

AUTO21 NETWORK OF CENTRES OF EXCELLENCE
IMPACT ASSESSMENT OF THE RESEARCH & HQP PROGRAMS
FOR
SELECTED PROJECTS IN THE PERIOD 2001 - 2009

BY



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EXECUTIVE SUMMARY

AUTO21 is Canada's national automotive research network. It brings Canada's best researchers from over 40 universities, colleges and hospitals together with more than 140 industrial and public sector partners to conduct applied research projects on topics of importance to the automotive industry and to Canadians who build, travel in and own automobiles.

Since its inception in 2001, AUTO21 has managed and directed research investments of \$90.5 million across more than 70 research and development (R&D) projects related to the automotive industry and the automobile in Canadian society. AUTO21 leverages public funding with private capital to match research university capabilities to industry needs. This total investment is comprised of \$52.2M in federal NCE grants funds and \$38.3M in funds invested in the research projects by research partners, chiefly in the private sector.

The Center for Automotive Research (CAR) was retained to independently assess the impacts of AUTO21's project funding. The purpose of this study is to estimate the economic and societal net contributions made by the R&D projects funded by AUTO21.

This report examines 62 research projects contained within AUTO21's research portfolio to estimate the economic and societal benefits associated with AUTO21 program efforts. Accounting for social, academic, economic, and environmental considerations, both realized and anticipated, CAR estimates that the benefits of the AUTO21 Network of Centres of Excellence to the Canadian economy are:

- 1,600 highly qualified personnel trained over ten years of the program
- 2,200 jobs created or retained, annually including 600 R&D personnel and 1600 indirect jobs
- 12:1 return on investment (ROI) based on the total of \$90.5M of public and private sector funding
- \$1.124 billion in total economic and societal benefits, of which
 - \$700 million from prevention of life loss, personal injury and property damages;
 - \$125 million associated with employment and the formation of household income;
 - \$100 million in industrial process improvements;
 - \$75 million in fuel savings

All of the benefits presented above and within the full body of this report are tabulated on the basis of returns to Canada. While the management of the various AUTO21 projects, the personnel involved and the government-to-industry relationships developed are maintained within the nation's borders, the technological, environmental, safety and process improvements that are developed in association with the AUTO21 program will yield benefits globally. By facilitating investments in R&D and providing a steady stream of people with relevant skills and knowledge, AUTO21 provides a business incentive for automotive companies to locate in Canada. The AUTO21 program creates economic and educational opportunities as well as sizeable societal benefits for the public and industry alike.

AUTO21: IMPACT ASSESSMENT OF THE RESEARCH & HQP PROGRAMS

INTRODUCTION

The purpose of this report is to provide an independent assessment of the benefits of 62 selected research projects funded by AUTO21. Within the automotive sector, AUTO21 has identified six key areas of interest or themes around which the Network automotive research program is organized:

- A) health, safety and injury prevention;
- B) societal issues;
- C) materials and manufacturing;
- D) powertrains, fuels and emissions;
- E) design processes; and
- F) intelligent systems and sensors.

These research projects, taken as a whole, work to improve the global competitiveness of the Canadian automotive industry, alleviate the impacts of vehicles on society, and maximize the dispersion of R&D resources and the involvement of excellent researchers and their students across the geography of Canada in a diverse group of relevant disciplines. Research projects are specifically designed to meet the needs of the external sponsoring companies and organizations and to satisfy the Network of Centres of Excellence (NCE) criteria for evaluating program grants. These goals are elaborated below:

- Excellence of the research program: the quality of the research and how it relates to other research being conducted, as well as how it aides in the achievement of real world goals of the industrial and public sector partners. This criterion also includes an evaluation of how the research contributes to Canada's ability to lead in areas of research with high economic and social impact.
- Development of highly qualified personnel (HQP): the degree to which a research project trains and retains exceptional researchers. In addition, this criterion considers how a project promotes multi-disciplinary and multi-sectoral research and encourages researchers to holistically consider the implications of their work.
- Networking and partnerships: the extent of involvement from academic institutions, governmental agencies, and private sector participants. The criterion takes into account not only official affiliations, but monetary contributions from the various participants and resource use optimization through the sharing of physical, informational, and human capital.
- Knowledge and technology exchange and exploitation: the likelihood that the products of research can lead to commercialized goods and services or effective public policies and provide benefits to the Canadian economy such as enhanced productivity, long-term economic growth and social benefits. The criterion also measures the ability to effectively manage and protect intellectual property produced as a result of research.

- Management of the network: refers to the management and leadership of the Network including scientific and business management, financial stewardship and the effectiveness and quality of the communications activities of the organization.

During the study period from 2001 to 2009, AUTO21 has undertaken the sponsorship of over 70 projects across a wide spectrum of disciplines related to the auto industry and society. Assessing and comparing 62 of these projects based on delivery of results is extremely difficult from a pure numerical return on investment (ROI) standpoint. Some projects (especially those in the materials and design themes) lend themselves to quantitative measurements as part of the outcome of the project, whereas other projects are not as explicit in the delivery of easily quantifiable results. The 62 selected projects evaluated in this report were all considered with the NCE criteria in mind to the extent possible from the available information.

Except where noted, the benefits to Canada from a given AUTO21 research project are quoted as annual values which will be fully realized when the research results of the respective project are fully implemented.

Automotive Research Programs – Described and Discussed

Research, by its nature, is unpredictable in regard to the length of time required to produce results and the certainty of achieving desired outcomes. Projects in the very early stages of research have a higher level of uncertainty as they may not produce results of value, while research in later stages may have results that are deployable into the commercial sector. It is likely that some of the projects examined in the present study may never actually be implemented and so the benefits from them may not be realized. However, the AUTO21 practice of requiring that a commercialization partner be involved in each project makes this less likely than in most traditional academic projects. In effect, AUTO21 utilizes a knowledge “pull” approach which is similar to the most successful industrial production systems.

Our review found that the AUTO21 portfolio of research projects is well balanced in the number of projects in each of the various stages of the research and knowledge commercialization process:

- discovery,
- development,
- early deployment, and
- late deployment.

AUTO21 requires that researchers provide an estimate of the level of activity of their projects in each of these categories. There is a greater likelihood that not all R&D work in the earlier discovery stage will reach commercialization, whereas projects in the later deployment phases are often well on their way to successful use in the economy. In other words, research in the discovery phase may not provide near-term benefits, but may eventually lead to significant benefits in the long-term. The overall AUTO21 research program also includes projects in later stages of development with results that are near the commercialization stage and have measurable benefits. By maintaining a well-balanced portfolio of projects in these various stages of research, AUTO21 ensures that there is enough encouragement of early experimentation of ideas (which is necessary to find the next great idea) offset by projects in later

stages of completion that can show measurable successes and provide the necessary assistance to industry that is required to enhance competitiveness.

An Example of How AUTO21 Research Functions

The portfolio philosophy of the AUTO21 research project program is one of laying out a long-term strategy as well as producing near-term and measurable results. One example of this is research related to the development of IntelliDriveSM systems and technologies.¹ While IntelliDriveSM refers specifically to a U.S. Department of Transportation (USDOT) program to develop vehicle-to-vehicle and vehicle-to-infrastructure communication systems to improve safety, mobility, fuel economy, and other aspects of vehicle transportation, this program also includes participation from at least nine automotive manufacturers, numerous suppliers, and U.S. state departments of transportation. In addition, similar efforts are underway in Europe and Japan. Perhaps, a more general term for IntelliDriveSM is the “connected car,” and this effort falls within the much broader category of intelligent transportation system (ITS). In this report, the term IntelliDriveSM will be used to describe vehicle communication technologies and the future (connected) automobile.

While some components and technologies are in use (GPS) or in testing and limited deployment, a fully developed system is not yet in use anywhere in the world. Furthermore, organizations that are most active in developing connected vehicle systems have not yet agreed on what such a system(s) might entail. Test results and readily available technology suggest that a connected vehicle system is feasible; however, coordination, communication and societal issues (such as ownership of data and legal concerns in the event of a system malfunction) mean that implementing the concept has a long way to go. In addition, preliminary research in the field indicates that once a ‘connected’ vehicle system is developed there is the potential for considerable savings and benefits to society, but also considerable costs for deployment. While the business model for the implementation of these concepts is still under development, it is clear that many jobs may be created in a field that does not even exist today. Any region that hopes to compete for these jobs must stay on the cutting edge of research in the field and be ready with both knowledge and people when the time comes to implement the concept.

CAR evaluators observed a strength in the AUTO21 program that reached across all key thematic areas: all research projects, regardless of the point in the research process, are highly focused on solving significant and relevant problems. To be funded, projects must have ‘a knowledge receptor’ or partner outside of the research organization. These organizations are businesses that are willing to invest in deploying new technology or public entities that are able to utilize research findings. This requirement ensures that projects focus on practical questions of importance to Canada.

AUTO21 management is involved in a hands-on way with the researchers and understands the technical and commercialization aspects of the projects. The AUTO21 board of directors, research management committee and the scientific director are all based around industry with a practical understanding of the work that needs to be done. This knowledge further ensures that funding will go to projects that will benefit society and industry, while still enabling projects with varying levels of risk and return.

¹ For more information on the IntelliDriveSM program, see: <http://www.intelldriv usa.org/>.

Another observation we made was that AUTO21 research projects are designed to promote understanding of the problems from many angles and aspects. With this type of design philosophy, most projects develop multiple lines of spinoff work, some of which is picked up by both private and public organizations outside of AUTO21 funding. The private sector would likely not undertake much of this research without the impetus of AUTO21 because of that sector's (necessary) focus on short-term financial returns.

Deployment of AUTO21 Research

AUTO21 research covers the full gamut of the automotive industry's role in society. The use of automobiles affects many facets of life in today's society. The six key areas or themes of AUTO21 research cover the breadth of the auto's impact on people's lives - an aspect that privately funded research is not able to achieve. AUTO21 research covers health, the environment, safety, employment, social aspects (such as auto theft, road rage and other vehicle related crimes), workplace and driver ergonomics, materials and manufacturing processes, design and vehicle connectivity and information systems for more productive factories. Some of the applications are immediately useful by industry (and some AUTO21 technologies have already been deployed by industry) while others have non-commercial societal benefits. This diversity of research projects creates new 'space' and new opportunities for the Canadian automotive industry, society, and technical advancements.

