and development (R&D) has always been an integral part of Canadian industry and government activities. A government review in 1978 of the state of R&D in Cánada, however, revealed that commitment to R&D in Canada was low overall compared to other industrialized nations, and that there was a growing imbalance between the government and industry sectors, both as a source of funds and as performers of R&D.

Of the initiatives that followed, the two most significant were the 1980 National Energy Program (NEP) that established specific targets for energy self-sufficiency, and the 1981 Ministry of State for Science and Technology (MOSST) Federal R&D Policy that identified transportation, energy, space, communications and oceans as the five areas for national R&D concentration.

The nature of the role chosen by the federal government (as promoter and financier) of R&D and its representative departments, as a result of these initiatives, necessitated the requirement for

1. A mechanism to ensure coordination of federal R&D activities and financial support, and
2. Development of an overall strategic plan aimed at identifying promising research directions characterized by a high return on investment.

To ensure coordination of energy R&D within the federal government, the Interdepartmental Panel for Energy Research and Development (PERD) was established. Federal R&D is categorized into six task areas: conservation (including transportation and demand programs); oil sands or heavy oil, and coal; nuclear energy; renewable energy; new liquid fuels; and conventional energy resources.

The latter requirement, that of developing a strategic plan and methodology to facilitate guiding the allocation of federal energy R&D resources in these areas, has been left to panel members, representatives of departments whose mandates encompass one or more of the aforementioned six areas. Of the six task areas, alternative fuels technology was chosen as the area to illustrate the development of a methodology; road transport was used as the specific example.

Road energy R&D is being undertaken or supported by a wide variety of parties in Canada (Figure 1). Various federal and provincial government departments and agencies, municipalities, universities, and private industry are active in this area.

Transport Canada has a clear mandate, as a result of legislation such as the Road and Motor Vehicle Safety Act, to be responsible for new vehicle safety, emissions, and fuel economy. To ensure that its responsibilities in these areas are met, a continuing R&D program was undertaken. The structure and content of this program has been derived from NEP objectives

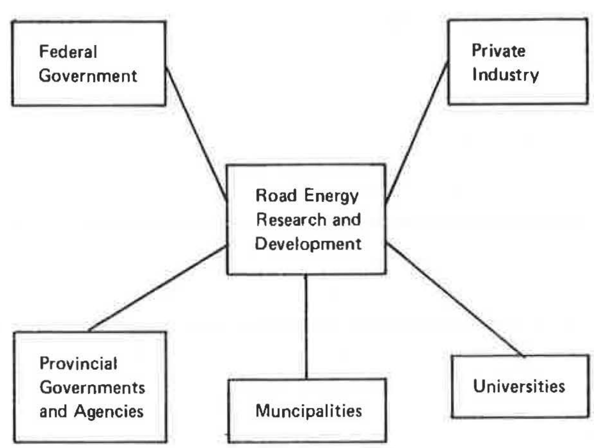

FIGURE 1 Players in road energy technology R&D.

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and priorities for transport end-use energy R&D. Research activity, in order of priority, includes

- Alternative liquid fuel use for motor vehicles,
- Conservation for intercity transport,
- Conservation for urban and regional transport, and
- Electrification and nonliquid substitute fuel use and transport.

Past, current, and projected Transport Canada R&D projects under these program headings have included all elements of the road transport system: fuels, vehicles, and highways.

The PERD approach has assisted in preventing R&D overlap and gaps within the federal government in broad terms. Within road transport energy R&D, however, there is a need for a further refinement that would *(a)* provide a framework to define R&D objectives, priorities and strategies; *(b)* place current and planned projects (federal, provincial, municipal, universities and private sector) within this framework; *(c)* permit identification of gaps or unaddressed technologies; and *(d)* provide the tool for a consensus on a national, concerted research and development effort.

