UNC GLOBAL

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

COLLEGE OF ARTS & SCIENCES

STUDY ABROAD OFFICE

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September 1, 2012

Administrative Board of the College of Arts & Sciences
Office of General Education
CB #3510
300 Steele Building
UNC-CH

Dear Colleagues:

Energy Tomorrow: An Engineering and Management Perspective

UNC-CH's Department of Physics and Astronomy, Curriculum for the Environment and Ecology, the Institute for the Environment, and the Study Abroad Office are submitting a proposal to seek approval for "Energy Tomorrow: An Engineering and Management Perspective," a summer study abroad course offered by the University of New South Wales (UNSW).

Rationale:

UNSW, located in Sydney, Australia, was established in 1949. UNSW is a member of the prestigious Australian Group of Eight (a group of leading research-intensive universities) and is renowned for Engineering, Science, Business, Design, and Law.

UNC-CH and UNSW established an undergraduate student exchange program in 1997 and have consistently exchanged an average of four students per semester. UNC-CH students also have the opportunity to study at UNSW as "non-exchange" students (and so paying UNSW tuition) for a semester or year.

In addition to these semester-long direct enrollment opportunities, UNSW has offered a number of programs for international students in the months of June and July for the past 15 years. "Energy Tomorrow: An Engineering and Management Perspective" is one of the six programs that make up the current UNSW Study Abroad Summer School (understood to refer to the northern hemisphere summer!). We seek approval for this program in order to meet the demand for energy-related classes beyond what is offered at UNC-CH.

Program Content:

"Energy Tomorrow" is a five-week program that explores energy and sustainability, with a focus on new developments in lower-emission fossil fuels, energy efficiency, renewable energy technologies, and nuclear power. The program is comprised of a combination of lectures, tutorials, laboratory work, demonstrations, site visits, computer simulations, assignments and discussion periods.

The program commences in Darwin with an orientation, several class sessions, and excursions. The program then spends three days in Melbourne for visits to a number of academically relevant sites. During weeks three and four, the program is based at the UNSW campus in Sydney for more class sessions and relevant excursions. Week five is in Cairns for the final section of the course and a field excursion to a renewable energy site.

Students are enrolled in ELEC0390, a UNSW course taught by UNSW lecturers and managed by the UNSW Global Education Office. Upon completion of the program, students receive a UNSW transcript and can earn six hours of transfer credit at UNC-CH provided they earn the equivalent of a C or better.

Contact hours include 53 hours in classroom-based lectures and 57 hours on academically related excursions with on-site lectures and discussions. The UNC-CH Study Abroad Office's calculation for contact hours allows inclusion of hours in the classroom and hours spent on related excursions provided the excursion includes academic lectures and discussions and provided the students are assessed on the material covered on the excursion. With this calculation, contact hours total 110, which exceeds the required 90 hours for six credits at UNC-CH. Additionally, the program offers optional social and cultural activities designed to introduce students to life in Australia in their free time.

Frequent question sets, a 13-18 page essay, a presentation, and a comprehensive final exam assess students on material covered in class, on excursions, and through independent research.

Attached is a course syllabus from the 2012 program that provides more details.

Enrollment:

The program enrolls between 20-30 participants, and enrollment is capped at 32 to ensure appropriate student participation and a hands-on approach to learning. UNSW requires that applicants are enrolled in a recognized higher education institution and have a minimum cumulative GPA of 2.8.

On-site logistics:

UNSW faculty and staff will provide support to participants for the duration of the program.

The program fee includes tuition, accommodation, excursion costs, airport shuttle services, orientation programs, USB modem hire, a UNSW student card allowing access to all UNSW facilities, all meals when camping in Kakadu National Park, breakfast in Cairns, and breakfast and lunch in Sydney.

Students will be housed in a variety of accommodation styles when travelling, including shared, budget-style accommodation, one night camping, single dorm rooms, and shared hotel rooms.

Safety:

Australia is a modern nation with a standard of living and level of medical care on par with US standards.

The UNSW Global Education Office reviews and ensures safety and security measures for the program and is available 24/7 to respond to emergencies. The following are components of the UNSW safety and security measures: The "Critical Incident Pathway" dictates the communication and action taken in emergency situations. Risk assessments are conducted prior to all excursions and field trips related to the program. And students are provided with emergency contact details for all program locations.

Students have access to medical facilities at all destinations throughout the program. UNSW distributes details of each city's medical center and major hospital to the students. While camping in Kakadu National Park, all program guides have access to satellite phones and can be in contact with the major hospital in Darwin in an emergency. There is an aerial access point and Medical Center in the main township Jabiru in the park.

Additionally, the UNC-CH Study Abroad Office will enroll all UNC-CH student participants in full medical and accident international insurance through HTH Worldwide for the duration of the program.

We are happy to provide any further information that you may need to evaluate this proposal.