AUTO21 strengthens the private and public automotive research network across Canada through its ability to coordinate and communicate research efforts. Significant benefits can be observed in commercial applications that are the byproducts of the research efforts, as well as in safety and environmental effects. Some of these results are difficult to quantify because the tangible benefits from high quality non-commercial research are often not realized for many years. Our examination of the program has found that the research projects in this study appear to be a part of, and a major contributing factor to an effective network of researchers and research partnerships. It is clear that the research network that has sprung from the AUTO21 program communicates well internally and externally, disseminates findings rapidly to a wide variety of audiences, and invites new partnerships and collaborations.

FINDINGS

CAR staff determined that the 62 projects evaluated will provide or have already returned \$1.1 billion to the Canadian economy as shown in Table 1 below. Based on the original investment of \$52M from the Canadian federal government and \$38M from the external industry and public sector partners totaling just over \$90 million, the return on this research is well over 10 to 1 (see Table 1).

It must be noted that while total investment of \$90M represents the total funding of the AUTO21 program in the 2001-2010 period, the \$1.1B in economic and societal benefits returned to Canada is the estimate just from the 62 selected projects studied in the present report. The impacts and benefits from the other projects not studied would be in addition to that amount.

Table 1: Payback Analysis of AUTO21 Research Investment Dollars

Contributing Investors	Investment (000s \$)	Estimated Total Research Benefits (000s \$)*	Estimated Payback Ratio (benefits / investment)
Private sector partners	38,300	Benefits accrue across several sectors. See tables 2-7 below.	
Public sector funding	52,200		
Public and private total	90,500	1,123,554	12.4

**Total benefits as outlined in Table 2 below*

It should be understood that CAR researchers had no preconceived notions about what to expect in analyzing the selected AUTO21 research projects. In general, CAR analyses are conducted with assumptions and decisions that are conservative, factual, defensible and reasonable. CAR reports are used by policy-makers throughout the U.S. and Canada, and at all levels – federal, state/provincial and local. For this reason, and also because CAR reports often are visible in various media, as a general guideline, CAR research states only those benefits it can independently verify.

Analysis Process

Information about the selected projects was gathered in two formats:

- 1) using data from the standard reporting procedures already in place at AUTO21 and
- 2) using CAR-generated data matrix forms that researchers completed specifically for this evaluation.

AUTO21 funds a variety of research projects that examine various aspects of the automotive industry. The research done under AUTO21 is multidisciplinary and provides a wide range of benefits. The following sections offer an overview of many of these benefits which are quantified in Tables 2 - 7. For all of the calculations, CAR used values obtained from peer-reviewed journal articles or government research sources. Many of the line items from Tables 2 - 7 are discussed at greater length in the key thematic research area assessments.

Table 2: Social & Health Benefits of AUTO21 Research Projects (Canadian Data)

Measured Impact of AUTO21 Research Projects	Quantity	Unit	Estimated \$ Impact
Lives saved	400	Mixed value for youth and elderly	250,000,000 ²
Injuries prevented	20,000	\$24,000 / injury	480,000,000 ³
Accidents Prevented	70,000	\$1,000 / accident	70,000,000 ³
WSIB claims avoided per year	50	Claims	100,000 ⁴
Measured annual value of thefts prevented			15,000,000 ⁵
TOTAL SOCIAL & HEALTH BENEFITS			815,100,000

Table 2 provides an estimate of benefits to Canada that are associated with several AUTO21 research projects primarily concentrated in the health, safety, injury prevention, societal, intelligent systems and sensors research areas. Multiple projects claimed significant reductions in the number of accidents that cause vehicle related fatalities, injuries and property damage. Several research projects estimated that once all of their findings were implemented, they would prevent between 10 percent and 25 percent of all traffic fatalities. CAR estimated the potential for saving lives from each project independently to verify the researchers’ own estimates. To allow for interdependencies that could occur if all of the recommendations from all projects are implemented, CAR estimated the potential for double counting (that is, independently, various projects might each save, for example, 10 lives, but when all projects are implemented, they might all be saving the same 10 lives).

CAR researchers concluded that an overall reduction of about 15 percent of traffic fatalities benchmarked to 2008 vehicle related fatalities⁶ is both reasonable and conservatively estimated. Based on these findings, 400 fewer fatalities per year in Canada should be prevented as a result of AUTO21 research project innovations realized and fully implemented. We also note that several of these projects are aimed at product improvements which could also prevent a substantial number of injuries and deaths in the U.S. and other jurisdictions, and so the benefits of AUTO21 research could be felt much more widely than in Canada as a result of the globalization of the automotive industry.

To quantify the benefits of reduced fatalities, CAR used a quality adjusted life years (QALY) measurement. A QALY analysis is a type of economic analysis that is widely accepted in econometric studies related to health and mortality. It measures the quantity and quality of life preserved associated

² The sum of lives saved from all projects is greater than 400. To avoid double counting, a standard of 15% of fatalities was used. Half of lives saved were assumed to be elderly people at \$250,000 QALY value, and half were assumed to be people under 55 years of age at \$1,000,000 QALY.

³ Discussed in the body of the report.

⁴ Estimates based on annual Workplace Safety and Insurance Board (WSIB) claims by type by cost.

⁵ Value provided by AUTO21 researchers based on government of Manitoba and Manitoba Public Insurance Corp. data.

⁶ There are approximately 2,800 traffic-related fatalities in Canada per year, as compared to approximately 40,000 traffic-related fatalities per year in the U.S.

with some sort of intervention or treatment. Assignment of a productive life-year value was used to determine the monetary benefit of a reduced fatality. A standard value of \$50,000 per year was used. Half of those saved were assumed to be people 55 or over, and were assigned a QALY of \$250,000 (\$50,000/year x 5 years). Half of those saved were assumed to be people younger than 55, and were assigned a QALY of \$1,000,000 (\$50,000/year x 20 years).

In addition to lives saved, AUTO21 research efforts are likely to reduce traffic-related injuries and property damage and/or minimize the health impacts of a collision. Improvements in driver training, visibility and in vehicle safety restraints such as seat belts and air bags are examples of the products and techniques being researched at AUTO21's various Centres of Excellence across Canada. To estimate a social benefit associated with reduced injuries from collisions the approach employed was to multiply each injury prevented by \$24,000, which is a middle-to-low average value obtained from a comprehensive literature review of injury valuation data. Likewise, property damage prevention was estimated to be valued at \$1,000 per property damage-only accident which is a low value given modern costs for the repair and replacement of vehicles and household items.

Adjustments to the manufacturing processes in the workplace to improve ergonomics are expected to yield benefits due to a reduction in back injuries, which is a key category of injury for people doing manual labor in manufacturing plants. Theft prevention programs and public policy outreach to communities with high incidences of drug use offenses and other antisocial behaviors are expected to yield benefits on the order of \$15 million annually across Canada.

Table 3: Canadian Employment Benefits of AUTO21 Research Projects

Measured Impact of AUTO21 Research Projects	Quantity	Unit	Estimated \$ Impact
Total HQPs	1,600	Total trained	Not measured
Current HQPs	600	Employment	Part of \$125 million
Jobs created or retained	500	Employment	Part of \$125 million
Spinoff jobs impacted	1,100	Employment	Part of \$125 million
TOTAL EMPLOYMENT CREATED OR RETAINED	2,200	EMPLOYMENT AND INCOME	125,000,000³

Table 3 highlights the employment and income benefits of training and retaining highly qualified personnel (HQP) associated with the research efforts of AUTO21. The average annual number of HQP for the study period (2001-09) was 600 individuals as indicated above. These 600 direct employees are employed in research and development related roles commensurate with their training and experience. These people support other workers in the economy who are employed in stores, restaurants and other industries. Once again, these are Canadian employees but it is clear that because of the far-reaching effects of R&D, additional jobs will be created outside of Canada as the deployment of new knowledge rolls out across the auto industry.

To develop an estimate of benefits associated with the training of HQPs, an economic simulation model was used to measure the total employment created or retained. CAR's simulations found that for every HQP trained and employed slightly less than 3 other jobs are developed in the Canadian economy. A more detailed discussion of benefits associated with training HQPs can be found in the *Job Creation Benefits* subsection on page 13.

Table 4: Environmental Benefits to Canada of AUTO21 Research Projects

Measured Impact of AUTO21 Research Projects	Quantity	Unit	Estimated \$ Impact
Fuel savings	75,000,000	Litres of gas / year @ \$1 / litre	75,000,000 ³
Metric ton reduction in carbon dioxide emissions per year	174,000	\$15 / metric ton	2,610,000 ³
Metric ton reduction in carbon monoxide emissions per year	4,480	metric tons	Not measured
Metric ton reduction in nitrogen oxides emissions per year	3,360	\$400 / metric ton	1,344,000 ³
Other pollution savings	190,000	litres of water	Not measured
TOTAL ENVIRONMENTAL BENEFITS			78,954,000

A major goal of AUTO21 research efforts is to assist in the development of technology and processes that will improve the performance of the automobile while reducing its impact on the environment. Table 4 details some of the environmental benefits associated with advancements in light weighting and manufacturing process improvements. AUTO21 researchers estimate that a minimum of 75 million litres of fuel will be saved per year if light weight materials are used in 10 percent of the vehicles produced in Canada. While some of the environmental benefits could not be quantified in dollar terms, such as reductions in contaminated water from manufacturing processes, a conservative estimate of benefits to society stemming from fuel use and emission reductions is slightly less than \$80 million.

Table 5: Canadian Industry Benefits of AUTO21 Research Projects

Measured Impact of AUTO21 Research Projects	Quantity	Unit	Estimated \$ Impact
Industrial process improvements - measured savings			100,000,000 ⁵
Product and design improvements	300	\$ cost savings / vehicle produced	4,500,000 ^{3,7}
TOTAL INDUSTRY BENEFITS			104,500,000

In addition to environmental and safety benefits that are derived from improved industrial processes, the automotive industry also realizes cost savings from AUTO21 research projects. The majority of cost savings are derived from improving light weighting efforts through the use of new materials such as renewable biofibers for interior parts, fine-cell foaming for plastic parts and improved light metal casting techniques used in the engine block. Table 5 outlines the estimated benefits to Canada’s auto industry associated with these industrial process, product and design improvements. Obviously, these benefits would also accrue to U.S. production and that in other jurisdictions as a result of wider adoption of new technologies.

Table 6: Academic Benefits of AUTO21 Research Projects

Measured Impact of AUTO21 Research Projects	Quantity	Unit	Estimated \$ Impact
Publications, book chapters, presentations	1,750		Economic value not counted in the benefits to Canada
TOTAL ACADEMIC BENEFITS			Not quantified

The development and contribution of academic materials associated with AUTO21 research efforts provides information and knowledge to academics and industry. Table 6 shows that the AUTO21 research projects contributed 1,750 publications, book chapters and presentations to the body of automotive knowledge during the study period. Note that the number of publications cited by AUTO21 researchers is much higher than this but CAR examined the list carefully and eliminated duplicate entries which were listed by more than one person, this type of duplication being inherent in a networked research program of the type supported by AUTO21. It should also be noted that while the monetary valuation of academic publications has been attempted (see below on page 14-15), CAR researchers concluded that the actual dollar value of these publications could not be sufficiently proven to be included in the financial tabulation of benefits to Canada.

