ENERGY TRANSFORMED:

SUSTAINABLE ENERGY SOLUTIONS FOR CLIMATE CHANGE MITIGATION

MODULE A

UNDERSTANDING, IDENTIFYING AND IMPLEMENTING ENERGY EFFICIENCY OPPORTUNITIES FOR INDUSTRIAL/COMMERCIAL USERS – BY TECHNOLOGY

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 3: ENERGY EFFICIENCY OPPORTUNITIES FOR INDUSTRIAL USERS

LECTURE 3.1: OPPORTUNITIES FOR IMPROVING THE EFFICIENCY OF MOTOR SYSTEMS

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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.

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

<u>Chapter 1: Climate Change Mitigation in Australia's Energy Sector</u>

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

<u>Chapter 2: Energy Efficiency Opportunities for Commercial Users</u>

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

<u>Chapter 3: Energy Efficiency Opportunities for Industrial Users</u>

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

[1] International Energy Agency (2005) 'World Energy Outlook 2005', Press Releases, IEA, UK. Available at http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=163. Accessed 3 March 2007.
[2] CSIRO (2006) *Energy Technology*, CSIRO, Australia. Available at www.det.csiro.au/PDF%20files/CET_Div_Brochure.pdf. Accessed 3 March 2007.
[3] The Climate Group (2005) *Profits Up, Carbon Down*, The Climate Group. Available at www.theclimategroup.org/assets/Carbon_Down_Profit_Up.pdf. Accessed 3 March 2007.
[4] Energy Futures Forum (2006) *The Heat Is On: The Future of Energy in Australia*, CSIRO, Parts 1,2,3. Available at http://www.csiro.au/csiro/content/file/pfnd.html. Accessed 3 March 2007.

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

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

Energy Efficiency Opportunities for Industrial Users

Lecture 3.1: Opportunities for Improving the Efficiency of Motor Systems[5]

The key to making motor systems more efficient and economical is to take advantage of high-performance technologies and the synergism among the various system components.

Nadel, S. *et al*, 2002[6]

Educational Aim

The aim of this lecture is to review the energy efficiency opportunities in motors systems. Lecture 3.1 covers key components of design, operation and maintenance. A clear understanding of energy efficiency opportunities will assist engineers and other students of these modules to realise potential energy efficiency improvements in their motor and similar systems.

Essential Reading

Reference	Page
1. Xenergy Inc. (2002) *United States Industrial Electric Motor Systems Market Opportunities Assessment*, US Department of Energy, USA. Available at www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/mtrmkt.pdf. Accessed 13 October 2012.	pp 7-8, 57-71
2. UK Carbon Trust (2007) Motors and Drives. Available At. www.pwtag.org/Motors%20and%20drives%20Carbon%20Trust.pdf. Accessed 13 October 2012.	
3. DRET (2012) 'DRET Energy Efficiency Exchange Technology page – Motors and Motor Systems'. Developed by Geoff Andrews and Dr Michael Smith (ANU). DRET EEX. Available at http://eex.gov.au/technologies/motors/. Accessed 16 October 2012.	
4. DRET (2012) 'DRET Energy Efficiency Exchange Technology page – Pumps and Fans'. Developed by Geoff Andrews and Dr Michael Smith (ANU).DRET EEX. Available at http://eex.gov.au/technologies/pumps-and-fans-2/. Accessed 16 October 2012.	
5. DRET (2012) 'DRET Energy Efficiency Exchange Technology page – Compressed Air'. Developed by Dr Michael Smith (ANU).DRET EEX. Available at http://eex.gov.au/technologies/compressed-air-2/. Accessed 16 October 2012.	

[5] Peer review by Geoff Andrews - Director, Genesis Now Pty Ltd and Glenn Platt – CSIRO.
[6] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.

