ENERGY TRANSFORMED:
SUSTAINABLE ENERGY SOLUTIONS FOR CLIMATE CHANGE MITIGATION

MODULE C

INTEGRATED APPROACHES TO ENERGY EFFICIENCY AND LOW EMISSIONS ELECTRICITY, TRANSPORT AND DISTRIBUTED ENERGY

This online textbook provides free access to a comprehensive education and training package that brings together the knowledge of how countries, specifically Australia, can achieve at least 60 percent cuts to greenhouse gas emissions by 2050. This resource has been developed in line with the activities of the CSIRO Energy Transformed Flagship research program, which is focused on research that will assist Australia to achieve this target. This training package provides industry, governments, business and households with the knowledge they need to realise at least 30 percent energy efficiency savings in the short term while providing a strong basis for further improvement. It also provides an updated overview of advances in low carbon technologies, renewable energy and sustainable transport to help achieve a sustainable energy future. While this education and training package has an Australian focus, it outlines sustainable energy strategies and provides links to numerous online reports which will assist climate change mitigation efforts globally.

CHAPTER 8: INTEGRATED APPROACHES TO ENERGY EFFICIENCY AND TRANSPORT

LECTURE 8.2: INTEGRATED APPROACHES TO ENERGY EFFICIENCY AND ALTERNATIVE TRANSPORT FUELS – PASSENGER VEHICLES
Copyright in this material (Work) is owned by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Griffith University. The Natural Edge Project and The Australian National University have been formally granted the right to use, reproduce, adapt, communicate, publish and modify the Project IP for the purposes of: (a) internal research and development; and (b) teaching, publication and other academic purposes.

A grant of licence ‘to the world’ has been formally agreed and the material can be accessed on-line as an open-source resource at www.naturaledgeproject.net/Sustainable_Energy_Solutions_Portfolio.aspx. Users of the material are permitted to use this Work in accordance with the Copyright Act 1968 (Commonwealth) [refs 40(1A) and (1B) of the Copyright Act]. In addition, further consent is provided to: reproduce the Work; communicate the Work to the public; and use the Work for lecturing, or teaching in, or in connection with an approved course of study or research by an enrolled external student of an educational institution. Use under this grant of licence is subject to the following terms: the user does not change any of the material or remove any part of any copyright notice; the user will not use the names or logos of CSIRO or Griffith University without prior written consent except to reproduce any copyright notice; the user acknowledge that information contained in the work is subject to the usual uncertainties of advanced scientific and technical research; that it may not be accurate, current or complete; that it should never be relied on as the basis for doing or failing to do something; and that in using the Work for any business or scientific purpose you agree to accept all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from so using. To the maximum extent permitted by law, CSIRO and Griffith University exclude all liability to any person arising directly or indirectly from using the Work or any other information from this website.


Acknowledgements

The Work was produced by The Natural Edge Project using funds provided by CSIRO and the National Framework for Energy Efficiency. The development of this publication has been supported by the contribution of non-staff related on-costs and administrative support by the Centre for Environment and Systems Research (CESR) at Griffith University, under the supervision of Professor Bofu Yu, and both the Fenner School of Environment and Society and Engineering Department at the Australian National University, under the supervision of Professor Stephen Dovers. The lead expert reviewers for the overall work were: Adjunct Professor Alan Pears, Royal Melbourne Institute of Technology; Geoff Andrews, Director, GenesisAuto; and Dr Mike Dennis, Australian National University.

Project Leader: Mr Karlson ‘Charlie’ Hargroves, TNEP Director
Principle Researcher: Dr Michael Smith, TNEP Research Director, ANU Research Fellow
TNEP Researchers: Mr Peter Stasinopoulos, Mrs Renee Stephens and Dr Cheryl Desha.
Copy Editor: Mrs Stacey Hargroves, TNEP Professional Editor

Peer Review

Principal reviewers for the overall work were: Adjunct Professor Alan Pears – RMIT, Geoff Andrews – Director, Genesis Now Pty Ltd, Dr Mike Dennis – ANU, Engineering Department, Victoria Hart – Basset Engineering Consultants, Molly Olsen and Phillip Toyne - EcoFutures Pty Ltd, Glenn Platt – CSIRO, Energy Transformed Flagship, and Francis Barram – Bond University. The following persons provided peer review for specific lectures; Dr Barry Newell – Australian national University, Dr Chris Dunstan - Clean Energy Council, D van den Dool - Manager, Jamieson Foley Traffic & Transport Pty Ltd, Daniel Veryard - Sustainable Transport Expert, Dr David Lindley – Academic Principal, ACS Education, Frank Hubbard – International Hotels Group, Gavin Gilchrist – Director, BigSwitch Projects, Ian Dunlop - President, Australian Association for the Study of Peak Oil, Dr James McGregor – CSIRO, Energy Transformed Flagship, Jill Grant – Department of Industry Training and Resources, Commonwealth Government, Leonardo Ribon – RMIT Global Sustainability, Professor Mark Diesendorf – University of New South Wales, Melinda Watt - CRC for Sustainable Tourism, Dr Paul Compston - ANU AutoCRC, Dr Dominique Hes - University of Melbourne, Penny Prasad - Project Officer, UNEP Working Group for Cleaner Production, University of Queensland, Rob Gell – President, Greening Australia, Dr Tom Worthington -Director of the Professional Development Board, Australian Computer Society.