⁷ Assumes 1.5 million units of production in Canada.

Table 7: Total Measured Impact of AUTO21 Research Projects

Measured Impact of AUTO21 Research Projects	Estimated \$ Impact
Social & health benefits	815,100,000
Employment benefits	125,000,000
Environmental benefits	78,954,000
Industry benefits	104,500,000
Academic benefits	Not counted in the total benefits to Canada
TOTAL ECONOMIC BENEFIT	1,123,554,000

As described in tables 2 through 6 and summarized in table 7, the estimated economic benefits of AUTO21 program efforts and project research are slightly more than \$1.1 billion. The remainder of this report expands on these summarized findings and describes the methods used in estimating these benefits in greater detail.

SUMMARY OF ECONOMIC IMPACTS AND BENEFITS TO CANADA

Health and Safety Benefits

Research aimed at saving lives and preventing injuries through improving vehicle safety features and reducing automotive collisions creates significant value for both consumers and society in general. Innovations in automotive systems as well as social programs to promote better and safer driving can reduce on-road risks, lowering the probability of fatalities, injuries, property damage and theft. In addition to studying ways of improving health and safety inside the automobile, AUTO21 research has examined the production process and has explored ways of improving health and safety inside the factory as well. The prevention of auto crash fatalities, injuries and property damage accidents as seen in Table 2 above is attributed to four specific research projects. To avoid double counting, CAR assumed that all four projects were cumulatively responsible for a 15% reduction in vehicle collisions.

While the benefits of the saving of human lives are not controversial, attempts to monetize the value of a human life has generated significant academic debate. After conducting a comprehensive literature search on the subject, CAR selected five high-quality, representative independent studies on which to base valuation assumptions. These sources vary from the quality adjusted life years (QALY) estimate of \$50,000 per year of remaining life to estimates of the monetary value of a life which ranged from \$250,000 to \$7.5 million per life, with most estimates in the \$1-3.5 million range.

CAR chose to use a conservative QALY estimate of \$50,000 per year of remaining life. For seniors a standard of five remaining years or \$250,000/life was used, while for children, a standard of 20 years of productive workforce participation (or \$1 million) was used. Injuries had estimates ranging from \$7,500 to \$130,000 or more depending on the severity of the injury. Half of the avoided injuries resulting from AUTO21 research were estimated to be head and neck injuries (based on research targets of the relevant projects); an estimate of \$24,000 was used. This is on the lower end of the middle-range estimates for those types of injuries.

A number of research projects were targeted towards preventing workplace injuries. However, given the lead time required to implement changes in industrial settings, the benefits for workplace injury prevention were not quantified.

Benefits from the AUTO21 Highly Qualified People (HQP) Training Program

A total of 1,600 people have pursued their education while working as researchers (in training) in projects funded by AUTO21 (see Appendix A for a chart showing the breakdown by discipline of the total AUTO21 HQP cohort). The research projects examined in the present study supported more than 600 HQPs during the most recent evaluation periods.

Training highly qualified personnel is critical to developing and maintaining Canada's capacity for highly effective industrial research and development output. Nearly seventy percent (70%) of AUTO21 funding is devoted to the training and development of HQP⁸. Without exception, all of the projects reviewed

⁸ AUTO21. *AUTO21 Book One: Network Progress Report*. Rep. Windsor, Ontario: AUTO21 Network of Centres of Excellence.

had attracted appropriate numbers of highly qualified personnel. The scope of work for these projects involved HQPs in significant and challenging aspects of the research. The majority of HQPs were or are pursuing Masters or Ph.D. degrees.

These projects retain graduates in their fields of study (and in Canada) at rates ranging from 50% to 100%. More importantly, participation in these research projects gave the HQPs a strong start in their chosen careers. Many of them published their research (sometimes as co-authors) during their tenure in AUTO21 research projects. Many more went on to positions that recognized their expertise in their fields including posts in industry or academe. In addition to assisting AUTO21's research efforts, HQPs gain strong technical skills and an understanding of how to effectively manage multi-year, multidisciplinary research projects, making them ideal candidates for firms seeking individuals with project management experience. For instance:

“With respect to research, the students have been exposed to all levels of the project, from project development to theoretical laboratory experiments right through to industrial data collection on plant floors. Our students have been very active contributors to knowledge exchange through publishing papers in peer-reviewed journals and presenting work at a very wide breadth of meetings, both purely academic and meetings with industrial ergonomics practitioners. Upon completion many of our HQP have either proceeded into higher degrees (i.e. Ph.D. from M.Sc.) or have ended up working in industry and ergonomists, many in the automotive area.”⁹

Job Creation Benefits

Results from an analysis done by CAR indicate that the work of the researchers, the 600 HQPs in the group of projects studied, and the jobs that are created or saved in industry because of increased competitiveness of private companies which partnered with the Network on these projects, support another 1,600 jobs providing for a total of 2,200 jobs in the Canadian economy (see Table 3 on page 8).

These 600 direct jobs in research, industry and manufacturing support about 1,600 other jobs in the economy: first, because people require supplies, materials and services to do their work. Secondly, the researchers and the people employed in businesses supplying goods and services spend their paychecks, creating other jobs in the economy (expenditure-induced employment resulting from spending by direct and intermediate employees). These 1,600 “indirect” jobs are located in a variety of sectors beyond the direct research or manufacturing jobs:

- Wholesale and retail trade 30% (approx. 480 jobs)
- Administrative and business support services 10% (approx. 160 jobs)
- Other services – primarily for consumers 40% (approx. 640 jobs)
- Transportation, utilities, construction and mfg. 20% (approx. 320 jobs)

Employment (see Table 3 on page 8) and Gross Regional Product (GRP) estimates are derived from analyses using a widely recognized dynamic, inter-industry regional economic model, supplied by Regional Economic Models, Inc. (REMI), of Amherst, MA.

⁹ Callaghan, Dr. Jack P. (2006). “Final Project Report for AUTO21 Project A03-AIH, Industrial Health and Safety in the Auto Industry.” Internal report – not published. March 31, 2006.

Manufacturing Benefits of AUTO21 for Enhancing Global Competitiveness

Industrial support of university research has been strong, especially in cases where there are frameworks already in place for developing research partnerships between industry and universities. There are several reasons why industry stands to benefit from such partnerships:

- rapidly developing technology makes it difficult for in-house industrial development to keep pace, especially for smaller Canadian companies;
- there has been a trend towards downsizing large centralized industrial research laboratories;
- universities have specialized facilities and staff that are expensive and difficult to replicate; and
- firms can explore new technologies at universities without committing to hiring permanent researchers.¹⁰

In addition, the products of the research itself can result in improvements to the bottom-line by reducing the conventional costs of production which are often factored into decision-making as well as reducing other costs (e.g., regulatory, overhead, and liability).¹¹ The research may also assist in improving the morale and productivity of workers through improvements in safety and comfort on the factory floor. Quality and design improvements can also serve to increase the competitiveness of Canadian automakers by improving the products delivered to consumers. The values produced for the manufacturing sector are based on research projects in the key research areas of materials and manufacturing, design processes, and powertrains and fuels. An explanation as to how the values for these benefits were generated can be found within the section of this report that deals with the applicable research theme evaluation.

Environmental Benefits of the AUTO21 Research Projects

By reducing the impact of the automotive fleet – whether through limiting tailpipe emissions, decreasing road wear, resolving congestion issues, or preventing accidents, there can be substantial savings in terms of taxes and business costs while improving air quality. The benefits from reductions in emissions include reductions in mortality, morbidity, smog formation, and acidification; increased visibility; preservation of materials and cultural resources; improved ecosystem health and recreational opportunities; and lower levels of greenhouse gas emissions.

Intellectual Property Creation and Dissemination Benefits

The dissemination of intellectual property is essential to the process of economic growth and has significant implications for economic development. Exploitation of intellectual property for economic development is considered to be one of the major benefits of publicly sponsored research. In the United States, it is estimated that hundreds of thousands of direct jobs have been created as a result of university licensing of patents.¹² Students have also benefited from increased interest in the

¹⁰ Nelsen, Lita. (1998). "The Rise of Intellectual Property Protection in the American University." *Science*. March 6, 1998. <<http://www.sciencemag.org/cgi/content/full/279/5356/1460>>.

¹¹ EPA. (1995). "An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms." U.S. EPA Office of Pollution Prevention and Toxics. June 1995. <<http://www.p2pays.org/ref/02/01306.pdf>>.

¹² Nelsen, Lita. (1998). "The Rise of Intellectual Property Protection in the American University." *Science*. March 6, 1998. <<http://www.sciencemag.org/cgi/content/full/279/5356/1460>>.

exploitation of intellectual property generated in universities. Students are motivated to increase their awareness of the potential commercial utility of their research findings. Many courses now include sessions on patenting and technology transfer. In addition, there is an emerging trend toward the creation of joint programs between engineering and business schools, creating a more collaborative environment on campuses and stressing the importance of commercializing technology.¹³

Besides being exposed to entrepreneurial opportunities that research presents, funding research projects is an effective way to provide research opportunities to students and assist in the training of HQPs who will be leaders in the future workforce. Creating opportunities for students to engage in cutting-edge research and encouraging involvement at all levels of research results in unique experiences that prepare these individuals for highly productive careers.

After reading through a large number (more than 20 in fact) of academic papers that had attempted to quantify the value of journal article publications, CAR found that valuations range from \$625 to \$7,000 per article published. At the low end, this would be a total economic impact of \$1 million for the 1,750 articles that have been published by AUTO21 researchers in the projects studied for this report while at the high end, the impact would be \$12.3 million¹⁴. Given the wide range of possible values and the resulting potential for controversy, CAR decided to not count the financial value of the academic publications in the total benefits to Canada. Nonetheless, the codification of research knowledge is undeniably beneficial to any advanced economy, especially when it supports a strategic industry sector.

Once again, we must emphasize that the number of publications used in these calculations is only those produced in the 62 projects studied for the present report. The benefits of those originating from the remainder of the AUTO21 research program would be in addition to those quoted above.