Learning Points

1. Estimates indicate that, in many processes, electric motor system energy efficiency can potentially be improved by 30-60 percent.[7] Energy transfer through the component systems are in series upstream to downstream. That is, energy is transferred from the electricity source in the following order: 1) to the electrical power transmission system, 2) to the power control system, 3) to the electric motor, 4) to the mechanical power transmission system, 5) to the driven system, 6) to the fluid distribution system, and finally 7) to the end use.
2. *Load management:* Motor system energy efficiency can be improved by implementing a load management strategy for bringing online and taking offline the right-sized motor systems to match loads. Control technologies assist good load management.
3. Premium efficiency motors are 2-10 percent more efficient than standard efficiency motors[8] and have a 10–30 percent higher capital cost.[9] The results indicate that it is generally cost-effective to invest in premium efficiency motors rather than standard efficiency motors. Since the operating energy cost for an average electric motor is 50-100 times the capital cost over 10-25 years,[10] premium efficiency motors are far more economical than standard efficiency motors over the long term.
4. *Electric motor design:* Premium efficiency motors are designed to minimise power transmission losses from electrical input to mechanical output. The three types of losses that occur in electric motor are fixed losses, load losses and stray losses.[11]
5. *Load matching:* Motor operating efficiency is improved by matching the motor size and speed to the load. Given that motors have a high operating energy cost, it is important to investigate options for using right-sized motors that operate near peak efficiency. Motor energy consumption increases with the cube of operating speed.[12] Thus, energy consumption can be minimised by using motors that provide the correct speed for the application.
6. *Control systems:* In practice, motor system loads are not constant. The consequences of not matching the motor system to the load include inefficient operation, reduced service life and poorer quality service delivery. Control systems efficiently adjust the motor speed and torque to match the load. The most popular control systems are variable speed drives (AC drives) for AC motors and DC drives for DC motors.
7. *Driven systems:* Typical driven systems include pumps, fans, compressors and conveyors. Driven system operating efficiency varies widely in a range lower than that for electric motors.[13] Simply load-matching a driven system can improve its operating efficiency by up to 50 percent.[14]

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[7] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.
[8] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[9] Ibid; Sustainability Victoria (2006) *High Efficient AC Motors FactSheet*, Victorian State Government, Australia. Available at http://www.sv.sustainability.vic.gov.au/manufacturing/sustainable_manufacturing/resource.asp?action=show_resource&resourcetype=2&resourceid=45. Accessed 14 April 2007.
[10] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/index.html. Accessed 14 April 2007;
[11] Sustainability Victoria (2006) *High Efficient AC Motors FactSheet*, Victorian State Government, Australia. Available at http://www.sv.sustainability.vic.gov.au/manufacturing/sustainable_manufacturing/resource.asp?action=show_resource&resourcetype=2&resourceid=45. Accessed 14 April 2007.
[12] Australian Greenhouse Office (2003) *The Motor System*, AGO. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.
[13] Australian Greenhouse Office (2003) *The Motor System*., AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.

8. *Power transmission:* The two main power transmissions in a motor system are by wire from the electricity supply to the motor and by mechanical coupling from the motor to the driven system. Larger wires provide less electrical resistance and hence are more efficient. Mechanical coupling is usually by belts, gears and chains. Where cost effective, direct drive, or gears and chains, which mesh with near 100 percent efficiency, are favourable over belts which couple with smooth pulleys.[15]

9. *Fluid distribution systems:* Fluid distribution systems either pipe, plumbing or duct systems, are typically undersized and over-complicated. Large, short, straight channels improve distribution efficiency. Repairing leaks is one of the most cost-effective maintenance tasks because energy reductions in the distribution system compound with efficiencies of upstream systems.

10. Other strategies to help ensure motor systems run efficiently include:

    - *Commissioning:* Comprehensive motor system commissioning[16] has several benefits including prolonged service life, reduced downtime, reduced maintenance costs, reduced operating costs, and improved safety.

    - *Maintenance:* Comprehensive motor system maintenance has several benefits including improved operating efficiency, improved reliability, prolonged service life, reduced operating and replacement costs[17] and reduced breakdowns and downtime.[18]

    - *Repair and replacement:* Failed or failing electric motors can be either repaired or replaced. Many motors are repaired several times before being replaced.[19] The decision on whether to repair or replace is mainly based on the lifecycle cost of either option.

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[14] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[15] Ibid
[16] Australian Greenhouse Office (2003) *Reference Manual – Commissioning*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r3.html. Accessed 14 April 2007.
[17] Australian Greenhouse Office (2003) *Reference Manual – Motor and system maintenance and operation*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r4.html. Accessed 14 April 2007.
[18] Australian Greenhouse Office (2003) *Reference Manual – Maintenance management systems: plant inventory and records*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r7.html. Accessed 14 April 2007.
[19] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.

Brief Background Information

Electric motors convert electrical power into mechanical rotational power. In most industrial applications, electric motors are used to move fluid by driving a pump, fan, or compressor, or to drive a conveyor. A motor system incorporates an electric motor, a power control system, a driven system, power transmission system and, where fluid is moved, a fluid distribution system. The energy efficiency of the motor system is determined by the efficiency of these components plus the design quality, the installation quality and the maintenance quality.[20]

High quality electric motors can operate at 90 percent energy efficiency non-stop for decades if well maintained. This efficiency and reliability is a major reason for using them to provide more than 80 percent of non-vehicular rotational power in the United States.[21] In Australia, electric motors contribute a significant percentage of electricity consumption by industry.[22] This consumption equates to almost AU$3 billion annually and 37 million tons of carbon dioxide.