Enquires should be directed to: The Natural Edge Project (TNEP) is an independent non-profit Sustainability Think-Tank based in Australia. TNEP operates as a partnership for education, research and policy development on innovation for sustainable development. TNEP’s mission is to contribute to, and succinctly communicate, leading research, case studies, tools, policies and strategies for achieving sustainable development across government, business and civil society. Driven by a team of early career Australians, the Project receives mentoring and support from a range of experts and leading organisations in Australia and internationally, through a generational exchange model.

Mr Karlson ‘Charlie’ Hargroves
Co-Founder and Director
The Natural Edge Project
www.naturaledgeproject.net/Contact.aspx

Prepared by The Natural Edge Project 2007  Page 2 of 22  Energy Transformed: Sustainable Energy Solutions
The International Energy Agency forecasts that if policies remain unchanged, world energy demand is set to increase by over 50 percent between now and 2030.\(^1\) In Australia, CSIRO has projected that demand for electricity will double by 2020.\(^2\) At the same time, The Intergovernmental Panel on Climate Change (IPCC) has warned since 1988 that nations need to stabilise their concentrations of CO\(_2\) equivalent emissions, requiring significant reductions in the order of 60 percent or more by 2050.\(^3\) This portfolio has been developed in line with the activities of the CSIRO Energy Transformed Flagship research program; ‘the goal of Energy Transformed is to facilitate the development and implementation of stationary and transport technologies so as to halve greenhouse gas emissions, double the efficiency of the nation’s new energy generation, supply and end use, and to position Australia for a future hydrogen economy’.\(^4\) There is now unprecedented global interest in energy efficiency and low carbon technology approaches to achieve rapid reductions to greenhouse gas emissions while providing better energy services to meet industry and society’s needs. More and more companies and governments around the world are seeing the need to play their part in reducing greenhouse gas emissions and are now committing to progressive targets to reduce greenhouse gas emissions. This portfolio, The Sustainable Energy Solutions Portfolio, provides a base capacity-building training program that is supported by various findings from a number of leading publications and reports to prepare engineers/designers/technicians/facilities managers/architects etc. to assist industry and society rapidly mitigate climate change.

The Portfolio is developed in three modules;

**Module A: Understanding, Identifying and Implementing Energy Efficiency Opportunities for Industrial/Commercial Users – By Technology**

Chapter 1: Climate Change Mitigation in Australia’s Energy Sector

*Lecture 1.1: Achieving a 60 percent Reduction in Greenhouse Gas Emissions by 2050*

*Lecture 1.2: Carbon Down, Profits Up – Multiple Benefits for Australia of Energy Efficiency*

*Lecture 1.3: Integrated Approaches to Energy Efficiency and Low Carbon Technologies*

*Lecture 1.4: A Whole Systems Approach to Energy Efficiency in New and Existing Systems*

Chapter 2: Energy Efficiency Opportunities for Commercial Users

*Lecture 2.1: The Importance and Benefits of a Front-Loaded Design Process*

*Lecture 2.2: Opportunities for Energy Efficiency in Commercial Buildings*

*Lecture 2.3: Opportunities for Improving the Efficiency of HVAC Systems*

Chapter 3: Energy Efficiency Opportunities for Industrial Users

*Lecture 3.1: Opportunities for Improving the Efficiency of Motor Systems*

*Lecture 3.2: Opportunities for Improving the Efficiency of Boiler and Steam Distribution Systems*

*Lecture 3.3: Energy Efficiency Improvements available through Co-Generation*


Module B: Understanding, Identifying and Implementing Energy Efficiency Opportunities for Industrial/Commercial Users – By Sector

Chapter 4: Responding to Increasing Demand for Electricity
Lecture 4.1: What Factors are Causing Rising Peak and Base Load Electricity Demand in Australia?
Lecture 4.2: Demand Management Approaches to Reduce Rising ‘Peak Load’ Electricity Demand
Lecture 4.3: Demand Management Approaches to Reduce Rising ‘Base Load’ Electricity Demand
Lecture 4.4: Making Energy Efficiency Opportunities a Win-Win for Customers and the Utility: Decoupling Energy Utility Profits from Electricity Sales

Chapter 5: Energy Efficiency Opportunities in Large Energy Using Industry Sectors
Lecture 5.1: Opportunities for Energy Efficiency in the Aluminium, Steel and Cement Sectors
Lecture 5.2: Opportunities for Energy Efficiency in Manufacturing Industries
Lecture 5.3: Opportunities for Energy Efficiency in the IT Industry and Services Sector

Chapter 6: Energy Efficiency Opportunities in Light Industry/Commercial Sectors
Lecture 6.1: Opportunities for Energy Efficiency in the Tourism and Hospitality Sectors
Lecture 6.2: Opportunities for Energy Efficiency in the Food Processing and Retail Sector
Lecture 6.3: Opportunities for Energy Efficiency in the Fast Food Industry