¹³ Nelsen, Lita. (1998). "The Rise of Intellectual Property Protection in the American University." *Science*. March 6, 1998. <<http://www.sciencemag.org/cgi/content/full/279/5356/1460>>.

¹⁴ CAR research based on this literature: Chang, Chen-Chi. "The of Value Knowledge Created by Individual Scientists and Research Groups." *Journal of Scholarly Publishing* 39.3 (2008); Cox, John. "The Changing Economic Model of Scholarly Publishing: Uncertainty, Complexity, and Multi-media Serials." *INSPEL* 32.2 (1998); Diamond, M. "What Is a Citation Worth?" *Journal of Human Resources* 21.2 (1986); Ealey, Lance. "What Drives Automotive Technology Penetration?" *Automotive Industries* 180.4 (2000); Henderson, Albert. "Research Journals: A Question of Economic." *Logos* 16.1 (1995); Houghton, John. "The Crisis in Scholarly Communication: an Economic Analysis." Proc. of Evolving Information Futures, 11th VALA Biennial Conference and Exhibition, Australia, Melbourne. (2002); Liebowitz, Stan J. "Copyright Reconsidered." *Issues in Science and Technology* 21.3 (2005); Nevo, Aviv, Daniel L. Rubinfeld, and Mark McCabe. "Academic Journal Pricing and the Demand of Libraries." *Competition Policy for Journals* 95.2 (2005); O'Connor, Steve. "Economic and Intellectual Value in Existing and New Paradigms of Electronic Scholarly Communication." *Library Hi Tech* 18.1 (2000); Oh, H. C., and J. F. Y. Lim. "Is the Journal Impact Factor a Valid Indicator of Scientific Value?" *Singapore Medical Journal* 50.8 (2009); Schonfeld, Roger C. "The Value of Scholarly Journals in a Two-Sided Market." *The Serials Librarian* 54.1 (2008); Stevens, Greg A., and Kurt Swogger. "Creating a Winning R&D Culture." *Research Technology Management* 52.1 (2009); Tuckman, Howard P., and Jack Leahey. "What Is an Article Worth?" *Journal of Political Economy* 83.5 (1975); Weston, Brendan. "Eek! It's Tech!" *Canadian Business* 74.11 (2001).

SUMMARY OF IMPACTS OF EACH AUTO21 RESEARCH THEME

THEME A: HEALTH, SAFETY AND INJURY PREVENTION SUMMARY

Table 8: Summary of Benefits from Theme A Projects

Number of Projects	10
Number of HQP	60
Total Amount Invested (Millions \$)	22.8
AUTO21 Contribution (Millions \$)	15.9
Partner Contributions (Millions \$)	6.9
Lives Saved	300
Injuries Prevented	15,000
Accidents Prevented	52,500
WSIB Claims Avoided/Year	50
Publications, etc.	350

The Health, Safety and Injury Prevention theme provides benefits to Canadian society. The work in this theme aims at preventing vehicle crashes and mitigating the outcomes of those that do occur by preventing injuries and fatalities in traffic, and by enhancing workplace safety. Key findings in this thematic area impact manufacturers by offering new research into product design for safety as well as work process improvements to achieve lower injury rates. The potential to save lives and prevent injury are the key outcomes of many of the projects in this research area.

The seven areas for which projects were evaluated are:

- Childhood Vehicle Safety
- Child Safety Seat (crash mannequin design)
- Industrial Improvements
- Driver Qualifications
- Vulnerable Populations
- Elderly Drivers (follow on from the Vulnerable Populations project)
- Advanced Seat Design

Training and Intellectual Property

As previously stated, a major aspect of AUTO21's program is to develop Highly Qualified Personnel (HQPs). The Health, Safety and Injury Prevention group has contributed greatly to the knowledge base of Canada and North America. Through these projects, 60 HQP have been trained on a variety of subjects including product design, computer simulation and model development, kinetics, injury assessment, industrial design for ergonomics and social services for the elderly.

In addition to training new researchers, the study group has promoted the knowledge it has acquired through various publications and presentations. They have produced at least 350 papers and presentations on a variety of topics.

The Health, Safety and Injury Prevention group also has a unique form of training by being actively involved with Canada's communities at-large. For example, through the child vehicle safety project, researchers are working with citizens in eight provinces to document parental involvement in child safety seat usage. The end result will produce procedures and tools to train and share information to all Canadian citizens on proper child seat usage.

Jobs Saved or Created

With the design of new testing techniques to assess the qualifications of both new drivers (mostly teens) and elderly drivers, the Health, Safety and Injury Prevention group has the potential to create 300 jobs in driver assessment activities.

Accident Prevention

A large part of the Health, Safety and Injury Prevention group's research is focused on accident prevention. Three projects with a high potential to affect accident rates estimated that approximately 10% of accidents involving their targeted populations may be avoided through the implementation of their research. To estimate the probable number of avoidable accidents, CAR researchers used Transport Canada data on traffic-related fatalities and injuries from various causes.

From the number of fatal accidents, accidents with injuries and accidents with property damage only, CAR subtracted the number of accidents that were caused by drug or alcohol-impaired driving. The reasoning is that the kinds of accidents that AUTO21 research in the Health and Safety theme (i.e. Theme A) will affect are unlikely to involve drivers who are impaired by alcohol or drug use because the target populations are children and the elderly. Impaired driving accidents are dealt with under the Societal Issues research theme and account for 15% to 30% of all accidents (15% of property damage only and nearly 30% of fatal accidents). Eliminating these types of accidents out of the total changed the estimated impacts of the Theme A research projects.

CAR staff used the quality adjusted life years (QALY) method described above to assign dollar values to lives saved and injuries prevented. Individual project accident prevention impacts of implementing AUTO21's Health, Safety and Injury Prevention program when fully implemented have potential as follows:

- Childhood Vehicle Safety and Child Safety projects: prevent 10% of traffic-related injuries and 10% of traffic-related deaths
- Driver Qualifications project: prevent up to 25% of traffic accidents caused by new drivers, thereby preventing related property damage, injuries and deaths of these accidents
- Research projects for improving the safety of senior drivers and their passengers: prevent 10% of traffic-related injuries to seniors and 10% of traffic-related deaths of senior drivers or their passengers

Summary

The projects within this theme were notable for their strong ties to public and private entities. University and provincial partnerships that were formed during the Child Safety Seat project or the Cooper Standard Automotive relationship of the Industrial Improvements project, allowed for thorough collection of data during the initial stages and provided for rapid dissemination of findings and results. These projects had very clear goals regarding desired safety achievements. The researchers demonstrated understanding of the broader needs of society when constructing their projects and when collecting and reporting the results and benefits of their work. The projects were well-documented at every stage of work.

One particular strength of at least three of the studies—Industrial Improvements, Childhood Vehicle Safety and Vulnerable Populations—was the unique approach to the issue. For the Vulnerable Populations study, driver safety and safe driving among seniors are common research themes. However, the point of view designed into the research captured new information about senior mobility, lifestyles and driving needs. The method used by researchers to collect data and perform the research was effective. This new information was widely disseminated throughout North America and led to multiple new avenues of study and more ways to achieve the study goals. Similarly, the Industrial Improvements study spurred new projects and partnerships.

Example Projects

Childhood Vehicle Safety

The Childhood Vehicle Safety project is an example of a project designed to reduce injuries to vehicle occupants. The intent is to use the results to develop tool kits for the provinces on how to increase the proper use of child booster seats. With research showing that, in the event of an accident, proper use of child safety seats can reduce child fatalities by 71% and injuries by 67%, there is a tremendous opportunity to protect the children of Canada through proper booster seat use (Weber), (Wegner and Girasek). In addition, a 1997 study demonstrated the need for such education with 30% of infant carriers and 33% of child seats improperly used in Canada (Transport Canada). Project researchers indicate that 10% of injuries due to improper use of child restraints could be eliminated through their research.

Through this project, researchers from the University of Windsor, Dalhousie University, University of Manitoba, McMaster University, University of Toronto, and University of Northern British Columbia combined efforts to work with the provinces of Canada to document the standard procedures parents use to secure children in a vehicle. Industrial partners included all of the Canadian provinces as well as Child Safety Link, Halifax Police Department, Northern Health, British Columbia Automobile Association, Winnipeg Regional Health Authority, Children's Hospital of Winnipeg, the Canadian Pediatric Society, Magna International, and SafeKids Canada.

Industrial Improvements

The Industrial Health and Safety in the Auto Industry project focused on developing standards that can be used to assess the risk of developing lower back pain from exposure to cumulative (repetitive)

loading activities in the workplace and the prevention of these injuries. The goal of the project was to measure cumulative exposure to ergonomic factors and assess the relationship between cumulative workplace exposure and the risk of developing lower back pain.

The project was a combined effort between the following universities: University of Waterloo, University of New Brunswick, University of Windsor, York University, and University of Western Ontario.

THEME B: SOCIETAL ISSUES SUMMARY

Table 9: Summary of Benefits from Theme B Projects

Number of Projects	8
Number of HQP	120
Total Amount Invested (Millions \$)	14.7
AUTO21 Contribution (Millions \$)	7.7
Partner Contributions (Millions \$)	7
Lives Saved	100
Injuries Prevented	5,000
Accidents Prevented	17,500
Publications, etc.	300

The Societal Issues research theme has two major focuses:

- 1) Influencing public policy and regulations related to vehicle operation and to the auto industry in Canada, and
- 2) Improving the quality of life of Canadians who work in the auto sector, through improvements in the education and regulatory regime of the labor market.

The overarching goal that projects within this theme strive to attain is to conduct research that continues to improve the quality of life in Canada through influencing environmental impact, government policies, workplace conditions, and driver experiences. Work done under this theme covers a plethora of issues from influencing policy relating to attracting and retaining investments to examining automotive crime and at-risk groups.

This evaluation considers eleven projects under this theme and attempts to assess both the academic as well as applied value they have provided.

Fatalities, Injuries, Collisions, and Crime

As a result of the work within this research theme, there has been a significant reduction in fatalities, injuries, and automotive collisions. These reductions are in addition to the over \$120 million in value that has been generated in terms of reduced crime over a seven year period due to research in this key theme area.

Training and Intellectual Property

The Societal Issues group has written more than 300 journal articles, books, chapters, and reports. More than 120 HQPs have trained and worked in this research area.

Scientific Excellence of Research

By encouraging partnerships between industry and academia, this theme has succeeded in promoting scientific excellence in a way that is sometimes overlooked in academic research, particularly in the social sciences and humanities disciplines. By incorporating members of industry into the research, academics and students have been able to gain a unique insight into the practical needs and capabilities in the “real” world outside of academe. Given the number of books, journal articles and other works that been published, it is clear that the research has met the criteria for peer review. Beyond that, given the unique partnerships that are involved with AUTO21 projects, it is quite likely that the resultant research is more useful than it might otherwise be if conducted outside the AUTO21 framework.