Estimates indicate that, in many processes, motor system energy efficiency can potentially be improved by 30-60 percent.[23] This estimate is consistent with findings of a 2002 United States program, the *United States Industrial Electric Motor Systems Market Opportunities Assessment,*[24] that has improved motor system efficiency by an average of 33 percent and as much as 59 percent. Some 62 percent of these reductions were from improving pumps, fans, and air compressors. Additional estimates indicate that electric motor efficiency can be improved 10-25 percent by using right-sized premium motors and incorporating motor management,[25] and that maintenance can contribute a further 10-15 percent to motor system efficiency improvement.[26]

In Australia, every one percent improvement in motor system efficiency prevents the use of about 400,000MWh of electricity and the release of 400,000 tons of greenhouse gas emissions – the equivalent of taking 9000 cars off the road.[27] Table 3.1.1 itemises the efficiency measures that were applied to typical motor-pump, fan and compressor systems in the US to achieve a 15 percent efficiency improvement. These efficiency measures are also relevant to Australian industry.

[20] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available atwww.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.
[21] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[22] Australian Greenhouse Office (2003) *Motor Selector Software*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/motorselector/m2.html. Accessed 14 April 2007.
[23] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.
[24] Xenergy, Inc. (2002) *United States Industrial Electric Motor Systems Market Opportunities Assessment*, US Department of Energy, USA. pp. 7-8. Available at http://www1.eere.energy.gov/industry/bestpractices/pdfs/mtrmkt.pdf. Accessed 18 April 2007
[25] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/index.html. Accessed 14 April 2007.
[26] Electrical Power Research Institute cited in Australian Greenhouse Office (2003) *Reference Manual – Motor and system maintenance and operation*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r4.html. Accessed 14 April 2007
[27] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/index.html. Accessed 14 April 2007.

Table 3.1.1: Itemised summary of potential efficiency improvements (US Figures)

Energy efficiency measure	Efficiency improvement (GWh/Year)			Midrange efficiency improvement (GWh % of)	
	Low	Midrange	High	Motor System	Specific system
Premium efficiency motors					
Upgrade all integral AC motors to EPAct Levels	-	13,043	-	2.3%	-
Upgrade all integral AC motors to CEE Levels	-	6,756	-	1.2%	-
Improve Rewind Practices	-	4,778	-	0.8%	-
Premium efficiency motors total	-	*24,577*	-	*4.3%*	-
Load matching/ efficient systems					
Correct motor oversizing	6,786	6,786	6,786	1.2%	
Pump Systems:					
System Efficiency Improvements	8,975	13,698	19,106	2.4%	9.6%
Speed Controls	6,421	14,982	19,263	2.6%	10.5%
Subtotal	*15,396*	*28,681*	*38,369*	*5.0%*	*20.1%*
Fan Systems:					
System Efficiency Improvements	1,378	2,755	3,897	0.5%	3.5%
Speed Controls	787	1,575	2,362	0.3%	2.0%
Subtotal	*2,165*	*4,330*	*6,259*	*0.8%*	*5.5%*
Compressed Air Systems:					
System Efficiency Improvements	8,559	13,248	16,343	2.3%	14.6%
Speed Controls	1,366	2,276	3,642	0.4%	2.5%
Subtotal	*9,924*	*15,524*	*19,985*	*2.7%*	*17.1%*
Specialized Systems:					
Subtotal	*2,630*	*5,259*	*7,889*	*0.9%*	*2.0%*
Load matching/ efficient systems total	*36,901*	*60,579*	*79,288*	*10.5%*	
***Total Potential Savings* (GWh/Year)**	***61,478***	***85,157***	***103,865***	***14.8%***	

Source: Xenergy (2002)[28]

[28] Xenergy, Inc. (2002) *United States Industrial Electric Motor Systems Market Opportunities Assessment*, US Department of Energy, USA, p 56. Available at http://www1.eere.energy.gov/industry/bestpractices/pdfs/mtrmkt.pdf. Accessed 18 April 2007.

Motor system efficiency programs, such as the United States program mentioned above, have demonstrated good improvements. Nadel *et al* describe how these programs can be made even more effective:[29]

> *...the programs for increasing drivepower* [motor system] *efficiency need to be broader in scope. Most drivepower efficiency programs have focused only on efficient motors instead of on the entire motor-decision process. A good program would address repair versus replace decisions, the implementation of life-cycle analysis of new motor purchase decisions, and the importance of demanding quality motor repairs.*
>
> *Improved motor repair practices have long been identified as significant opportunities for energy efficiency. Unfortunately, we have only begun to see the first, tentative steps toward implementing programs to realize these savings...*
>
> *A number of programs were motivated by the opportunity created by ASDs* [adjustable speed drives or variable speed drives]*, and have attempted to focus on motor-driven systems, particularly fan, pump, and compressed air systems... the largest opportunities for cost-effective saving are in improved optimization of these systems...*
>
> *...most programs have ignored other efficiency-related topics, such as motor sizing, rewinding, and controls other than ASDs. Few programs that we know of have addressed the savings available from electrical tune-ups, better selection and maintenance of drivetrains and bearings, better system monitoring, and the upsizing of distribution wires in new installations. While the savings from these measures may appear incremental, they are frequently among the most cost-effective, and they also offer significant non-energy benefits in the form of improved reliability and productivity.*