Yours sincerely,

Chris Clemens
Chair: Department of Physics and Astronomy

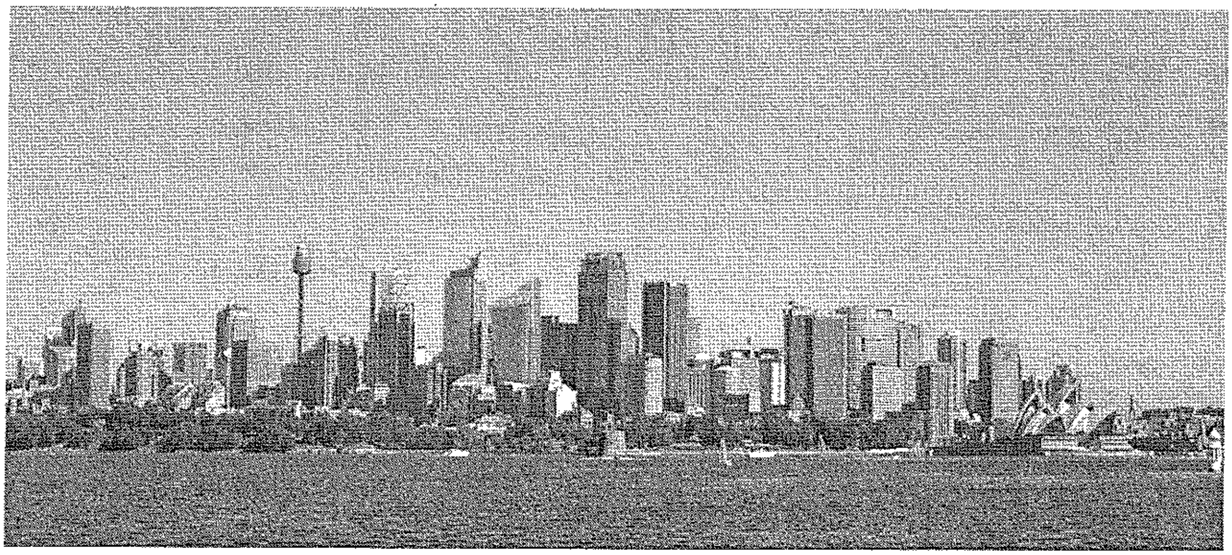
Date 8/24/2012

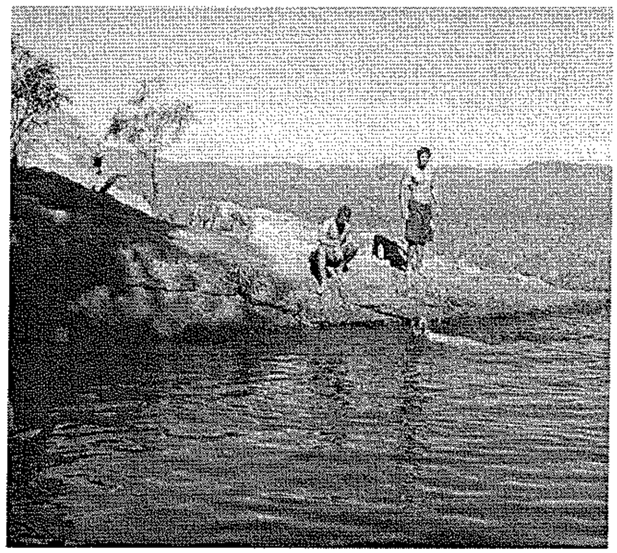
Jaye Cable
Chair: Curriculum for the Environment and Ecology

Date 8/29/12

Bob Miles
Associate Dean: Study Abroad and International Exchanges

Date 8.30.12





UNSW

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · CANBERRA · AUSTRALIA

ELEC0390
Energy Tomorrow: An Engineering and Management Perspective

Global Education Global Networks Global Opportunities

UNSW Study Abroad
Summer School 2012
15 June - 19 July

UNSW Study Abroad
The University of New South Wales
Sydney NSW 2052 Australia

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Email: studyabroad@unsw.edu.au

CRICOS Provider No. 00098G

Contents

Course Syllabus

Energy Tomorrow: An Engineering and Management Perspective

Course Code: ELEC 0390

This five-week course for engineering students explores energy and sustainability, with a focus on new developments in lower-emission fossil fuels, energy efficiency, renewable energy technologies and nuclear power. The program is based on a 75-hour combination of lectures, tutorials, laboratory work, demonstrations, site visits, computer simulations, assignments and discussion periods.

The University of New South Wales is recognized as the top university for energy R&D in Australia with many of the research groups among the world leaders in their field.