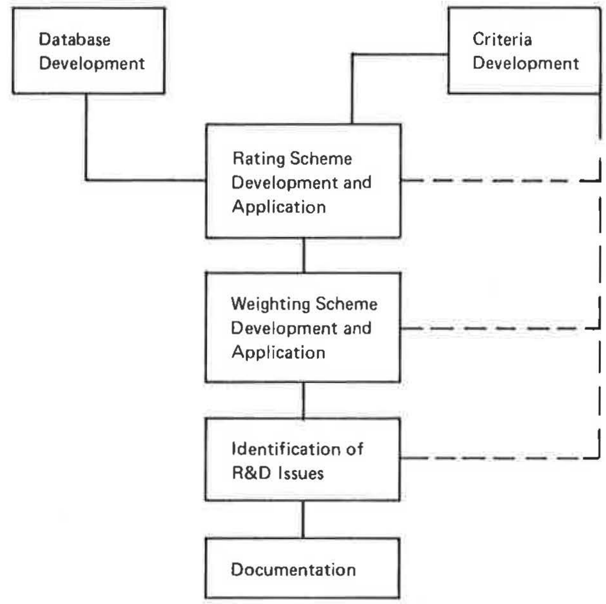

FIGURE 2 General approach to assess the effectiveness of road energy technology innovation.

METHODOLOGY

With a full appreciation of these requirements, Sypher-Mueller International was contracted to develop a framework that would enable

1. Identification of the ongoing road energy R&D being conducted in Canada, and of new technologies that show promise for Canadian application;
2. Assessment of the effectiveness of ongoing R&D in meeting national needs;
3. Updating and assessment of new R&D technologies or projects; and
4. Evaluation of road energy R&D effectiveness under a variety of current and future energy environments.

The general approach used to develop a complete technology project assessment included five basic steps as shown in Figure 2.

Step 1: The identification of federal, provincial, municipal, industrial, and university programs and projects that are currently the subject of road energy R&D. Technologies not currently the focus of Canadian R&D but which show promise for meeting national objectives were also identified. In addition, previous relevant studies were reviewed.

Step 2: The development of criteria for the objective assessment of technologies and R&D projects.

Step 3: The assessment of technologies and of specific R&D projects.

Step 4: The ranking of technologies and R&D projects using the quantitative criteria and weighting factors developed.

Step 5: The identification of gaps in R&D in each technology in federal programs, the programs of others (e.g., provinces, universities, etc.), and combined programs.

These steps form an integral part of the assessment methodology and are described in the following pages. Prior to embarking on Step 1, an overview of alternative fuel technologies was taken.

Technology Overview

Real and perceived fuel shortages in the transportation and utility or industrial sectors have historically acted as the driving force behind the development of alternative fuels and energy conservation technologies. In times of conventional fuel shortages, these sectors have been affected most immediately and widely. Consequently, it is anticipated that they will continue to drive the development of alternative fuels and affect fuel types, availability (quantities, time frames, and location), and costs, as well as the application of energy conservation technologies.

Potential New Liquid Fuels

Potential alternatives to gasoline and diesel fuel are given as follows:

- Conventional fuel equivalents—broadcut and synthetically derived diesel fuel;
- Gaseous—compressed natural gas (CNG), liquified natural gas (LNG), hydrogen, propane, butane;
- Alcohols—ethanol, methanol, alcohol-gasoline blends, alcohol-diesel fuel blends; and
- Others—electric-hybrid vehicles, vegetable oils.

Note that methanol-gasoline blends generally require the addition of higher order alcohols as cosolvent (for improving blend water tolerance characteristics). Also, the term alcohol-diesel fuel blends is used as a convenience throughout this report to describe various methods of introducing alcohols into diesel engines. Depending on specific engine configuration, alcohols can be adapted to diesel engine applications by various means, including solutions with diesel fuels, via mechanical or chemical emulsification, dual-fuel injection, fumigation into the engine air intake stream or by more extensive conversion of the engine to provide spark ignition assist. Finally, CNG and LNG include biomass and synthetically derived fuels. These fuels are most widely considered as alternative liquid and gaseous fuels for the transportation sector. Some of the fuels noted are currently used as fuels, and others are produced in commercial quantities, but not for fuel markets. Several resources are available to supply the alternative fuels. These may generally be divided into fossil fuel and renewable (e.g., solar, biomass, etc.) resources. Currently, many of the new liquid fuels are produced from petroleum, natural gas feedstocks, or both. However, they can also be derived from tar sands, coal lignite, peat, oil shale, and the renewable resources.