Taking a 'Whole System Design' Approach

The remainder of this lecture describes potential energy efficiency improvements for the component systems of a motor system. It is important to note that all efficiency improvements in a system amass to an improvement greater than the sum of the individual improvements. In the case of a motor system, energy transfer through the component systems are in series, upstream to downstream. That is, energy is transferred from the electricity source to 1) the electrical power transmission system, 2) the power control system, 3) the electric motor, 4) the mechanical power transmission system, 5) the driven system, 6) the fluid distribution system, and finally 7) to the end-use. Reducing end-use load by 5 percent will also reduce the load on every component system upstream (the whole motor system) by 5 percent. Also, improving the efficiency of the fluid distribution system by 5 percent will not affect the downstream end-use load, but will reduce the load on every component system upstream by a further 5 percent. Continuing efficiency improvements upstream, each increment compounds with the previous increments. The result is that instead of consuming 95 percent of the energy that a standard motor system would consume, the efficient motor system (with six efficient component subsystems in series) consumes only 74 percent ($=0.95^6$) of the energy. For systems with component subsystems in series, a downstream to upstream sequence is optimal for enabling efficiency improvements. (Note that, in this lecture, component systems are presented in an upstream to downstream sequence.)

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[29] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.

Load Management

Every industrial site has many electric motor; often hundreds. Since motors consume large quantities of energy, eliminating even a few can have a substantial impact on consumption. Onsite applications for motors can vary as often as daily and there is temptation to assign every motor to an application just so that investments are not sitting idle. However, having fewer motors operating at higher loads is generally more energy efficient than having all motors operating at lower loads. A load management strategy for bringing online and taking offline the appropriate motors to match the loads can greatly increase energy efficiency. Informed motor selection is assisted by a comprehensive inventory of available motors, their performance specifications and their performance history.[30] Control technologies[31] assist good load management by taking motors offline when their services are not required. Control technologies are usually cost-effective and include:

- calendar time switches, which prevent motors from starting up on public holidays and RDO's
- level float switches, which control pumps that would otherwise be running continuously
- thermostats, which allow chilled water pumps to operate only in warm weather

Premium Efficiency Electric Motors

The operating energy cost for an average electric motor has been estimated at 50-100 times the capital cost over 10-25 years[32] (see Figure 3.1.1) and can be as high as ten times the capital cost annually.[33] Thus, there is clear value in considering operating energy costs when selecting motors for purchase or for a particular application.

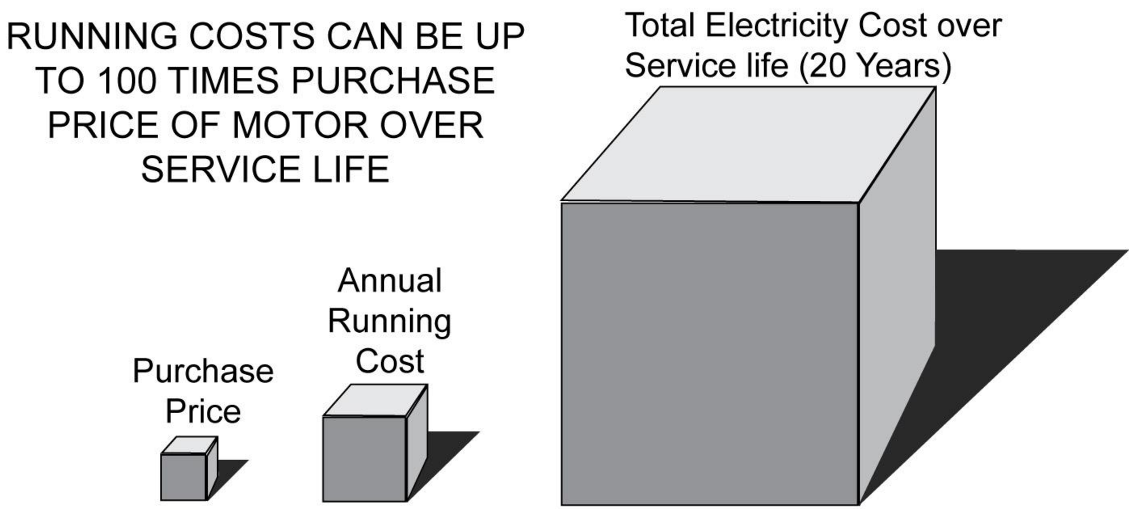

Figure 3.1.1. Comparing electric motor capital costs with operating energy costs.