Various UNSW lecturers will cover the following topics:

Energy and Sustainable Development

Our society's energy systems have a critical role to play in driving sustainable development. Key sustainability drivers are energy poverty in the developing world, energy for social welfare and development and the environmental harms of present energy systems. We consider three key issues:

The current status of global energy systems

This topic examines the current status and present international outlook for both traditional and renewable energy sources; energy, economic growth and the environment, implications of the international climate negotiations; and structural change in the electricity supply industry.

Sustainability challenges and options

This topic will consider the current status and trends of existing energy systems with regard to the three sustainability drivers of energy poverty, social welfare and development, and environmental impacts.

A sustainable 'energy services' paradigm

This topic describes an 'energy services' model for designing sustainable energy systems that are highly energy efficient and use cleaner fossil-fuel and renewable energy sources. There is a particular focus on sustainable energy technology innovation.

Energy and the Built Environment

Energy use in buildings, domestic and commercial; sustainable architecture; thermal comfort; passive design; energy performance modelling; building systems; HVAC and lighting in buildings. Computer simulations are used to highlight the effects of various design techniques on energy usage – glazing of windows, thermal storage, insulation, and ventilation.

Energy Storage

Energy storage systems include electrochemical, chemical and thermal. The principles of electrochemical energy systems and fundamentals of electrochemistry, secondary batteries and fuel cells are considered. The latest advanced batteries for stationary and mobile applications, including the vanadium redox flow battery, sodium sulphur, zinc-bromine, sodium metal chloride and nickel-hydride are discussed. Laboratory work includes battery design, testing and performance calculations.

Energy and the Process Industries

Process industries form the basis of modern society and will continue to play a major role. Research initiatives worldwide have paved the way for advancing the development of sustainable processes. Energy efficiency and waste utilisation are some of the key features of many of the sustainable processes that will be discussed.

Renewable Energy technologies

This topic will cover the key renewable energy sources for sustainable energy systems:

Biomass

Considers biomass and agricultural wastes in the production of alternative fuels. Ethanol production technology, from both yeasts and bacteria including genetically engineered micro-organisms (GMOs) and all the issues that this raises for large-scale ethanol production; methane via biogas technology; and other fuels via pyrolysis and combustion.

Photovoltaic Devices and Systems

Will examine the basics of converting sunlight into electricity; the behaviour of solar cells; cell properties; system components; applications; grid connection; system design, including for RAPS (remote area power supply) applications. Experimental work will be carried out at the Photovoltaic Centre teaching laboratories where there are operating PV systems connected to the grid, solar pumping systems and where development work has taken place on the solar powered car.

Wind Energy

Will describe the components of a wind turbine; examine the interaction of wind and rotor; consider fatigue; and examine the process of electricity generation and supply to the grid (wind farms).

Emerging Energy Technologies

There are a number of highly promising but, as yet, commercially unproven energy technologies which may play a very important role in our future energy systems over the longer term. We focus on emerging Carbon Capture and Storage (CCS), geothermal, solar, Generation III and proposed Generation IV nuclear power plants and hydrogen technologies

Assessment

Students are required to attend all lectures and tutorials and to complete all assessment tasks. Failure to do so without legitimate reason will result in failure to graduate from the course.

Students will be assessed throughout the program. The assessment is in three parts:

(1) Most units of the program will have some form of assessable activity. Questions will be assigned from the readings and class work.

(2) Essay and oral presentation. Students will be assigned in week one to small groups, to work on a project specifically in one of the topics covered by the course. Students will write a report to be completed by week four and also make a short verbal presentation on the project.

(3) Final examination. A multiple-choice exam covering all course work will be given in the final week of the program.

All marking will be in accordance with the UNSW scale:

Fail	<50%
Pass	50-64%
Credit	65-74%
Distinction	75-84%
High Distinction	>85%

An international grade equivalence sheet will accompany the official UNSW transcript when mailed to the student following completion of the program.

Textbooks

A handbook of notes will be provided.

Course Information

Energy Tomorrow: An Engineering and Management Perspective is one of six programs that make up the UNSW Study Abroad Summer School in 2012. Each program has approximately 20-30 participants and all travel a similar itinerary within Australia with some having a course-specific field trip in week three or five. Generally, all groups will be staying at the same destination at approximately the same time, however programs will break up into their individual groups for classes and field excursions.

Location

The program commences in **Darwin**, in Australia's 'Top End'. While based in Darwin there will be a two-day camping expedition into **Kakadu National Park**. Crocodiles, Aboriginal art sites and spectacular scenery are some of the highlights of this field trip.

On the way to Sydney from Darwin we make a three-day stop in **Melbourne** which will include visits to a number of acedmically relevant sites.

For weeks three and four, the program will be based at the campus of The University of New South Wales (UNSW), located 20 minutes from downtown **Sydney** and within walking distance from the beachside suburb of Coogee.

Week five will be on location in **Cairns** for the final section of the course and a field excursion to a renewable energy site. This will leave a few days at the end of the course to relax and participate in the wide range of activities available.