Module C: Integrated Approaches to Energy Efficiency and Low Emissions Electricity, Transport and Distributed Energy

Chapter 7: Integrated Approaches to Energy Efficiency and Low Emissions Electricity
Lecture 7.1: Opportunities and Technologies to Produce Low Emission Electricity from Fossil Fuels
Lecture 7.2: Can Renewable Energy Supply Peak Electricity Demand?
Lecture 7.3: Can Renewable Energy Supply Base Electricity Demand?
Lecture 7.4: Hidden Benefits of Distributed Generation to Supply Base Electricity Demand

Chapter 8: Integrated Approaches to Energy Efficiency and Transport
Lecture 8.1: Designing a Sustainable Transport Future
Lecture 8.2: Integrated Approaches to Energy Efficiency and Alternative Transport Fuels – Passenger Vehicles
Lecture 8.3: Integrated Approaches to Energy Efficiency and Alternative Transport Fuels - Trucking

Chapter 9: Integrated Approaches to Energy Efficiency and Distributed Energy
Lecture 9.3: Beyond Energy Efficiency and Distributed Energy: Options to Offset Emissions
Integrated Approaches to Energy Efficiency and Transport

Lecture 8.2: Integrated Approaches to Energy Efficiency and Alternative Transport Fuels – Passenger Vehicles

Educational Aim

Using the best technologies on existing internal combustion engine vehicles can provide up to 25 percent energy efficiency gains, and that is a good start, but taking a whole system design approach to energy efficiency opportunities for transportation vehicles (cars, trucks, motorbikes, SUVs) can yield larger savings. This lecture introduces how taking a whole system approach to energy efficiency in the design of new transportation vehicles can achieve in excess of 50 percent overall energy efficiency improvement. This lecture also describes key technological innovations that enable this large energy efficiency improvement. Finally, this lecture demonstrates how these innovations open up options for new low carbon alternative fuels to be used in most types of transportation vehicles, and focuses on how such integrated approaches to energy efficiency and low carbon fuel options create the potential for still greater reductions in greenhouse gas emissions. A clear understanding of how to take a whole system approach to identifying energy efficiency opportunities will help enable designers to realise larger potential energy efficiency improvements in the transportation vehicle sector.

Essential Reading

Reference Page


---

5 Peer review by Dr Paul Compston - ANU AutoCRC.
Learning Points

1. Roughly half\(^6\) of the 4.8 trillion litres (82.1 million barrels per day) of oil consumed globally in 2004\(^7\) was used for transport. In the case of cars, incorporating the best conventional technologies would reduce fuel consumption by at least 25 percent with a less than one-year payback period (in the US).\(^8\) However, taking a whole system approach to the design of cars can improve fuel efficiency and reduce fuel consumption by 50 percent at roughly no cost and by more than 70 percent with a two-year payback period.\(^9\)

2. A whole system approach to energy efficiency opportunities in the development of a modern, sports utility vehicle (SUV) can reduce its fuel consumption by 71 percent in comparison to a similar, conventional vehicle. The substantially reduced fuel consumption arises from acknowledging the systemic nature of the vehicle. A system approach to reducing fuel consumption assists in identifying two important considerations: a) some individual improvements instigate a series of compounding and iterative improvements in other subsystems, and b) some individual improvements are better incorporated before other improvements.

3. **Low-density, high-integrity materials:** New metals and plastics have allowed the mass of cars to be reduced, thus reducing the required propulsion power. Reducing the mass also reduces rolling resistance and thus further reduces the required propulsion power. Generally, reducing the vehicle mass by 10 percent reduces the fuel consumption by 5-7 percent.\(^10\)

4. **Low-drag form:** Aerodynamic drag forces are the result of pressure imbalances as a vehicle moves through the air. The vehicle’s size, exterior shape and the function it is designed to perform are all major influencing factors.

5. **Low-rolling resistance tires:** Rolling resistance is defined as the energy dissipated by a tyre per unit of distance covered. Decreasing rolling resistance decreases fuel consumption. ‘Green’ tyres (currently available) can reduce fuel consumption by 3-8 percent. New generation ‘green’ tyres may reduce fuel consumption by an additional 2-9 percent.

6. **Hybrid-electric power plants:** Hybrid-electric vehicles typically consume at least 50 percent less petrol than conventional vehicles. The typical hybrid—electric power plant configuration comprises a petrol internal combustion engine, and an electric motor and battery.

7. **Computer control systems:** A computer controller\(^11\) simultaneously controls a hybrid-electric vehicle’s two drivetrains – one powered by an internal combustion engine and one by an electric motor. As part of the Energy Transformed Flagship, ‘CSIRO is working with Holden developing energy management control systems which integrate supercapacitors and advanced batteries for the next generation of hybrid powered vehicles. These collaborative projects have the potential to

---


make a real difference in the development of cleaner and greener vehicles.\textsuperscript{12}

8. **Rechargeable batteries**: Hybrid-electric vehicles use rechargeable ‘deep cycle’ batteries,\textsuperscript{13} which can be fully discharged and recharged continuously. The size of the battery is not as large as that of a pure electric vehicle because the demand for propulsion power is shared by a petrol engine. Super-capacitor technology offers very high electrical capacitance in a small package.