Source: Australian Greenhouse Office (2003)[34]

[30] Australian Greenhouse Office (2003) *Reference Manual – Motor repair and replacement*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r5.html. Accessed 14 April 2007.,
[31] Genesis Automation (2005) *Energy Audit and Energy Management Training Notes*, Genesis Auto, p 46.
[32] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene,* AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/index.html. Accessed 14 April 2007.
[33] Australian Greenhouse Office (2003) *The Motor System* AGO, Australia. Available at http://www.greenhouse.gov.au/motors/motorselector/m2.html. Accessed 14 April 2007; Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[34] Australian Greenhouse Office (2003) *Reference Manual – Introduction: setting the scene*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/index.html. Accessed 14 April 2007.

Premium efficiency motors are 2-10 percent more efficient than standard efficiency motors, with smaller motors at the high end of this range and larger motors at the low end.[35] Premium efficiency motors have capital cost of 10–30 percent more mainly due to higher quality materials[36] and higher tolerance manufacturing (see *Electric Motor Design*). Table 3.1.2 compares the ten-year life cycle cost of a AUD$1000 standard efficiency motor with that of the equivalent worst and best case (based on efficiency and capital cost ranges) premium efficiency motors. The results indicate that it is generally cost-effective to invest in premium efficiency motors rather than standard efficiency motors.

Table 3.1.2: Comparing the ten-year life cycle cost of a AUD$1000 standard efficiency motor with that of the equivalent worst and best case premium efficiency motors

	Standard Efficiency Motor	**Premium Efficiency Motor (worst)**	**Premium Efficiency Motor (best)**
Capital cost	$1000	$1300 (+30%)	$1100 (+10%)
Operating cost	$50,000	$49,000 (-2%)	$45,000 (-10%)
Total Cost over Life	*$51,000*	*$50,300*	*$46,100*
Payback Period	–	*3 years*	*73 days*

Source: Compiled by The Natural Edge Project (TNEP)

While simple analysis was used to create Table 3.1.2, it is noted that life cycle costs of motors are better determined by incorporating the 'time value of money', which has significant influence over ten years.[37] Additional benefits of premium efficiency motors over standard efficiency motors are that they are more reliable, have a longer service life and are less sensitive to voltage and load fluctuations.[38]

Electric Motor Design

Premium efficiency motors are designed to minimise power transmission losses from electrical input to mechanical output. The three types of losses that occur in electric motors are fixed losses, load losses and stray losses.[39]

Fixed Losses

Fixed losses include: 'core loss' – which contributes to about 25 percent of the total losses; and 'windage and friction loss' – which contributes to about five percent of the total losses. Core loss is comprised of hysteresis and eddy current loss due to the magnetic materials. Hysteresis is reduced by using high quality steel laminations and eddy current loss is reduced by using thinner laminations. Core loss is reduced by lengthening the core to reduce the required flux density.

[35] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[36] Ibid.
[37] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/motorselector/m2.html. Accessed 14 April 2007.
[38] Sustainability Victoria (2006) *High Efficient AC Motors FactSheet*, Victorian State Government, Australia. Available at http://www.sv.sustainability.vic.gov.au/manufacturing/sustainable_manufacturing/resource.asp?action=show_resource&resourcetype=2&resourceid=45. Accessed 14 April 2007.
[39] Ibid.

Windage and friction loss is from bearing and air friction loss when the rotor is rotating, and can be reduced by improved bearing and airflow designs and by reducing other losses so that a smaller fan can be used.

Load Losses

Load losses include: 'stator copper loss' - which contributes to about 35 percent of the total losses; and 'rotor copper loss' - which contributes to about 25 percent of the total losses. Stator copper loss is reduced by increasing stator slots and using larger cross-section conductors. Rotor copper loss is reduced by increasing the cross-section of rotor bars and end rings and by improving the quality of the joint between the bars and end rings.

Stray Losses

Stray load losses, which contribute to about 10 percent of the total losses, are from load-current-induced leakage flux and increase with the square of the load. Stray load losses are difficult to measure and reduce, but most premium motors incorporate higher quality and thinner steel laminations in the stator, more copper in the windings, a smaller air gap, reduced fan losses and closer machining tolerances.

Load Matching

Motor operating efficiency is improved by matching the motor size and speed to the load. Motors are oversized in most applications. However, oversized motors operate at part load and hence low efficiency. Most motors[40] have peak efficiency somewhere between 75 and 100 percent of load. Efficiency is near-constant between full load and 50 percent load and then decreases dramatically below 50 percent. Given that motors have a high operating energy cost, it is important to investigate options for using right-sized motors that operate near peak efficiency. Table 3.1.3 indicates how the main motor size concerns that lead to using oversized motors can be alleviated so that right-sized motors can be used. The additional capital costs of an oversized motor can instead contribute to the additional capital costs of a premium efficiency motor and power control system.