Step 1: Project or Program Identification

This step of the study involved

- A literature and general information search,
- Identification and review of relevant federal projects,
- Identification and review of revelant provincial, municipal, industrial, and university projects, and
- Identification and review of relevant technologies of potential interest in Canada, but not the subject of current R&D.

For each R&D project or program identified as relevant, a project summary sheet was prepared. To ensure that the projects selected were relevant, the following boundaries were applied in selecting projects for inclusion in the analysis:

1. Only projects or programs in progress after 1981 were considered. Projects completed in 1981 or earlier were not included. Projects completed in 1982 or 1983, currently ongoing or planned were included.
2. R&D was considered to include all aspects of a technology necessary for its potential for ultimate commercialization, including technical, economic or marketing, and policy issues.

Step 2: Criteria Selection, Definition, and Development

Alternative fuel technologies were divided into three major categories: technical or environmental, economic or marketing, and policy. Separate criteria were developed within each of the three categories. This allowed subjective comparisons to be made relative to the base technology using quantitative and qualitative information.

The technical and environmental category deals with technology infrastructure, technology performance, and environmental issues; the economic or marketing category deals with user cost economics, export market potential, and lead time for commercialization; and finally, the policy-related category addresses national, institutional, and energy-related issues associated with using the new fuel. Several evaluation factors, although not identified separately, were combined into others. For example, intersectoral demands are addressed by the employment impacts criterion and market demand for the alternative fuel is covered by the user cost economics, industry cost economics, and fuel supply criteria.

The criteria were defined to ensure that the approach was as objective and universal as possible: that assessment by two different agencies or individuals would yield similar results.

Step 3: Technology Evaluation

This is one of the most important steps in the methodology. Twelve alternative fuel technologies were evaluated based on a comparison to a conventional system. Many of the technologies are at different stages of development and therefore affect the speed at which they are developed and commercialized. This was taken into account in the evaluation.

Each alternative fuel technology was scored relative to a base equipment system on a scale of +2 and –2. Positive scores indicate advantages and negative scores indicate disadvantages relative to the base system. For example, positive scores for the alcohols will generally relate to their being cleaner fuels. Negative scores will also result from materials compatibility problems and their lower energy densities. The summed numerical scores (unweighted or weighted) cannot be interpreted as the value of the technology, but only as an indication of the relative potential of the technology from the viewpoint of the current knowledge base. Low scoring fuels or technologies may point to the need for R&D to improve the base of knowledge.

The ratings were established on the basis of a consensus of expected trends and the professional judgment of the study team. They are based on the state-of-the-art of the fuel technologies in the 1984 time frame. Many factors or assumptions combined to alter the ratings. The following are the major assumptions used during the fuel technology evaluations:

- The alcohol blends do not contain more than 15 percent alcohol (by volume). In the case of methanol, some cosolvent would be part of the 15 percent alcohol content to reduce the chances of separation of the methanol from the gasoline in the presence of water and to minimize vapor pressure increase.
- The use of methanol with diesel fuel may require emulsifiers or in-line emulsors.
- Methanol is a formulated fuel produced from natural gas.
- Vegetable oils are used neat in diesel vehicles.
- Synfuels are derived primarily from tar sands with properties or specifications comparable to conventionally derived base fuels.
- Electric vehicles use advanced batteries and conventional motor technology. Electricity is produced via hydroelectric or nuclear power.
- Hybrid vehicles contain a small internal combustion engine operating at constant speed in conjunction with an energy storage device such as batteries, hydraulic accumulators, or flywheels.

• The gaseous fuels (CNG), (LNG), propane, and hydrogen are envisioned for use in dedicated vehicles equipped with spark ignition engines optimized for each fuel.
• Hydrogen is produced via electrolysis of water.