9. **Regenerative braking**: Regenerative braking\textsuperscript{14} uses the vehicle’s own inertia to reclaim some of this lost energy and store it as electric charge. When the brakes are applied, the torque (rotating force) of the wheels is transferred to the electric motor shaft where it is converted to electrical energy and stored in the vehicle’s battery for later use.

10. **Alternate-fuel power plants**: Substantially reducing the fuel consumption of vehicles can open up the possibility of sustainable biofuels and hydrogen to replace petrol. Sufficiently reducing the fuel demand of the transport sector will enable it to run on biofuels made from farm and forestry wastes.\textsuperscript{15} Ethanol, a biofuel, is one of the cleanest fuels available.\textsuperscript{16} Sufficiently reducing the fuel consumption of vehicles can make hydrogen fuel cell power plants viable by reducing the required hydrogen fuel volume, and fuel cell capacity and cost.\textsuperscript{17}

11. **Plug-in hybrid-electric power plants**: Plug-in hybrid-electric vehicles (PHEVs) are a promising alternative to hydrogen fuel cell vehicles. They are similar to hybrid-electric vehicles, but have larger batteries that can be recharged by plugging them into an electrical outlet. A PHEV can run on electricity alone for relatively short trips, with the combustion engine engaging only when the battery has insufficient power. PHEVs can have an equivalent fuel consumption of 34-68 km/litre, which is roughly double the efficiency of hybrid-electric vehicles.

12. **Energy Source Flexibility**: Some automotive companies are now developing vehicles that can run on many fuels, thus ensuring that their vehicles are competitive no matter which fuel blends dominate the market in the future. General Motors’ new plug in hybrid-electric concept car, eFlex, is designed to run on petrol, biofuels or hydrogen.\textsuperscript{18} Volvo has developed a new truck engine that can be adapted to run on seven different renewable fuels.\textsuperscript{19}

13. **Hypercar Revolution**: A whole system approach to the development of the Rocky Mountain Institute’s (RMI) Hypercar Revolution concept passenger vehicle\textsuperscript{20} focussed on reducing its mass by 52 percent and reducing its drag by 55 percent, which then reduced its rolling resistance by 65 percent and made a fuel cell propulsion system cost effective. The Revolution is also almost fully recyclable, generates zero operative emissions and has a 95 percent better fuel-mass-consumption per kilometre than an equivalent conventional vehicle. Many innovations and concepts incorporated into the development of the Revolution have also been used to transform


\textsuperscript{13} Ibid.

\textsuperscript{14} Ibid.


other types of transportation vehicle transportation.

**Brief Background Information**

Roughly half\(^{21}\) of the 4.8 trillion litres (82.1 million barrels per day) of oil consumed globally in 2004\(^{22}\) was used for transport. This level of oil consumption has many direct and hidden costs, including climate change, insecurity, geopolitical rivalry, price volatility, and degradation of economic and social development.\(^{23}\) Perhaps the ideal means of reducing oil consumption in the transport sector is to directly reduce the amount of automotive commuting and hence the amount fuel consumed. At the urban level, automotive commuting can be reduced by promoting planning strategies and introducing transport policies that encourage low energy (walking and bicycling) and high occupancy (light rail and bus) transport, rather than low occupancy transport (cars). Large communities of this type are a reality in cities such as Singapore and Curitiba, Brazil,\(^{24}\) both of which evolved their strategies and policies over many decades. However, these communities are the exception, not the rule, and with seven-eighths of the world's population currently without cars\(^{25}\) but rapidly transitioning to more affluent economies, there is a substantial need to develop highly efficient passenger vehicles and other transport vehicles to help smooth the transition.

In the case of cars, incorporating the best conventional technologies would reduce fuel consumption by at least 25 percent with a less than one-year US payback period.\(^ {26}\)

![Figure 8.2.1. Reductions in car fuel consumption contributed by the best conventional technologies for various subsystems](image)

*Source:* Pears, A. (2000)\(^ {27}\)


\(^ {24}\) Ibid.

\(^ {25}\) Ibid.

\(^ {26}\) Ibid.

However, taking a whole system approach to the design of cars using hybrid engines and the latest advances in automotive technologies can improve energy efficiency significantly and thus reduce fuel consumption by 50 percent at roughly no cost and by more than 70 percent with a two-year payback period (in the US).28 These substantial reductions are possible because the vast majority of fuel energy in cars is lost during tasks other than moving passengers, as described by Amory Lovins,

A modern car’s engine, idling, driveline, and accessories dissipate seven-eighths of its fuel energy. Only one-eighth reaches the wheels. Of that, half heats the tires and road or heats the air that the car pushes aside. Only the last 6 percent accelerates the car (then heats the brakes when you stop). And since about 95 percent of the mass being accelerated is the car, not the driver, less than 1 percent of the fuel energy ultimately moves the driver – unimpressive, considering it is the fruit of 120 years of engineering effort.29

As Director of the CSIRO Energy Transformed Flagship John Wright stated,

The transport sector (comprising private cars, fleet cars, freight vehicles, public transport and their required infrastructures) is growing rapidly in Australia along with transport GHG emissions. The sector is currently heavily reliant on liquid fuels for which indigenous oil production is declining, and future imported oil dependence is poised to increase and weaken our balance of trade. The transport component of Energy Transformed will be based on the development of advanced vehicle drive technologies together with intelligent transport systems. The technology development will build upon CSIRO’s successful role in the development and demonstration of the ECOmmodore and aXcessAustralia Mark II vehicles, existing transport operation and decision support tools and international developments in hybrid electric and fuel cell powered cars30.