[40] Ibid.

Table 3.1.3: Alleviating concerns about motor size to use right-sized motors

Reason for oversized motors	Remedy using right-sized motors
Insurance against motor failure in critical processes	Premium efficiency motors are very reliable and have a long service life.
Accommodate higher start-up loads	Motors that accommodate short-term overloads are available. These motors have service factors of over 1.0 and operate satisfactorily at that load and near peak efficiency. A motor with a load factor of 1.15 can operate at 115% load. Control systems such as variable speed drives and soft starters assist motors to accommodate high start-up loads.
Accommodate higher future loads	In many applications, the reduced cost of operating a right-sized motor will surpass the additional cost of an oversized motor before a higher load needs to be accommodated. It is thus more cost effective to purchase a new, larger motor if/when required (and perhaps sell the smaller motor).
Accommodate unexpected load fluctuations	Premium efficiency motors are less sensitive to voltage and load fluctuations. Motors that accommodate short-term overloads are available.
Accommodate voltage imbalance	Premium efficiency motors are less sensitive to voltage and load fluctuations.

Source: Sustainability Victoria (2006)[41]

Motor energy consumption increases with the cube of operating speed (i.e. X times X times X).[42] Thus, energy consumption can be minimised by using motors that provide the correct speed for the application. The Australian Government has a freely available software program called *Motor Selector.*[43] Motor Selector provides a simple way of analysing the complex factors that determine whether a motor will provide long-term cost benefits. These factors include purchase price, load profile, life cycle costs, plant data, efficiency, financial risk, noise, warranty, tariff and carbon dioxide emissions. Motor Selector draws on a database of nearly 1000 motors currently available in Australia.

Control Systems

In practice, motor system loads are not constant. Start-up and shut-down loads are substantially different to nominal loads and operating loads vary with end-use behaviour and transients. The consequences of not matching the motor system to the load include inefficient operation, reduced service life and poorer quality service delivery.

> *...fan-, compressor-, and pump-driven systems moving gaseous or liquid loads may require frequent changes in the rate of flow. This is the case for fans and chillers for ventilation and cooling of commercial buildings, pumps for hydronic heating and/or cooling systems, fans*

[41] Ibid.

[42] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007

[43] Australian Greenhouse Office (2003) *Motor Selector Software,* AGO, Australia. Available at http://www.greenhouse.gov.au/motors/motorselector/index.html. Accessed 14 April 2007.

and feed water pumps for industrial and power plant boilers, and municipal water and wastewater pumps.[44]

Some motor systems control fluid flow using mechanical restricting devices such as inlet vanes, outlet dampers and throttling valves in the driven system or fluid distribution system while the motor operates a full load against the restriction.[45] It is more energy efficient to use control systems that adjust the motor speed and torque to match the load.

The most popular AC control system is the variable speed drive, an electrical device that controls power to the motor thereby reducing energy consumption. Variable speed drive energy consumption has been measured[46] in industrial applications to be proportional to $\omega^{2.6}$ (where ω is rotational speed), so halving the speed of a given motor and load system will reduce the energy consumption to 16 percent ($=0.5^{2.6}$) of the full speed energy consumption. Variable speed drives act as soft starters, which prevents overloading and avoids the cost of other starter controllers.[47] There are also alternative technologies that are better suited to some applications. As Nadal *et al.* write,[48]

Other technologies include microprocessor-based controllers that monitor system variables and adjust motor load accordingly, and power-factor controllers that can trim the energy use of small motors driving grinders, drills, and other devices that idle at nearly zero loading most of the time. There are also application-specific controls such as those that sequence the operation of multiple compressors in a compressed air system.

Other developments enlarge the range of control applications. For instance, advanced sensors are allowing ASDs [adjustable speed drives or variable speed drives (VSDs)] *to be used in applications (lumber drying kilns, for example) where they previously would not work due to limitations in sensing or in matching the response time required by a control loop. Electronic advances also are allowing lumber* (timber) *mills to control cuts better and to mill more product from raw stock without increasing energy use. These developments and others in the controls area represent the largest slice of the drivepower* [motor system] *savings pie...*

Driven Systems

Typical driven systems include pumps, fans, compressors and conveyors. Driven system operating efficiency varies widely in a range lower than that for electric motors.[49] Simply load-matching a driven system can improve its operating efficiency by up to 50 percent.[50] There are also several specific efficiency measures that can be applied to pump systems, fan systems and compressed air systems, as in Table 3.1.4, Table 3.1.5, and Table 3.1.6, respectively.