The scores for the neat alcohols reflect their lower volumetric energy contents and solvent, and materials compatibility Characteristics. Without financial incentives, the alcohols will be expensive in the short-term, although in the long-term, methanol may become available at comparable costs (on an energy basis). The alcohol blends essentially exhibit the same characteristics as gasoline with some problems of materials compatibility and phase separation. Their costs should not differ significantly from the base fuel.

The synthetically derived fuels, if sufficiently upgraded, should operate well in existing vehicles, although emissions from coal- and tar sands-derived fuels are of greater concern due to their higher aromatic content. The use of synfuels may also incur higher operating and equipment costs.

One of the issues surrounding vegetable oils is quality control if segregated pipelines are not devoted to them, but their environmental impact is considerably better than diesel fuel. Another predominant problem with vegetable oils is their propensity to cause combustion deposit that can lead to clogging and other problems.

Negative scores for electric and hybrid vehicles are due primarily to poorer economics and limited vehicle range and performance. Broadcut represents a good diesel fuel substitute with a moderately adequate cetane number. However, it has a vapor pressure that is significantly higher than diesel fuel but lower than gasoline. Its primary advantage relates to lower energy usage during production in the refinery.

With respect to gaseous fuels, propane, CNG, and LNG rate well technically. The major drawbacks include their low energy densities and the lack of an adequate distribution system. Other problems relate to user acceptability and market system barriers. For hydrogen, the major problems relate to transporting it in the current distribution system, as well as to safety and resultant institutional implications. However, it does have good combustion thermal efficiency characteristics and positive environmental impacts.

Step 4: Ranking of Technologies

Overall rankings for alternative fuels technologies using unweighted and weighted scores, respectively, are given as follows.

1. Unweighted
   • CNG: 9
   • Neat methanol: 9
   • LNG: 6
   • Alcohol-gasoline blends: 6
   • Propane: 5
   • Electric-hybrid vehicles: 5
   • Vegetable oils: 4
   • Neat ethanol: 3
   • Synfuels: 3
   • Alcohol-diesel fuel blends: 1
   • Broadcut
   • Hydrogen: –6
2. Weighted
   • Neat methanol: 20
   • CNG: 18
   • Vegetable oils: 12
   • Alcohol or gasoline hybrids: 12
   • Electric or hybrid vehicles: 10
   • Propane: 9
   • LNG: 7
   • Synfuels: 4
   • Broadcut: 4
   • Neat ethanol: 2
   • Alcohol or diesel fuel blend: –1
   • Hydrogen: –26

Eleven of the twelve fuels showed positive sums for their composite score; only hydrogen showed a negative score. When the unweighted scores are considered, the new liquid fuels fall into roughly four groups with CNG and methanol constituting the top-rank group and hydrogen the lowest. Even when the weighted scores are considered, the fuel groups remain almost identical. Neat ethanol would fall into the third group with hydrogen still constituting the lowest-rank group.

The results of the alternative fuels ranking indicate that CNG and methanol represent the most promising fuel alternatives for Canada followed by LNG, alcohol-gasoline blends, propane, electric-hybrid vehicles, vegetable oils, neat ethanol, and synfuels. Finally, it should be noted that the low scores given do not indicate any inferiority, only that certain obstacles remain to be resolved before the fuel technologies can be commercialized.

In consultation with the Transport Canada Steering Committee, a rating scheme was devised for each topical category to evaluate the influence of various criteria within each evaluation category.

Step 4A: Project Assessment

Individual projects information collected in Step 1 was ranked in the same manner as technologies. In order to assess the effectiveness of R&D projects, a two-stage approach was developed. The first stage dealt with scoring alternative fuel technologies that were addressed prior to 1982. These were scored on a basis of zero, one, and two. Zero indicated that little or no information is available about the criteria; one, that some information is available and further R&D efforts are necessary to adequately address the issue; and two, that the issue has been well addressed and does not require further R&D. Thus, the issues with scores of one and zero suggest that some R&D investigation is necessary.