The target contributions of improvements and radical changes in vehicle technology and implementation of Intelligent Transport Systems (ITS) on Australia’s transport greenhouse gas emissions are shown in Figure 8.2.2.
A Whole System Design (WSD) Approach to Transportation Vehicles

To achieve a rapid mainstreaming of hybrid and fuel cell vehicle design within the transportation vehicle sector – cars, SUVs, buses, motorbikes – it will help that more engineers and vehicle designers are trained in how to take a whole system design approach to transportation vehicle design. Even though now most major car companies are investing significantly in hybrid and fuel cell vehicle designs, currently many engineers receive little or no formal training in this new and exciting area of automotive/vehicle design.

Hence this lecture and the following Lecture 8.3 on trucking vehicles provides practising engineers and vehicle designers, lecturers and students with an overview of how to take a whole system approach to the design of vehicles. This lecture and Lecture 8.3 which follows is complimented by a still more technical training unit entitled Passenger Vehicles which outlines the benefits of a whole system approach to the design of vehicles.

It is important to note that hybrid and fuel cell car designs are further examples of taking a whole system approach to the sustainable redesign of a highly technical and complex engineered system. A whole system approach - which examines and optimises the whole system (not just subsystems) - is needed to achieve the required 50 percent plus energy efficiency improvements for hybrid and fuel cell vehicle design in order to achieve the goals set out by the CSIRO Energy Transformed Flagship.

Figure 8.2.3 below shows the whole system design improvements to a typical, modern, sports utility vehicle (SUV) that can reduce its fuel consumption by 71 percent.

Figure 8.2.3. The improvements to a typical, modern, sports utility vehicle (SUV) to reduce its fuel consumption


The substantially reduced fuel consumption arises from acknowledging the whole system and how best to optimise several interacting subsystems. The presence of these interactions creates a

---


33 Ibid, Unit 7: Worked Example 2 – Passenger Vehicles.
situation in which a modification to a subsystem can impact on other subsystems. A whole system approach to reducing fuel consumption assists in identifying two important considerations:

1. Some individual improvements instigate a series of compounding and iterative improvements in other subsystems. For example, reducing the mass of the vehicle body by using low-density, high-integrity materials also reduces rolling resistance, required power plant capacity, required drivetrain integrity, and required chassis component integrity. Most of these additional impacts then lead to further mass reductions by using smaller subsystems and components. A similar but lesser series of impacts arises from using low-rolling resistance tyres.

2. Some individual improvements are better incorporated before other improvements. The first improvement is an extensive mass reduction, which contributes 68 percent of the total reduced fuel consumption. Figure 8.2.4 shows the optimal and iterative sequence for incorporating improvements to minimise fuel consumption and to introduce many other performance improvements.

![Diagram of improvement sequence](image)

**Figure 8.2.4.** Incorporating improvements in a passenger vehicle to reduce its fuel consumption

*Source: Adapted by TNEP from Brylawski, M.M. and Lovins, A.B. (1998)*

**Low-Density, High-Integrity Materials**

New, low-density, high-integrity metals and plastics have allowed the mass of cars to be reduced, thus reducing the required propulsion power, which is especially favourable to the introduction of

---

relatively heavy batteries and relatively expensive fuel cells as a power source. Reducing the mass also reduces rolling resistance and thus further reduces the required propulsion power. A 10 percent reduction in vehicle mass can produce roughly a 5-7 percent reduction in fuel consumption, provided that the power plant and drivetrain are downsized.35

Low-Drag Form

Aerodynamic drag forces are the result of pressure imbalances as a vehicle moves through the air. The vehicle’s size, exterior shape and the function it is designed to perform are all major influencing factors. Progress in reducing aerodynamic drag can now be accelerated through innovations in basic technologies such as computer based modelling, which allows for complex and accurate optimisation of aerodynamic body features. WalMart is currently seeking to double the fuel efficiency of all its trucks by 2015.36 One of the key strategies for achieving this reduction is to reduce aerodynamic drag through a low-drag body form.

Low-Rolling Resistance Tyres

Rolling resistance is defined as the energy dissipated by a tyre per unit of distance covered. It can only be overcome by the application of more energy. Thus, decreasing rolling resistance decreases fuel consumption. Increasing tyre inflation reduces rolling resistance but over-inflation causes tyres to wear faster. A similar compromise applies to tyre tread patterns – a more detailed tread pattern may grip the road better but due to air trapped between the tread pattern and the road, more rolling resistance is encountered. The reason for the compromise is that grip is maximised using tyre tread compounds that maximally absorb high frequency energies (from the tyre encountering small disturbances in the road surface), while rolling resistance is minimised using tyre tread compounds that maximally absorb low frequency energies (from tread deflection as the tyre rotates).37 Consequently, when using conventional tyres, a compromise must be made between the vehicle’s handling ability on the road and fuel consumption. ‘Green’ tyres (currently available), also known as ‘Fuel Saver’ tyres, solve the compromise between grip and rolling resistance by replacing some of the carbon black in the tyre’s tread compound with silica.38 Silica allows the tyre to absorb both high frequency and low frequency energies. Green tyres can reduce fuel consumption by 3-8 percent, and new generation green tyres may reduce fuel consumption by an additional 2-9 percent.