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[44] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[45] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007; Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[46] Private communication, Genesis Now, 11 Oct 2007
[47] Genesis Automation (2005) *Energy Audit and Energy Management Training Notes*, Genesis Automation, p 48.
[48] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[49] Australian Greenhouse Office (2003) *The Motor System*, AGO, Australia. Available at www.greenhouse.gov.au/motors/case-studies/cs_system.html. Accessed 14 April 2007.
[50] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.

Table 3.1.4: Energy efficiency opportunities in pump systems.

Energy efficiency measure for pump systems	Improvement Percentage (% of motor system)
Reduce Overall System Requirements	
Equalize flow over production cycle using holding tanks.	10-20%
Eliminate bypass loops and other unnecessary flows.	10-20%
Increase piping diameter to reduce friction.	5-20%
Reduce 'safety margins' in design system capacity.	5-10%
Match Pump Size to Load	
Install parallel systems for highly variable loads.	10-50%
Reduce pump size to better fit load.	15-25%
Reduce or control pump speed	
Reduce speed for fixed loads: trim impeller, lower gear ratios.	Up to 75%
Replace throttling valves with speed controls to meet variable loads.	30-80+%
Improve Pump Components	
Replace typical pump with the most efficient model, or one with an efficient operating point better suited to the process flows.	2-5% plus 10-25% for degrading, most likely 2-10%
Replace belt drives with direct coupling.	Up to 30%[51]
Operation and Maintenance	
Replace worn impellers, especially in caustic or semi-solid applications. Inspect and repair bearings, lip seals, packings and other mechanical seals.	1-6%

Source: Xenergy (2002)[52]

[51] Private communication, Genesis Now, 11 Oct 2007
[52] Xenergy, Inc. (2002) *United States Industrial Electric Motor Systems Market Opportunities Assessment*, US Department of Energy, USA pp 57-58. Available at http://www1.eere.energy.gov/industry/bestpractices/pdfs/mtrmkt.pdf. Accessed 18 April 2007.

Table 3.1.5: Energy efficiency opportunities in fan systems.

Energy efficiency measure for FAN systems	Improvement(% of motor system)
Reduce Overall System Requirements	
Reduce 'system effect' through better inlet and outlet design.	25%
Reduce fan over-sizing.	1-5%
Reduce or control fan speed	
Replace inlet or outlet dampers and variable inlet vane with electronic speed controls to meet variable loads.	14-49%
Improve Fan Components	
Replace Standard V-Belt with Cogged V-Belt.	Up to 8%
Replace fan with more efficient model.	
Operation and Maintenance	
Improve O&M practices: tighten belts, clean fans, change filters regularly.	2-5%

Source: Adapted from Xenergy (2002)[53]

[53] Ibid.

Table 3.1.6: Energy efficiency opportunities in compressed air systems

Energy efficiency measure for COMPRESSED AIR systems	Improvement (% of motor system)
Reduce Overall System Requirements	
Reduce overall system pressure through better system design and better ancillary components (filters and dryers).	4-6%
Reduce system demand by eliminating poor applications of compressed air.	Up to 20%
Segment system and provide satellite or booster compressors or storage when remote locations have special requirements such as higher pressures, cleaner air, or short term high volumes.	5%
Improve supply conditions; use outside air.	4-6%
Match Compressor Size to Load	
Size compressors for efficient trimming.	5%
Compressor Control	
Install standard part load controls which include automation and storage.	3-7%
Install microprocessor controls on compressor system.	2-4%
Use parallel compressors and install multi-unit controls to reduce compressor part loading.	3-33%, most likely 10-16%
Install VSDs for rotary compressors.	About 10%
Improve Compressor Components	
Replace older single stage reciprocating compressors and symmetrical screw compressors with more efficient model.	10-20%
Operation and Maintenance	
Reduce leaks by instituting an ongoing program of system maintenance on regulators, quick connect fittings, tubing, pipes and other points of connection.	2.7-59%, most likely 15-25%
Improve maintenance on compressor: e.g., valves for reciprocating compressors and intercoolers for centrifugal compressors.	2-5%
Change compressor filters and point of use filters regularly to reduce pressure drops.	1-6%

Source: Adapted from Xenergy (2002)[54]

[54] Ibid, pp 59-60.