The second stage involved scoring each road energy R&D project against the same criteria used to assess technologies. A scale of zero and one was used. A score of one indicates that the R&D project has addressed or is addressing an issue, and a score of zero suggests that the project does not address an issue. This stage, therefore, relates to the breadth of a project. For example, if a project scores many ones, it indicates that sufficient information has been or will be generated by the

R&D NEEDS MATRIX				NEW LIQUID FUELS			SUBJECT AREA: METHANOL	
Major Assessment Factors	**Raw Material**	**Raw Material Transport**	**Fuel Manufacture**	**Fuel Distribution**	**Fuel Retailing**	**Road Vehicle Manufacture**	**Road Vehicle Use**	**Road Vehicle Maintenance**
Technical			Fuel specification Security of cosolvent supply Octane level enhancer			Wear mechanism	Additives	Elastomers Corrosive magnesium/ aluminum
Operations				Distribution Fungibility	Storage	Systems performance Materials compatibility	Lubricating oil formulation	Engine wear
Economic			Technology/ product export potential	Impact on gas pool displacements				
Marketing			Export potential Benefit cost analysis					
Policy	Employment impacts Government financial impacts		Energy impact of production	Institutional impacts				
Regulatory								
Environmental	Air quality effect				Emissions		Emissions control	
Safety/Health		Education of fire-fighting personnel Modification of fire-fighting equipment			Leak detection Toxicity Explosion hazard		Crash vulnerability	

FIGURE 3 Example of an R&D needs matrix for methanol.

R&D project relative to the various criteria. In other words, the R&D project is assessing many issues concurrently. Multiplying each score by the weighting factors for each criterion and then summing up the score provides relative ranking of the R&D projects in terms of scope and weight of criteria addressed. The second stage relates to the amount of information currently being generated by the various road energy R&D projects, and does not indicate whether an issue has been adequately described.

This step of the methodology leads to total project scores that give the relative impact of each R&D project. The exercise can also be used to assess proposed projects. This step leads to the GAPS analysis—the identification of those areas that have not been satisfactorily addressed.

Step 5: Analysis of Gaps

From the technology and project assessment, an overview of R&D needs in the alternative fuels area of road energy was developed. Matrices were constructed for each fuel (Figure 3) summarizing areas needing further research and development.

The matrix format permits the use of each matrix as a multiyear work plan; for full commercialization potential of a fuel technology, the needs matrix should be completely void of entries. Working towards this target by addressing issues and removing from the matrix provides a framework for R&D in each fuel technology. By examining all the matrices, it is possible to develop a picture of R&D programs that encompass several fuel technologies.

The needs matrices also tend to put technical R&D in perspective. Although traditional R&D often focusses on the technical issues, other issues are equally important if the potential for use of a fuel is to be fully exploited. Many of the less glamorous but important aspects of the overall R&D picture will be carried out only by government, including issues relating to government policy, regulations, environmental impact, safety, and health.

Based on the matrix analysis of the 12 alternative fuel technologies, overall Canadian R&D needs fall into the following five areas:

1. R&D is required for regulatory changes (federal and provincial) necessary to provide an environment for new liquid fuels.

2. Benefit-cost models are required for general application to new fuels and new technologies, taking into consideration all aspects of a fuels impact. As a generalization, there is a shortage of knowledge on the national benefits and costs of the use of alternative fuels. The models should be readily modifiable to cope with changing relative costs of petroleum and new fuel technologies.

3. Development of minimum acceptable vehicle performance characteristics guidelines in terms of cold start, acceleration, and drivability could provide a useful benchmark for R&D into individual fuels.

4. Research into leak detection, refueling systems, toxicity, crash vulnerability, and fire-fighting equipment needs including development of a national training and information package for fire fighting each one of the new fuels would enhance safety.

5. Continued development of fuel specifications and labeling requirements is needed.

FUTURE OUTLOOK

In the area of alternative fuel technologies, the gaps analyses will serve as the parameters for setting priorities for future expenditures. These gaps will form part of a comprehensive transportation R&D strategic plan for Transport Canada. Now that gaps have been identified in a rational manner, what remains to be done is to determine in consultation with the provinces, industry, and others what R&D should be conducted or supported federally and what projects are best tackled by others.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.