In addition, due to the creation of the network of people from academia, governments, and industry, the issues that are examined through the research projects in this theme are ones that are important to those who might eventually use the research results. The examinations and conclusions are likely to be in a form that will be useful to industry and policy-makers in the government.

Strategic Importance of AUTO21 Societal Issues Research

Because the automotive industry is a vital part of the Canadian economy, the research conducted in this thematic area in particular is of great strategic importance. Any work done to understand the role of the Canadian government in ensuring the economic health of the industry is done under this key area. To be certain that policy solutions such as regulations, standards, R&D spending, incentives, and infrastructure support are appropriately applied, policymakers must be well informed to ensure a more sustainable future and protect against the unintended consequences that can result from careless or ill-timed public policy.

The potential benefits of research in this key area can be pursued locally, at the provincial level, or nationally. Though much of the research appears intended to affect high level decisions, where national or provincial action on a particular issue is limited, many of the research findings could be useful to municipalities and communities. For instance, the work on antisocial behavior and crime prevention, though critical in informing provincial or national policy, could be used by single cities in developing education programs, ordinances, or community outreach initiatives. Similarly, the work on labor and public policy issues can also be useful to communities that have a large automotive footprint and wish to attract or retain jobs.

Societal Impacts

The research done under this key area also has significant social impacts. In particular, the research on vehicle thefts can serve not only to protect vehicle owners, but also to deter potential at-risk youth from committing vehicle theft crimes, which may represent the first involvement in serious crime for some. Similarly, studying how to reduce anti-social behavior while driving can keep communities safer and

have broader impacts on drug and alcohol consumption – possibly benefitting communities even when people are not behind the wheel. The work aimed at improving labor conditions and direct government investment in the industry can indirectly serve to keep manufacturing communities strong by better ensuring availability and security of jobs.

Summary

A strength within the Societal Issues group is its ability to work with local governments in developing policies to combat relevant issues. By better understanding the causes and consequences of automotive-related issues, decision-makers can respond more effectively to current needs and improve public welfare. Research conducted under this group has led to – and will likely continue to promote – reductions in automotive fatalities, injuries, collisions, and crimes, while at the same time promoting increased private investment and more thorough impact analysis on the automotive life cycle.

Not only has the group been able to assist government and industry partners, it has also made a considerable contribution to the knowledge base of the entire industry. The experience gained through the research and publication of over 300 journal articles, books, chapters, and reports is able to be further developed for future benefits to governments, industry, and consumers.

Example Projects

Public Policy and the Automobile in Canada

This research project examined the effects of government policy and support for the automotive industry. The issues that were explored included regulations, standards, financing of new technologies, and infrastructure support and the outcomes of these policies on the industry. As many of these policies are critical to the health of the industry, it is important to understand the implications for government decisions with respect to these issues.

There were several deliverables associated with this research: nine paper publications, four books, and six chapters that have been written for other books. In addition, there have been dozens of presentations spanning the world from North America to Europe to Asia. There have also been multiple reviews written and one course was developed as a result of this research, “The Car in History: Business, Space, and Society in North America”. This project has resulted in the training of six researchers all of whom have reported that they will be staying in Canada either working in industry or continuing with their research.

Since the beginning of the research, the Province of Ontario has changed its policy on supporting industry investment in new assembly plants and upgrades. This policy change and others have resulted in increased public and private investments in plants through expansions and retooling. CAR maintains a database of major automotive industry investments known as the *Book of Deals*. CAR’s Book of Deals has records for five investments made in Ontario since the beginning of this research project on public policy and the auto industry.

This represents a total investment of nearly \$2.3 billion and the creation or retention of 4,650 jobs. Since the total national, provincial, and local incentives for these investments have been slightly less

than \$220 million, these investments suggest that for every dollar of public spending, \$10 of private spending occurs. In addition, public spending per job created or retained was a little less than \$47,000. None of the \$2.3B in private sector investment or the 4650 jobs have been counted in the total of AUTO21 benefits to Canada, however, it is likely that the input of the researchers had some bearing in the realization of these economic enhancements to the nation.

Teen and Novice Driver Network

This research project examines a network of various solutions aimed at reducing injuries and deaths among youth resulting from traffic collisions. The research findings were disseminated among organizations, institutions, governments, and training programs as well as used in technology development. The current work involves testing the effect of drugs on collision risk among young adults with attention deficit – hyperactive disorder (ADHD). The work has involved two studies, one that has been completed, and another that is ongoing and testing the efficacy of a different drug for ADHD.

There have been several deliverables associated with this research. Presently there have been 20 journal articles and conference proceedings that have come from the project as well as 13 other publications that include articles in preparation, submitted articles, and conference presentations. This project has resulted in eight students graduating and becoming researchers in their fields and has provided work for an additional 16 students in Canada, for a total of 24 HQP.

The project has obvious implications for collisions and spillover effects for human health and the economy, but estimates as to the effectiveness of the research in decreasing accidents by young drivers are not readily possible to calculate at this point. Having said that, the prevalence of the ADHD disorder among young people suggests that the outcomes of this research could be important in keeping many young drivers safer on the roads.

Antisocial Behavior and the Automobile

This research project includes two thrusts, one entitled “Young Offenders and Vehicle Thefts” that was funded from 2001 to 2005, and an ongoing project entitled “Antisocial Behavior and the Automobile” which began in 2001 and is funded through 2011. The vehicle theft project set out to fill a knowledge gap in understanding automotive property crimes, an area that had seen relatively little research. The methodology involved interviewing young offenders who had been caught up in auto thefts. The antisocial behavior research focuses on several behaviors, and in addition to continuing the work on auto theft, also examines the effects of drugs and alcohol on collision risk, the issue of road rage, and links between intoxication and angry driving.

Because the project is rather large in scope and has been funded for a long period of time, there have been significant outputs resulting from this work. There have been a total of 217 publications to date, with another 18 more expected to be published in the near future. This project has resulted in the training of 73 researchers and is currently providing support for 10 students in Canada.

The research that was conducted could have a significant impact when fully implemented, by informing policy changes that could reduce automotive fatalities, injuries, and collisions. AUTO21 research in the area of impaired driving influenced changes to Canada’s impaired driving laws. In addition, the research

on vehicle thefts has more than paid for itself with the net benefits from reduced stolen property being nearly \$120 million over a seven-year period according to the Manitoba government and the provincial public insurance corporation.

The net benefits of vehicle theft research are relatively high compared with initial research investments. The project received \$215,716 in AUTO21 cash support, \$936,586 in in-kind support from its external partners, and has generated \$921,000 in spin-off research funding from other agencies.

Other Projects

There are more projects within the key area beyond those listed above. For example, the project, Evolution of Life Cycle Assessments, was funded from 2003 to 2007. The project resulted in 18 papers and seven presentations and trained 12 HQP. Another project, Labour Market Regulation, Industrial Relations, and Innovation in the Canadian Automotive Industry trained 18 HQP and resulted in the production of 19 articles, books, and book chapters as well as three reports, one database, two workshops, 30 conference presentations, and over 80 media interviews which highlight the importance of the research issues to the general public.

THEME C: MATERIALS AND MANUFACTURING SUMMARY

Table 10: Summary of Benefits from Theme C Projects

Number of Projects	19
Number of HQP	230
Total Amount Invested (Millions \$)	27.3
AUTO21 Contribution (Millions \$)	14.7
Partner Contributions (Millions \$)	12.6
Fuel Savings (million liters of gas/year)	75
Carbon Dioxide Reduction (metric ton/year)	174,000
Carbon Monoxide Reduction (metric ton/year)	4,480
Nitrogen oxides Reduction (metric ton/year)	3,360
Contaminated Water Reduction (liters/year)	190,000
Industrial Process Improvement Savings (\$ millions)	100
Cost Savings per Vehicle (\$)	300
Publications, etc.	550

The Materials and Manufacturing group has influence in many key areas that benefit Canada and the world as a whole. Through its research, the Materials and Manufacturing group impact to Canada has resulted in materials and processes that will reduce vehicle emissions, resource usage, and manufacturing costs. It will create or save jobs and train the future technological leaders of the Canadian workforce. The outputs of its research program will contribute to saving lives through enhanced safety and reduced environmental impacts of both manufacturing and vehicle operation.

Investments in Materials and Manufacturing Research

A total of 19 projects were studied for this report and reported cost figures for their work. A total investment of \$27.3 million was reported for these projects within the Materials and Manufacturing theme. AUTO21 contributed a little under \$14.7 million dollars for the projects which represents approximately 53% of the total funding. The remainder of the funding came from cash and in-kind contributions from industrial partners. The 50/50 split of project funding indicates the value industry sees in the group's work and the desire to benefit from its success.

Training and Intellectual Property

The Materials and Manufacturing group has contributed greatly to the knowledge base of Canada and the world. Through the program, over 230 Highly Qualified Professionals have been trained on a variety of subjects including light weight magnesium casting, powder metallurgy, and biomaterials. Of those trained, at least 120 HQPs have remained in Canada – to work within industry or to carry on further research in their chosen fields.

In addition to the newly trained engineers and scientists, the group has promoted the knowledge it has acquired through various publications and presentations. The research group in the 19 projects studied for this report produced at least 550 papers and presentations on a variety of topics. Some of the intellectual property generated through the research includes patents, of which 11 have either been filed or are in process.

Jobs Saved or Created

The Materials and Manufacturing group projects deal primarily with improvements to existing infrastructure and processes; therefore, most research is focused on jobs saved rather than jobs created. It is possible that without ongoing research the industrial partners in the program could lose jobs as a result of uncompetitive technology and processes. To date, the Materials and Manufacturing group in the projects studied has saved at least 200 jobs and has the potential of saving an additional 200 jobs as a result of continued plant operations. In one case, an industrial partner for a project was able to acquire a new contract with an automotive manufacturer using the processes developed during the AUTO21 research project.

There are, moreover, some examples where new jobs or at least the potential for new jobs is possible. For example, research into light weight composites based on natural fibers has spurred the creation of a new company, Greencore Composites of Toronto, ON. With \$2.8 million in venture capital seed funding, the company was able to establish a new pilot plant to introduce new renewable light weight composites which are presently being marketed to automakers and parts companies globally.

Vehicle Performance and Emissions Reductions

A large part of the Materials and Manufacturing group's research is focused on materials and manufacturing processes that produce lighter weight vehicles. Lighter weight vehicles, in general, improve fuel economy and thus reduce vehicle emissions. A key challenge is to accomplish these improvements while maintaining or enhancing the safety of the vehicle.