Hybrid-Electric Drivetrain

Hybrid-Electric Power Plants

Hybrid-electric vehicle markets globally are one of the fastest growing vehicle markets. Almost all major automobile companies now have hybrid vehicle programs. Hybrid-electric vehicles typically consume at least 50 percent less conventional vehicles. The typical hybrid–electric power plant configuration comprises a petrol internal combustion engine, and an electric motor and battery. Like

38 Ibid.
the combustion engine, the electric motor provides propulsion power, but is also used to recharge the battery through other functions such as regenerative braking.\textsuperscript{39}

\textit{Computer Control Systems}

A computer controller\textsuperscript{40} simultaneously controls a hybrid-electric vehicle’s two drivetrains – one powered by an internal combustion engine and one by an electric motor. The controller manages communications between multiple layers of control and communications systems, i.e. the electric motor controller, engine controller, battery management system, brake system controller, transmission controller, and electrical grid controller.

\textit{Rechargeable Batteries}

Hybrid-electric vehicles use rechargeable ‘deep cycle’ batteries,\textsuperscript{41} which can be fully discharged and recharged continuously. Nickel-Metal-Hydride (NiMH) is being used for batteries instead of lead acid because it reduces the mass and delivers more energy from a smaller package. The size of the battery is not as large as that of a pure electric vehicle because the demand for propulsion power is shared by a petrol engine. In the past, electrical energy storage has been the main barrier to producing electric and hybrid-electric vehicles. Battery storage, the best option at the time, was too heavy to allow any reasonable travel range. Today, batteries can be made to last longer, while taking minutes, rather than hours, to charge. Super-capacitor technology offers very high electrical capacitance in a small package. They store static charge rather than electro-chemical energy and can thus be reused almost endlessly.

\textit{Regenerative Braking}

Braking in conventional vehicles involves a braking mechanism applying friction to the drums and rotors of the wheels to slow or stop the vehicle by force of friction – a process that results in a substantial amount of energy being lost in the form of heat. However, with regenerative braking,\textsuperscript{42} the vehicle’s own inertia is used to reclaim some of this lost energy and store it as electric charge. when the brakes are applied, the torque (rotating force) of the wheels is transferred to the electric motor shaft – the magnets on the moving motor shaft (rotor) move past the electric coils on the motor stator (a stationary component), generating magnetic fields through the coils and producing electricity. This electrical energy is stored in the vehicle’s battery for later use.

\textit{Alternate-Fuel Power Plants}

Unless new economically viable oil reserves are found, Australia’s domestic oil supply is forecast to run out by 2030. Thus it is important that Australia considers future energy options of transport vehicles and transportation infrastructure. As Director of the Energy Transformed Flagship Dr John Wright has stated, ‘In the medium term, Australia will have to plan for a decline in indigenous oil supplies.’\textsuperscript{43} The 2006 Mobility Study by the World Business Council for Sustainable Development\textsuperscript{44}
summarised the wide range of primary energy source options and energy carrier options which can help to achieve a sustainable transport future, seen in Figure 8.2.5. Substantially reducing the fuel consumption of vehicles can open up the possibility of sustainable biofuels and hydrogen to replace petrol.

**Figure 8.2.5.** Sustainable transport primary energy sources, energy carriers and power trains


**Biofuels**

Sufficiently reducing the fuel demand of the transport sector will enable it to run on biofuels made from farm and forestry wastes. For example, in Brazil, where oil imports have been eliminated, about 75 percent of new cars can run on any blend of ethanol and petrol, although all available fuel in Brazil contains at least 20 percent ethanol. Brazil’s own sugarcane ethanol production has replaced about 40 percent of previous oil imports. Sweden is planning to also be oil-independent by 2020, primarily through producing its own ethanol from forest wastes and then requiring that its top-selling 60 percent of fuel stations offer renewable fuel by 2009. In Australia, the maximum portion of ethanol currently allowable in petrol is 10 percent while in Europe, it is 5 percent. To use fuel with

---

45 Ibid.
47 Ibid.
48 Ibid.
49 Ibid.
50 Ibid.
a richer ethanol blend than E15 (15 percent ethanol), modern Australian cars require a bi-fuel converter to be installed at a current cost of about AUD$300-400.\textsuperscript{51}