Power Transmission

High efficiency power transmission is equally as important to a motor system as a premium motor or a high efficient driven system. The two main power transmissions in a motor system are from the electricity supply to the motor and from the motor to the driven system. Power transmission from electricity supply to the motor is by wires. Wires[55] are usually sized to code, which is mainly concerned with safety issues. Larger wires provide less electrical resistance and hence, are more efficient, but also cost more. While wire size must be optimised against both efficiency and cost, most current systems would benefit from larger wires. Power transmission from the motor to the driven system, when not directly coupled, is by belts, gears or chains. Typically, belts, gears and chains[56] receive limited installation and maintenance attention and hence can substantially reduce the efficiency of the motor system and increase downtime. Where cost effective, gears and chains, which mesh with near 100 percent efficiency, are favourable over belts, which couple with smooth pulleys. Belts are also more sensitive to tension variations. Loose, worn belts can slip and reduce transmission efficiency from 90 percent to 60 percent,[57] and tight belts can overload bearings and reduce service life.

Fluid Distribution Systems

Fluid-moving motor systems have fluid distribution systems; either pipe, plumbing or duct systems. Distribution system channels are typically undersized and over-complicated. Small channel diameters result in unnecessarily high energy consumption. A major energy loss in distribution systems is from wall friction, which decreases with the 5th power of diameter for circular channels and proportionally with pipe length. Another major energy loss is from variations in channel cross-sectional profile, such as contractions, bends, valves and other components. Thus, large, short, straight channels improve distribution efficiency. The higher cost of larger channels is offset by reduced length and components. While channel size must be optimised against both efficiency and cost, most current systems would benefit from larger channels. Additional energy losses in distribution systems are from fluid leaks. Fluid leaks are most common at channel section joints and around valves and other components. Repairing leaks is one of the most cost-effective maintenance tasks because energy reductions in the distribution system improve in a compounding manner with efficiencies of upstream systems.

Other Strategies

Other actions needed to ensure motor systems are running as efficiently as possible are commissioning, good maintenance and repairs/replacement:

- Comprehensive motor system commissioning[58] has several benefits including prolonged service life, reduced downtime, reduced maintenance costs, reduced operating costs, and improved safety. The Australian Greenhouse Office's (AGO) Motor Systems web page[59] covers the steps to complete a comprehensive motor system commission and also provides a checklist that anyone can use.

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[55] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[56] Ibid.
[57] Genesis Automation (2005) *Energy Audit and Energy Management Training Notes*, Genesis Auto, p 48.
[58] Australian Greenhouse Office (2003) *Reference Manual – Commissioning*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r3.html. Accessed 14 April 2007.
[59] Ibid.

- Comprehensive motor system maintenance has several benefits, including improved operating efficiency, improved reliability, prolonged service life, reduced operating and replacement costs,[60] reduced breakdowns and downtime, opportunities to log patterns in motor system performance to identify potential improvements and predict future expenditures, and opportunities for continuous improvement.[61] Comprehensive maintenance is comprised of several tasks that are outlined on the AGO's motor systems web page.[62]
- Failed or failing electric motors can be either repaired or replaced. Many motors are repaired several times before being replaced.[63] The decision on whether to repair or replace is mainly based on the lifecycle cost of either option. Repairs, which involve rewinding the coil, cost 60-80 percent of the capital cost of an equivalent new standard efficiency motor[64] and may reduce the motor efficiency by up to 3 percent.[65]

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[60] Australian Greenhouse Office (2003) *Reference Manual – Motor and system maintenance and operation,* AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r4.html. Accessed 14 April 2007.
[61] Australian Greenhouse Office (2003) *Reference Manual – Maintenance management systems: plant inventory and records*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r7.html. Accessed 14 April 2007.
[62] Australian Greenhouse Office (2003) *Reference Manual – Motor and system maintenance and operation*, AGO, Australia. Available at http://www.greenhouse.gov.au/motors/reference/r4.html. Accessed 14 April 2007.
[63] Nadel, S. *et al* (2002) *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*, (2nd Ed), American Council for an Energy-Efficient Economy, USA, Chapter 1: Overview and Summary. Available at http://www.aceee.org/motors/ch1.pdf. Accessed 18 April 2007.
[64] Sustainability Victoria (2006) *High Efficient AC Motors FactSheet*, Victorian State Government, Australia. Available at http://www.sv.sustainability.vic.gov.au/manufacturing/sustainable_manufacturing/resource.asp?action=show_resource&resourcetype=2&resourceid=45. Accessed 16 April 2007..
[65] Genesis Automation (2005) *Energy Audit and Energy Management Training Notes*, Genesis Auto, p 47.

Optional Reading

1. DRET (2012) 'DRET Energy Efficiency Exchange Technology page – Motors and Motor Systems Energy Efficiency Opportunities'. Developed by Geoff Andrews and Dr Michael Smith (ANU). DRET EEX. Available at http://eex.gov.au/technologies/motors/opportunities/ Accessed 16 October 2012.
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Key Words for Searching Online

Motor system, electric motor, premium efficiency motor, variable speed drive, pump, fan, compressor, conveyor, chain drive, coil rewinding.