The overall fuel economy and emissions impact of implementing the results from AUTO21's Materials and Manufacturing research projects into 10% of annual Canadian vehicle production¹⁵ is:

- 75,000,000 litres of fuel saved per year - At \$1/litre (per Natural Resources Canada) Canadian consumers would save approximately \$75,000,000 per year at the current price of fuel
- 174,000 metric ton reduction in Carbon Dioxide (i.e. GHG) emissions per year

Other emissions reductions reported by researchers were:

- 4,480 metric ton reduction in Carbon Monoxide emissions per year
- 3,360 metric ton reduction in Nitrous Oxide emissions per year

The emissions reductions play a role in the overall health of Canadian citizens (particularly in populated areas). A recent report by the Health Effects Institute providing a synthesis of health related effects found that there is suggestive but not sufficient evidence that mortality and morbidity, asthma and respiratory symptoms are outcomes of traffic-related exposure (Health Effects Institute). Although not quantified, the benefits of fuel consumption reductions due to weight savings can go well beyond litres of fuel used. As noted previously, the technological improvements realized through AUTO21 research will also accrue in the U.S. and any other jurisdiction where Canadian technology is used.

Manufacturing Process Improvements

Interaction with industrial partners is a fundamental component of the AUTO21 program and forms a large part of the success of AUTO21 in realizing actual benefits to Canada as well as savings and process improvements to manufacturing. The Materials and Manufacturing group has been successful in achieving these goals by reducing the amount of material used during processing, improving part quality, and increasing productivity. Successes identified in the research projects studied include:

- Over \$100 million in savings due to manufacturing improvements
- Over \$300 cost savings per vehicle (i.e. \$45M/year assuming 1.5M vehicles produced in Canada)
- New low cost material for a Tier One supplier to be used in engine intake manifolds
- 200 jobs retained because of manufacturing process improvements and cost savings
- Adoption of a new evaluation method for assessing the severity of a metal forming process (which will speed the time to market and enhance quality)
- 190,000 litre reduction in contaminated water per year

In addition, the projects in this group have the potential of delivering:

- Additional 200 jobs saved, estimated from current production line at a large Canadian Tier One supplier
- \$20 million material cost savings on new TPO bumper fascia material
- 750,000 litre reduction in contaminated water per year

¹⁵ Assumes that new technology will be installed on approximately 160,000 of the vehicles manufactured in Canada per year; each vehicle having 200,000 km lifespan and average fuel economy of 25 mpg (10.6 km/litre).

Summary

The Materials and Manufacturing group is very strong in its ability to work with industry partners. In most cases the industry partner was able to realize either a new capability, process improvement, or improved automotive grade material within a very short time frame. This is particularly important given the competitive landscape of materials technology and the constant quest to make materials both stronger and lighter at competitive cost.

Not only has the group been able to provide solutions for its industrial partners, but it has also made a considerable contribution to the knowledge base of the entire industry – with over 550 papers published during the study period. The experience gained through the research is able to be further developed for future benefits to the industry and to consumers. The group has also done an effective job at training HQPs and has so far recruited and trained over 230 individuals.

The research results from this group have also played a significant role in the reduction of harmful vehicle emissions and improving fuel economy which are both core priorities for today's auto industry. In many cases, the projects focused on light-weighting approaches that can be realized within industry due to their practical approach and cost-competitive processes. This indicates that the research is geared towards projects that will bring realizable results.

Example Projects

Renewable Biofibers and Biomaterials for Interior Parts

The Renewable Biofibers and Biomaterials for Interior Parts project is one example of a project capable of reducing overall energy usage made possible through contributions by AUTO21. Through this project, researchers have been able to develop new and more effective methods to create economically viable light-weight natural fiber plastic parts.

Composite vehicles present the opportunity to reduce the weight of the body by as much as 5%. A weight reduction of this magnitude can save more than 1,000 litres of gasoline during the life of the vehicle. However, using today's technology, the use of carbon fiber automotive parts is limited due to the high cost that ranges from \$44/kg to nearly \$90/kg. Through the use of natural fibers, AUTO21 researchers, Dr. Sain et al., are creating composite plastic parts that may soon be available at a considerably lower cost around \$11-15/kg, yet offer a similar performance to carbon fiber parts. These materials not only reduce vehicle weight and fuel consumption during driving, they are in many instances made from renewable resources (such as wood pulp) reducing the amount of petro-based material in plastics.

In the process of completing this one project, a total of 26 HQP were trained and 53 scientific papers were published. In addition, a total of eight patents were processed during the project.

Finally, the project led to a spin-off company, Greencore Composites, and has raised over \$2.8 million in venture capital to develop a pilot plant. The company has been recognized as one of Canada's Top 10 Clean Tech Companies and is marketing its products to auto industry companies around the world.

Integrated Development of Light Metal Cast Components and their Processing Technologies

The Integrated Development of Light Metal Cast Components and their Processing Technologies project focused on an integrated approach to light-weight cast product and process development. Four key processing steps were considered: melt treatment/alloy development, casting, heat treating, and machining.

Through the project's research, the OEM and parts sector industrial partners and their suppliers have acknowledged a savings of over \$100 million. In addition, the process technique led to a weight savings of 15% to 25% for the engine block which will have a significant impact on both GHG and smog-forming exhaust emissions and fuel economy in Canada and abroad.

Foam Processing for Automotive Parts

The Foam Processing for Automotive Parts project was directed to develop technology that would reduce the weight of plastic parts through fine-cell foaming. A total of 25 HQP were trained throughout the project and 150 papers were published. Highlights from the project include:

- Potential \$20 million material cost savings on TPO bumper fascias;
- Potential 20-25% weight reduction of PP/TPO plastic parts;
- Potential 1% reduction in overall vehicle weight;
- \$300 cost savings per vehicle (thus improving competitiveness);
- Three patents awarded during project.

THEME D: POWERTRAINS, FUELS AND EMISSIONS SUMMARY

Table 11: Summary of Benefits from Theme D Projects

Number of Projects	11
Number of HQP	90
Total Amount Invested (Millions \$)	13.7
AUTO21 Contribution (Millions \$)	5.9
Partner Contributions (Millions \$)	7.8
Publications, etc.	225

The Powertrains, Fuels and Emissions group's primary objective is to reduce exhaust pollution of automobiles through technologies that modify current engine designs, develop powertrain technology capable of running on new energy sources, and develop solutions for the infrastructure of new energy sources. To this end, the group is focused on issues that reduce fuel consumption of vehicles and improve the health of Canadians through reduced vehicle emissions.

Investments in Powertrains, Fuels and Emissions Research

A total of 11 powertrain-related projects were studied for this report and reported investments of \$13.7M for their work. AUTO21 contributed a little under \$5.9 million dollars for all projects, amounting

to about 43% of the total funding. The remainder of the funding was from cash and in-kind contributions from industrial partners. Over 50% funding by industry shows the strong potential industry sees in the value of the group's work and indicates a desire to receive and implement the research results. The technologies being investigated in this research theme are crucial to the industry's ability to meet current and forecasted fuel economy mandates in Canada and the U.S.

Training and Intellectual Property

For this particular theme, over 90 Highly Qualified Personnel have been trained on a variety of subjects including next generation homogeneous charge-compression ignition (HCCI) combustion controls for reduced vehicle emission, ultra clean diesel technology, and hydrogen safety and infrastructure issues for future vehicles.

Of the 90 HQP trained, at least 45 individuals report having remained in Canada either to work within the industry or to carry on further research in their chosen fields. In addition to the newly trained engineers and scientists, the group has promoted the knowledge it has acquired through various publications and presentations. They have produced at least 225 papers and presentations on a variety of topics. Some of the intellectual property generated through the research includes patents, of which 13 have either been filed or are in process.

Jobs Saved or Created

The Powertrains, Fuels and Emissions projects deal with both existing and future technologies infrastructure and processes. It is possible that research in this area can lead to saving existing jobs as well as creating new ones. Advancing technology in the areas of vehicle electrification and hydrogen infrastructure can create a number of new jobs. It is important to note that many of the components and technologies to date are based in other countries. This drives a key point: to realize job opportunities due to new technology requires communities to be on the leading edge of research and development. The Powertrains, Fuels and Emissions group, through its projects, has worked to make this a reality in Canada.

Emissions Reductions

The primary goal of the Powertrains, Fuels and Emissions group is to create new technologies and processes that reduce vehicle emissions. The reductions can be achieved through a variety of approaches, both short- and long-term.

In the short term, research into Homogeneous Charge Compression Ignition (HCCI) technology can offer a 10% improvement in the efficiency of internal combustion engines. Assuming that 10% of the total vehicle market adopted the new HCCI technology, a saving of 800,000 Metric Tons of CO₂ emissions and 3.6 million barrels of oil would result - *each year*.

Research into new technologies for use in battery electric and plug-in hybrid electric vehicles can yield a 60% reduction in tailpipe emissions. A recent panelist group at the 2010 SAE World Congress indicated

that as many as 10% of all vehicles could be BEV or PHEV by the year 2020¹⁶. Given the projected emission reduction potential, estimated CO₂ GHG emissions reductions could be as high as 48 million metric tons and 21.6 million barrels of oil *annually* by the year 2020. In addition, other tailpipe emissions such as NO_x, Carbon Monoxide, and hydrocarbons will be reduced by as much as 60%.

Finally, research conducted on fuel cell vehicles (FCV) holds great potential for reduction of tailpipe emissions. At an ideal state, FCVs will produce only water vapor, thereby eliminating all other tailpipe emissions in the process. However, the implementation timing of FCVs is yet to be determined, and it may be several decades before any direct FCV benefits will be realized.

In addition to the cost savings that can be realized by the fuel economy improvements of vehicles, emissions reductions may play a role in the overall health of Canadians (particularly in populated areas). A recent report by the Health Effects Institute providing a synthesis of health-related effects found that there is suggestive but not sufficient evidence that mortality and morbidity, asthma and respiratory symptoms are outcomes of traffic-related exposure. Although not quantified, the benefits of fuel consumption reductions due to weight savings can go well beyond litres of fuel used and will be felt both within and outside of Canada's borders.

Global Competitiveness

There has been a large push for new energy sources for automobiles. The impetus may be due to several issues including environmental concerns (air quality, health, and climate change) and fuel consumption (increased demand and cost of fuel). As a result, there are many powertrain technologies in various stages of research to combat these issues.