Ethanol is one of the cleanest fuels available. A CSIRO report\textsuperscript{52} that examines life cycle greenhouse gas emissions and particulate emissions of alternative fuels for heavy vehicles presents the results shown in Figures 8.2.6 and 8.2.7. An E95 fuel blend (95 percent ethanol) with ethanol made from wood is consistently among the low emitters. The wider variability in the bio fuels (ethanol blends and biodiesel blends) is largely due to the variability in feedstock and by the source of power used for the production process.\textsuperscript{53} Other fuels investigated are diesel, low sulfur (LS) diesel, low sulfur diesel (LSD) with 5 percent waste oil (W5), ultra-low sulfur (ULS) diesel, ultra low sulfur diesel (ULSD) with 5 percent waste oil (W5), liquefied petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG), biodiesel 20 percent blend (BD20) and biodiesel (BD100). In the report, buses were taken as representative of urban heavy vehicles while non-bus heavy vehicles were taken as representative of highway vehicles, which typically have better fuel economy due to their relatively undisrupted operations. ‘Pre-combustion’ emissions refer to all emissions associated with acquiring raw materials, producing the fuel and delivering the fuel to the vehicle; and ‘combustion’ emissions refer to vehicle tailpipe emissions. Particulates were based on risk-weighted estimates of human health.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{(a)}
\end{figure}

\textsuperscript{53} Ibid, p 74.
Figure 8.2.6. Fossil-fuel greenhouse gas emissions (CO$_2$-equivalents) for (a) buses and (b) non-bus heavy vehicles


---

$^{54}$ Ibid, pp 30, 32.
Hydrogen Fuels

Sufficiently reducing the fuel consumption of vehicles can make hydrogen fuel cell power plants more viable because:

- Hydrogen gas requires more volume than any current liquid fuel for the same energy content. Consequently, storing hydrogen fuel in a conventional vehicle requires an excessively large tank. Reducing the required propulsion power reduces the required fuel storage for a given range and hence reduces the volume of the tank.

- Fuel cells are a relatively costly technology and are cost prohibitive in a conventional vehicle. Reducing the required propulsion power reduces the capacity of the power plant and hence reduces its cost. A low-fuel-consumption, fuel cell vehicle would be cost effective at only 3 percent of the cumulative production volume of a conventional vehicle.\(^{56}\) In addition, fuel cells typically convert fuel to useable energy more efficiently than petrol engines thus further reducing the quantity of the fuel required.

There is also the potential for fuel cell vehicles to act as distributed electricity generators, especially during peak times, as described by Amory Lovins,

\[
\text{Such cars when parked (which is 96 percent of the time) could even become profitable power plants on wheels, selling electricity back to the grid when and where it's most valuable. In a parking structure, there would be a pipe to get hydrogen into the car and wires to get...}
\]

\(^{55}\) Ibid, p.34.
electricity out. At times of peak power demand, you could turn the fuel cell on and the car could run as a power plant, crediting the owner's account.57

Plug-In Hybrid-Electric Power Plants

While numerous governments now have plans to shift to a hydrogen economy over the next 20-50 years, the public is getting increasingly impatient for a climate neutral car option now. Plug-in hybrid-electric vehicles (PHEVs) are a promising alternative to hydrogen fuel cell vehicles that provide the potential to get very close to climate neutrality, especially when their internal combustion engines run on renewable biofuels and their batteries are recharged with renewable electricity.

PHEVs are similar to hybrid-electric vehicles, but have larger batteries that can be recharged by plugging them into an electrical outlet. A PHEV can run on electricity alone for relatively short trips, with the combustion engine engaging only when the battery has insufficient power. PHEVs can have an equivalent fuel consumption of 34-68 km/litre, which is roughly double the efficiency of hybrid electric vehicles. If the entire US vehicle fleet was replaced with PHEVs, US oil consumption would be reduced by 70 percent, completely eliminating the need for petroleum imports.

Energy Source Flexibility

Some automotive companies are now developing vehicles that can run on many fuels, thus ensuring that their vehicles are competitive no matter which fuel blends dominate the market in the future.

General Motors’ new plug in hybrid-electric concept car, eFlex, is designed to run on petrol, biofuels or hydrogen. General Motors' Head of Development, Jon Lauckner, has committed to producing the world’s first commercial plug-in hybrid-electric vehicle within a couple years.

On ABC Catalyst, John Lauckner stated,

This is our Chevrolet concept car to demonstrate our new eflex propulsion system, it’s the first application of eflex. E’ standing for electric and ‘Flex’ standing for flexibility. When the car exceeds electric range, it switches automatically to either petrol, or a biofuel or hydrogen. It’s really to give us the flexibility of a range of propulsion systems and basically reduce and, over time, eliminate our dependency on petroleum fuels. It’s really the electrification of vehicles on a scale that we haven’t seen in the past.58

Volvo has developed a new truck engine that can be adapted to run on seven different renewable fuels, and the engine can be commercially produced within a few years if the fuels were available.59

Fuels such as:60

- **Biodiesel**: Presumably 100 percent biodiesel (B100) for its carbon neutrality.
- **Biogas**: Can be extracted in sewage treatment works, at garbage dumps, and from other sites at which biodegradable materials are found.
- **Biogas plus Biodiesel**: Stored in separate tanks and used in separate injection systems, a small percentage (10 percent) of biodiesel, or synthetic diesel, is used for achieving compression

---

57 Ibid.
ignition in the diesel engine. The biogas in this alternative is in a cooled and liquid form, which increases its range.

- **Dimethyl ether (DME):** A gas that is handled in liquid form under low pressure, like Propane. DME can be produced through the gasification of biomass.

- **Ethanol/Methanol:** Methanol can be produced through the gasification of biomass; ethanol through the fermentation of crops rich in sugar and starch.

- **Synthetic Diesel:** A mixture of synthetically manufactured hydrocarbon produced through the gasification of biomass. Synthetic diesel can be mixed with conventional diesel fuel.

- **Hydrogen gas plus Biogas:** Hydrogen gas is mixed in small volumes with compressed biogas. The hydrogen gas can be produced through the gasification of biomass or electrolysis of water with renewable electricity.

**Inspiration from RMI's Hypercar Revolution Concept Passenger Vehicle**

Many engineers and designers of hybrid vehicles in most of the major automotive companies were inspired by Rocky Mountain Institute’s (RMI) Hypercar Revolution concept passenger vehicle, the plans and details of which RMI made freely available online in the mid-1990s. The Revolution is a safe, well-performing, ultra-efficient passenger vehicle that is almost fully recyclable and competitively-priced. Hypercar applied a whole system approach to overcome the compromises of conventional automobile design, such as making cars ‘light or safe’ and ‘efficient or spacious’ – the Revolution is ‘light and safe’ and ‘efficient and spacious’.

Hypercar determined that reducing the mass of the Revolution’s primary structure and reducing the drag of the shell would ultimately assist in meeting ambitious targets for cost (see Figure 8.2.8(a)), safety, efficiency, performance and comfort. Hypercar identified that these two improvements would instigate a series of compounding and iterative improvements (see Figure 8.2.8(b)):

- The primary structure is made from an advanced composite material and consists of only 14 major components, which is about 65 percent fewer than that of a conventional, stamped steel structure. The components are made using a manufacturing process called Fibreforge™. Fibreforge requires very few sharp bends or deep draws, and thus has low tooling costs, high repeatability and fewer processing steps than conventional car assembly. Unlike steel, the composite materials are lightweight, stiff, fatigue-resistant and rust proof. The higher cost of the composite materials is compensated by a reduction in replacement parts and assembly complexity. The smoothly-shaped shell components also reduce the Revolution’s drag (about half that of a similar-sized conventional vehicle).

- The low mass of the primary structure and low drag of the shell reduces the mechanical load on the chassis and propulsion subsystems, which thus can be made relatively small and, again, low.

---


64 Ibid, p 66.

mass. Furthermore, some technological substitutions also become viable. For example, relatively small and more efficient electric motors can power the wheels and thus eliminate the need for axles and differentials.66

- The Revolution’s low mass (about half that of a similar-sized conventional vehicle) requires only 35 kW for cruising.67 The low power requirement makes viable ambient pressure fuel cell technology, which emits only pure water vapour and which would be too expensive at a large capacity. The fuel cell operates efficiently since it is mainly for cruising and thus can be optimised to operate over a very small power range. Additional power for acceleration is drawn from auxiliary 35 kW batteries. The batteries are recharged by a regenerative braking subsystem,68 which is coupled with the electric motors. The braking system reduces energy losses to the surroundings.

---

![Figure 8.2.8](http://www.rmi.org/images/other/Trans/T98-01_CarAtCrossroads.pdf)

**Figure 8.2.8.** Potential (a) cost and (b) mass reductions arising from a low mass primary structure and a low drag shell in passenger vehicles


---


67 Ibid.


The Natural Edge Project’s Whole System Design Suite includes a ‘Worked Example’ that discusses Hypercar Revolution in detail.\textsuperscript{70}

Many innovations and concepts incorporated into the development of the Revolution have also been used to transform other types of transportation vehicle transportation. Trucks, trains, ships and aircraft can double or triple their fuel efficiency compared to conventional vehicles by 2025, by incorporating: low mass primary structures; low drag shells; small, high efficiency propulsion systems and drive trains; and electronic control.\textsuperscript{71} Some organisations are already taking the first steps. Boeing has announced that its new passenger aircraft, which incorporates low mass composite materials, will consume 20 percent less fuel than other comparable aircraft. WalMart has announced that its fleet of 6800 heavy trucks, which incorporate low drag shells, will double fuel efficiency by 2015, saving US$494 million by 2020 (see Figure 8.2.9(a)).\textsuperscript{72} In England, the first double-decker hybrid bus was launched in 2005\textsuperscript{73} (see Figure 8.2.9(b)) and already there are numerous hybrid motorbikes on the market\textsuperscript{74} (see Figure 8.2.9(c)).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure829.png}
\caption{(a) Wal-Mart heavy trucks; (b) hybrid-electric bus; (c) hybrid-electric motorbikes.}
\end{figure}

\textit{Source:} (a) Rocky Mountain Institute (2007);\textsuperscript{75} (b) BBC (2006);\textsuperscript{76} (c) World Changing (2004)\textsuperscript{77}


Optional Reading


Key Words for Searching Online

Transport fuel economy, light metals, light plastics, aerodynamic drag, rolling resistance, hybrid-electric, regenerative braking, vehicle to grid.