A lack of understanding can leave an industrial corporation with questions as to whether their systems will work with new energy sources. As a result, they may improperly utilize systems and thus provide faulty products to their customers. For example, Engine Control Systems, a manufacturer of diesel particulate filters, was concerned with how their filters work with biodiesel fuels. Through an AUTO21 research project, the group was able to properly and confidently identify the proper filters for this new type of fuel. This project also eased concerns the industrial partner had in regard to exhaust component interaction with biodiesel fuel emissions.

In other cases, new energy sources offer opportunities to industrial partners in new and novel ways. Through experience developed as part of the on-board fuel cell power unit research, AUTO21 funded researchers were able to assist a large OEM with the design of a new system that simultaneously reforms volatile organic emissions at the paint line and produces electrical power for the factory from the reformed waste gas.

¹⁶ SAE Subject Meeting 4/15/2010. Near Term PowerTrain Solutions Before 2016. Barbara Samardzich "12.5% BEV & PHEV penetration by 2020" and SAE Subject Meeting, Far Term PowerTrain Solutions 2016 and Beyond. Joerg Rueger, Sr. VP Diesel Systems, Bosch "3 million (of 19.2 million vehicles in Canada) will be PHEV by 2020".

Summary

The Powertrains, Fuels and Emissions group works heavily with developing new technologies in a field that is undergoing tremendous and very rapid change. A variety of new energy choices are emerging and the group has been pivotal in their development. Although it is possible that not all technologies will be realized due to the competitive nature of this field, the projects do lay the framework for a new energy and emissions strategy within Canada.

This group has played a significant role in the reduction of harmful vehicle emissions. All of the projects focus in some way on the reduction of harmful vehicle emissions. It is difficult to measure the total reduction in vehicle emissions based on the research conducted by the group. However, from estimates on the reported benefits and prospects for adoption of the group's research, there is a potential for a reduction of CO₂ GHG emissions by as much as 49 million metric tons in Canada. In addition, 25 million barrels of oil per year in Canada will be saved due to potential improvements in fuel consumption. It should be noted that these figures do not account for fuel cell technology, where the payoff could be even larger.

The group as a whole has made a considerable contribution to the knowledge base of the entire industry. With over 225 published papers, the experience gained through the research is able to be further developed for future benefits to the industry and to consumers.

Finally, the projects have done a great deal to train a new workforce with the skills necessary to provide relevant solutions to their employers. With over 90 individuals trained through the projects, the Powertrains, Fuels, and Emissions group is working as a catalyst for innovation within the industry.

Example Projects

Development of an On-Board Fuel-Cell Powered Auxiliary Power Unit

The Development of an On-Board Fuel-Cell Powered Auxiliary Power Unit project focused on the modeling and development of new materials for solid oxide fuel cells (SOFC). This project is a good example of high risk research that has resulted in indirect benefits. Through this project, researchers were able to form new relationships resulting in a partnership between German and Canadian researchers on the modeling of SOFC. Researchers from the project also assisted in the design of a new process within a large OEM with major operations in Canada and globally. The processes enabled toxic exhaust fumes from the paint process to be reformed and used to generate electricity for the adjacent auto assembly factory. This unique project provides an opportunity to use a fuel cell in an industrial setting which will provide experience for future technologies.

During the project a total of 10 HQP were trained, many of whom have gone on to work at various Canadian fuel cell companies including Hatch Engineering, Ontario Power Generation, Ballard Power Systems, Mesoscopic Devices, Office of Sustainability, and HTC Pureenergy.

THEME E: DESIGN PROCESSES SUMMARY

Table 12: Summary of Benefits from Theme E Projects

Number of Projects	8
Number of HQP	60
Total Amount Invested (Millions \$)	3.8
AUTO21 Contribution (Millions \$)	2.6
Partner Contributions (Millions \$)	1.2
Publications, Presentations, etc.	90

The Design Processes group's primary objective is to develop comprehensive design methodologies and tools for rapid vehicle component design. To this end, the group is focused on documenting and sharing current design practices as well as improving existing and introducing new design methodologies and techniques.

Investments in Design Processes Research

A total of eight projects were studied and reported cost figures for their work. A total investment of \$3.8 million was reported for the projects within the Design Processes group. The contribution from AUTO21 was a little under \$2.6 million dollars for all projects, amounting to just over 68% of the total funding. The remainder of the funding was from cash and in-kind contributions from industrial partners.

Training and Intellectual Property

Through projects conducted by the Design Processes group, over 60 Highly Qualified Personnel have been trained on a variety of subjects including: rapid manufacturing, flexible inspection systems, collaborative design tools, and optimization of vehicle batteries.

In addition to the newly trained engineers and scientists, the group has promoted the knowledge it has acquired through various publications and presentations. The group has been able to produce at least 90 papers and presentations on a variety of topics.

Jobs Saved or Created

Training engineers who then have a stronger understanding of the process of creating new products for the market is one key output of the Design Processes theme. As such, this theme has the potential to protect as well as create a significant number of jobs in the manufacturing sector – both directly in design engineering functions and for general manufacturing workers who will make the products designed by the engineers. In addition, the average engineering position supports another two jobs in any regional North American economy.

A recently funded Design Processes project deals with optimization of hybrid and electric vehicle batteries. As was discussed with the Powertrains, Fuels and Emissions group, advancing technology in the areas of vehicle electrification and hydrogen infrastructure can create a number of new jobs. It is

important to note that many of the components and technologies to date are based in other countries, and so not all of the jobs would be based in Canada or North America.

Emissions Reductions

Again, the project focusing on advanced electric vehicles offers an opportunity for significant emissions reductions. At full implementation, the potential for GHG emissions reductions is over 100,000 metric tons of CO₂ per year. In addition, the researchers point out that a nearly 5 kilometer per litre increase in fuel economy is possible. Implementing this technology across 10% of Canada's production could save over \$50 million in fuel cost to consumers each year. There will also be savings in fuel and reduced emissions in other countries as the technologies are adopted.

Enhancing the Global Competitiveness of Canada's Industry

With a focus on improving and introducing design methodologies and techniques, the Design Processes group is keen on improving global competitiveness through the optimization of processes. Although difficult to quantify, there have been several Design Processes projects that could lead to the global competitiveness of Canada's industrial base. A list of results that have increased or have the potential to increase Canada's global competitiveness follows:

- Development of a new machine vision inspection system (QVision) with the potential to reduce manufacturing cost by \$250,000 per year through the replacement of manual inspections
- Improvements in material property modeling through correlation with experimental techniques
- Improved quality of machined complex parts and dies through virtual and rapid prototyping

Reducing Work Place Injuries

One project within the group is focusing on the implementation of a continuous feed fastening tool. Continuous feed tools often increase risk of injury due to the demands placed on the operator. The project is investigating the ergonomic effects of the tools and is developing processes to reduce the likelihood of injuries during operation.

The results from the project are expected to reduce the number of Workplace Safety and Insurance Board (WSIB) claims from 30 down to five (a reduction of over 83%) upon completion of the project. Initial development and testing are planned for various OEM and supplier based industries that have supported this project.

Summary

The Design Processes group has used its resources to combat a variety of issues within the automotive sector including: part inspection systems, rapid prototyping, human machine interfaces, and electric vehicle optimization. In total, the projects from the group have the potential to reduce vehicle emissions, reduce manufacturing cost, improve part quality, and reduce workplace injuries.

The group as a whole has made a considerable contribution to the knowledge base of the entire industry. The experience gained through the research, and the publication of over 90 papers, is able to be further developed for future benefits to the industry.

Finally, the projects have done a great deal to train a new workforce with the skills necessary to provide relevant solutions to their employers. With over 60 individuals trained through the projects, the Design Processes group has been a catalyst for innovation within the industry and enhanced Canada’s capacity to create and product new automotive products in the future.

Example Projects

Neuro-Fuzzy Systems for Inspection in Manufacturing Processes

The Neuro-Fuzzy Systems for Inspection in Manufacturing Processes project focus was on the development of a flexible machine-vision based inspection system capable of adapting to product changes with minimal manual adjustment. The resulting system would improve part inspection of manufacturing processes through intelligent data processing and it would contribute to enhanced production flexibility and productivity as well as improved product quality.

Industry partners collaborated on the project by providing specific applications to conduct case studies with the new system. For example, one of the case studies focused on the porosity detection of cast metal components.

At the end of the reporting period, the project had produced new hardware and software for automotive component inspections. Testing of the new system was completed in the partner’s factories and indications were that the results far exceeded those of existing commercial systems. The new QVision system is undergoing acceptance testing and, once completed, can be rolled out to additional manufacturers. By replacing manual inspection techniques, the direct cost savings for one production installation is estimated at \$250,000 per year. Additional savings due to a reduction in the number of defective parts passing inspection are also expected, and these benefits will be multiplied as other companies adopt the new technology.

THEME F: INTELLIGENT SYSTEMS AND SENSORS SUMMARY

Table 13: Summary of Benefits from Theme F Projects

Number of Projects	6
Number of HQP	81
Total Amount Invested (Millions \$)	8.2
AUTO21 Contribution (Millions \$)	5.4
Partner Contributions (Millions \$)	2.8
Publications, etc.	236

The Intelligent Systems and Sensors group manages projects that are focused on improving the safety, mobility and environmental impact of operating vehicles and enhancing the productivity of automotive factories through the use of improved systems, sensors and information technology. Through its research and development efforts in the fields of connected car (aka IntelliDriveSM) systems and noise abatement technologies, the Intelligent Systems and Sensors group provides a cutting edge technical advantage to industrial partners in Canada.

Investments in Intelligent Systems and Sensors Research

A total of six projects were studied and reported cost figures for their work. A total investment of \$8.2 million was reported of which AUTO21 contributed \$5.4 million dollars or approximately 66% of the total funding. The remainder of the funding was cash and in-kind contributions from industrial partners.

Training and Intellectual Property

The Intelligent Systems and Sensors group has trained a total of 81 HQPs. These individuals will continue to provide valuable insights and contributions in the development of such systems as electrical power management and safety systems, dynamic collaborative driving, and pollution and particle sensors for environment-aware vehicles. The per-HQP training investment by AUTO21 of roughly \$10,000-11,000 is very low given the traditionally high costs associated with advanced technical training in North America.

In addition to the newly trained engineers and scientists, the group has promoted the knowledge it has acquired through various publications and presentations. The group has produced 236 papers and presentations on a variety of topics, including one complete book. Through this group's research, 6 patents have been submitted or awarded.

Jobs Saved or Created

The Intelligent Systems and Sensors group projects deal primarily with systems and technologies that are in the development phase. Producing precise jobs saved or created estimates would be premature, but the economic value of IntelliDriveSM technologies is likely to be very large. In addition to the economic benefits, discernible environmental, safety, and other non-pecuniary benefits are likely to be realized as potentially 80 percent of crash scenarios can be addressed by IntelliDriveSM systems. It is possible that, without ongoing research, the Canadian industrial partners to the program may lose jobs as a result of uncompetitive technology and processes.

Vehicle Performance and Emissions Reductions

The Intelligent Systems and Sensors group's research is focused on technologies that would enhance the safety and reduce the environmental impacts of operating vehicles. A fleet of integrated and informed vehicles will move people and goods in a far more efficient and safe manner, leading to large emissions reductions, reduced accidents, reduced travel delays, and reduced fuel use, and in general will provide an offset to the negative impacts of vehicle travel.

In addition to emissions reductions from improved mobility, potential safety savings are large—particularly so in the elderly driver population. An estimate of quality adjusted life years (QALY) using Transport Canada data on traffic-related fatalities and injuries indicates that large savings could be realized if the nation’s elderly drivers are retrained through a simulator tool to become better drivers. In 2007, the elderly (65+ years) in Canada were involved in 446 traffic-related fatalities and 15,369 traffic-related injuries. Given a conservative incident prevention estimate of 10 percent based on simulator retraining, some \$30 million QALY improvements could be realized annually in Canada.

Summary

The Intelligent Systems and Sensors group is making significant contributions to the development and implementation of technologies that will improve the safety, ease, economic, and environmental effects associated with vehicle movement. Widespread adoption and deployment of products and technologies associated with the group’s projects is still a few years away, but testing is taking place in several developed nations including Canada. Given the system’s far-reaching impacts on vehicle safety and performance, merging the technology into a regulatory framework is crucial for the long-term success of systems like IntelliDriveSM. To this end, in the United States, the USDOT is projecting 2013 as the target date for determining if NHTSA will regulate vehicle-to-vehicle safety systems.

The group has had a positive impact through its contribution to the knowledge base of the entire industry. With over 200 published papers, the experience gained through the research is able to be further developed for future benefits to the industry and to consumers. The group has also done an effective job at training HQPs and has so far recruited and trained over 80 individuals.

Given that most of the technologies remain in a development and testing phase, the benefits stemming from group activities are just beginning to transfer to industrial partners in Canada. Once these new technologies are incorporated into the on-road fleet, they will play a significant role in the reduction of harmful vehicle emissions and will prevent a number of vehicle-related deaths and injuries. Economic benefits will also be realized as the technologies under review will dramatically change the way goods and people are moved.

Example Projects

Integrated Vehicle Navigation and Communication Systems Development

The Integrated Vehicle Navigation and Communication Systems Development project is one example of a project capable of improving vehicle-to-vehicle and vehicle-to-infrastructure systems made possible through contributions by AUTO21. Through this project, researchers have been able to develop close partnerships with industrial partners, file a patent for vehicular navigation and positioning technology, and develop a database fusion technique that can reduce the time needed to merge databases by 70 percent.

Concluded in March 2009, this research project sought to develop low-cost navigation sensor systems, integrate data from these sensors, and share the information with security and privacy in place. Over the course of the project, the principal investigators and their students and collaborators produced 20

journal papers and 17 conference papers, as well as made 25 presentations on the concept and technology. This project also served as the basis for nine master's theses and seven doctoral dissertations. Furthermore, four additional graduate students worked on the project but had not yet completed their theses by the time the project ended.

Finally, the research provides fundamental contributions to the development of location-based services and vehicle-to-vehicle and vehicle-to-infrastructure systems, which are the backbone of forthcoming IntelliDriveSM systems.

Simulation Environment for the Evaluation of Cephalo-ocular Behavior and Visual Search Patterns on Drivers

The Simulation Environment for the Evaluation of Cephalo-Ocular Behavior and Visual Search Patterns on Drivers project sought to develop a system for characterizing the visual search behaviors and situational awareness of drivers in realistic driving situations. Making use of video, virtual reality, eye trackers, and other components, the simulation environment developed enables real-time analysis of data and behavior, allowing driver performance to be assessed and reported back to the subjects.

This evaluation can be accomplished on a PDA such as a Palm Pilot™ or Blackberry™ and in real driving situations (as opposed to just in the simulator). As a result, this system can be used to provide objective feedback to those learning to drive, as well as (and perhaps most promisingly) for retraining elderly drivers, with deteriorating cognitive, hearing and vision skills.

Given the developed world's aging population, the potential safety impacts of this technology are large and will grow with widespread adoption of the system.

CONCLUSION

It is clear to the CAR research team that the AUTO21 Network Centres of Excellence is creating considerable value from the initial investment of \$52.2M in public and \$38.3M private sector funds. In this independent evaluation of selected projects from AUTO21's research program, CAR estimates that the returns to research investments are more than 10 to one. The benefits associated with a \$90 million initial investment into research and development have an estimated value of more than \$1.1 billion annually once the projects are fully implemented.

The research that is done under AUTO21 sponsorship is multidisciplinary and provides a wide range of benefits. The benefits that are quantified in this study include health, safety, HQP training, job creation, environmental improvements, and intellectual property creation and dissemination. These research projects work to mitigate the negative impacts of vehicle use on society and to improve the global competitiveness of the Canadian automotive industry.

Through AUTO21, the dispersion of R&D resources is maximized across Canada to researchers throughout higher level academic institutions from coast to coast representing a diverse group of disciplines. All projects must have a partner that is willing to invest in the project and commit to use the

new technology or other research findings. This ensures that projects focus on practical questions and that the resultant knowledge is put to effective use in a timely manner.

Another unique and promising aspect of the program is the diverse research project portfolio which is well balanced across all stages of research, including work in discovery, development, and early and late deployment. The investments that have been made under the guidance and support of the AUTO21 program have already provided significant overall benefits.

Finally, our evaluation has found that the investment in AUTO21 and its engagement with researchers addressing all aspects of the global automotive industry will ensure Canada remains a significant contributor to the advancement of the industry. Continued funding of the program will ensure further advantages for the industry and society in Canada and abroad.

APPENDIX A. AUTO21 HIGHLY QUALIFIED PERSONNEL – BREAKDOWN BY DISCIPLINE

Department	BA	MA	PhD	PD	RA	Total
Adult Education			1			1
Aerospace Engineering			1			1
Agricultural & Bioresource Engineering	2	1	1		1	5
Applied Chemistry		1			1	2
Applied Health Science	1					1
Applied Science	2	2				4
Applied Science & Engineering		2				2
Applied Science/Metals & Materials Engineering	1	2		1		4
Arts & Sciences	2					2
Business					1	1
Centre for Automotive Materials & Manufacturing		1			1	2
Chemical & Materials Engineering	5	1	1	1	5	13
Chemical Engineering	24	29	19	17	4	93
Chemistry	5	1	1		2	9
Chemistry & Chemical Engineering		4	1	1	1	7
Civil & Environmental Engineering		1		1		2
Civil Engineering	5	12	11	6	4	38
Community Health & Epidemiology		1				1
Community Health Sciences			1			1
Computer Science	6	26	18	3		53
Computer Science & Software Engineering	2	4	1			7
Computing & Information Science	8	4	1			13
Criminology			3			3
Economics	1		3			4
Electrical & Computer Engineering	9	58	36	8	8	119
Electrical Engineering	7	20	10	6	6	49
Engineering	5	5	5	4		19
Engineering & Applied Science	7	7	1	1	1	17
Engineering & Design	3	2	6			11
Engineering Science	2	5	4			11
English	1					1
Epidemiology & Biostatistics		1	1			2
Family Medicine		1				1
Forestry		4		1	3	8
Frost Centre for Canadian Studies			1			1
Genie informatique (Information System)		1				1
Geography	4	2	1			7
Geomatics Engineering		12	6			18
Health Professions	2	2	1			5
Health Sciences	1					1
Health Studies & Gerontology		1	1	1		3

Department	BA	MA	PhD	PD	RA	Total
Human Biology & Nutritional Sciences	6	13	8			27
Human Kinetics/Kinesiology/Physical Education	7	48	14	2	3	74
Industrial & Manufacturing Systems Engineering		2	7	1	1	11
Industrial Engineering & Mechanical Engineering			2			2
Industrial Relations					1	1
Information Technology		2	1			3
Institut de Recherche sur l'Hydrogene	1					1
Institute for Aerospace Studies		2	2			4
Institute for Integrated Energy Systems					1	1
Institute for Resources, Environment & Sustainability		2	2	1		5
Labour Studies	2	1	1	1		5
Law	7	2				9
Management Science				1		1
Materials & Metallurgical Engineering				1		1
Materials Engineering	8	13	4	1		26
Materials Science & Engineering		5	1	7	2	15
Mathematics & Computer Science		1	2			3
Mathematics & Engineering	2	5	1	1		9
Mechanical & Industrial Engineering	5	29	28	17	6	85
Mechanical & Manufacturing Engineering	1	6	11	3	1	22
Mechanical & Materials Engineering	1	9	6	4	2	22
Mechanical & Mechatronics Engineering				1		1
Mechanical Engineering	32	191	90	34	26	373
Mechanical, Aerospace & Industrial Engineering		4	2		4	10
Mechanical, Automotive & Materials Engineering	6	45	18	4	5	78
Medicine		2	1		2	5
Metals & Materials Engineering	2	8	6	2	1	19
Mining & Metallurgical Engineering		1	1	1		3
Mining Engineering	2			1		3
Mining, Metals & Materials Engineering		5	3	2	3	13
Norman Paterson School of Int. Affairs		8			1	9
Nursing	22	10	4	3	3	42
Occupational Therapy		5	1		1	7
Odette School of Business	1					1
Pediatrics				1	1	2
Physics	4	11	5	4	5	29
Physics & Astronomy	6					6
Political Science	2	2	2			6
Population Health					1	1
Psychiatry & Behavioural Neurosciences		1				1
Psychology	39	14	6		4	63
Public Health Sciences		2		1		3
R&D Department (CRIM)	1		1			2

Department	BA	MA	PhD	PD	RA	Total
Rehabilitation Science		1	3			4
Research Data Centre			1			1
School of Design	7				3	10
Science	2					2
Social & Preventive Medicine		3	1		1	5
Social Prevention & Health Policy Research			3			3
Social Sciences/Psychology	1	6	5	1	2	15
Social, Prevention & Health Policy Research			1	2	1	4
Sociology	1	5	1	1		8
Sociology & Anthropology		2				2
Urban Studies		2	1			3
TOTAL	273	681	382	149	119	1604

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