Program length

The course consists of 75 hours of class contact time over five weeks, and is comprised of lectures, laboratory work and related excursions. The program is valued at the equivalent of 6 units of credit at UNSW; and is the international equivalent of 6 or 8 units of credit, subject to home institution policy.

Program fee

The program fee includes:

- tuition
- all accommodation
- all meals in Kakadu National Park
- breakfasts in Melbourne
- breakfasts and lunches in Sydney
- breakfasts and a final program dinner in Cairns
- all excursion travel and entry fees
- orientation program and airport shuttle services
- Internet device
- UNSW student card (allowing access to all UNSW facilities).

Please note: Other meals and airfares are not included in the program fee.

Summary of Course Itinerary

Darwin and Kakadu

Date	Time	Activity
Wednesday 13 June	11.20pm	Depart Los Angeles on QF 16 to Brisbane
Friday 15 June	6.10am	Arrive Brisbane
	9.15am	Depart Brisbane on QF 824 to Darwin (from Domestic Airport)
	12.55pm	Arrive Darwin Met at Darwin International Airport by UNSW Summer School staff and taken to accommodation Staying at: Melaleuca on Mitchell Backpacker 52 Mitchell St Darwin, NT 0801 Australia Ph: +61 8 8941 7800 Fax: + 61 8 8941 7900 http://www.momdarwin.com/
	3.00pm – 4.00pm	Collect course materials
	4.30pm – 6.00pm	Orientation and introduction of academic staff
	6.00pm – 7.30pm	Welcome Reception
Saturday 16 June	1.00pm – 4.00pm	Class: Course Introduction
Sunday 17 June	AM	Excursion
	1.00pm – 4.00pm	Class: Photovoltaic Devices and Systems I
	Evening Activity	Mindil beach markets
Monday 18 June	1.00pm – 4.00pm	Class: Photovoltaic Devices and Systems II
Tuesday 19 June	1.00pm – 4.00pm	Class: Energy and Environmental Implications
Wednesday 20 June - Thursday 21 June		2-Day Field Trip to Kakadu National Park
Friday 22 June	1.00pm – 4.00pm	Class: Energy and Sustainable Development I
Saturday 23 June	9.00am – 1.00pm	Excursion
	1.00pm – 4.00pm	Class: Energy and Sustainable Development II
Sunday 24 June	12.45pm	Depart Darwin on QF839 to Melbourne

Melbourne

Date	Time	Activity
Sunday 24 June	5.15pm	Arrive Melbourne and transfer to accommodation
Monday 25 June	9.00am - 5.00pm	Field Trip: PV Facilities and/or Windfarm
Tuesday 26 June	9.00am - 1.00pm	Field Trip: TBA
Wednesday 27 June	1.00pm	Depart Melbourne on QF434 to Sydney

Sydney

Wednesday 27 June	2.25pm	Arrive Sydney and settle into UNSW dorms
Thursday 28 June	9.00am - 12.00pm	Class: Energy and the Process Industries
Friday 29 June	9.00am - 12.00pm	Class: Energy Storage I
Saturday 30 June to Sunday 1 July		Free days
Monday 2 July	9.00am - 12.00pm	Class: Energy Storage II
Tuesday 3 July	9.00am - 12.00pm	Field trip: Ausgrid Energy Efficiency Centre, Silverwater
Wednesday 4 July	9.00am - 12.00pm	Class: Energy Efficiency I
Thursday 5 July	9.00am - 1.00pm	Field trip: OneSteel Plant
Friday 6 July	9.00am - 12.00pm	Class: Energy Efficiency II
Thursday 7 July	9.00am - 1.00pm	Class: Wind Energy
Friday 8 July	9.00am - 12.00pm	Class: Emerging Energy Technologies
Saturday 7 to Sunday 8 July		Free days
Monday 9 July	9.00am - 12.00pm	Class: Energy and the Built Environment
Tuesday 10 July	9.00am - 3.00pm	Class: Introduction to energy from agricultural resources and related biotechnology principles
Wednesday 11 July	9.00am - 12.00pm	Group Presentations

Cairns

Thursday 12 July	9.15am	Depart Sydney on QF 924 to Cairns
	12.25pm	Arrive Cairns and transfer to accommodation Staying at: Rydges Esplanade Resort Cnr The Esplanade and Kerwin Street, Cairns Queensland 4870 Phone: +61 7 4044-9000 Fax: +61 7 4044-9001 http://www.rydges.com/hotel/0/RQESPL/Rydges-Esplanade-Resort-Cairns.htm
Friday 13 July		Free day
Saturday 14 July	7.30am - 4.30pm	Field trip: Biomass site
Sunday 15 July	9.00am - 1.00pm	Class: Biomass Energy
Monday 16 July	10.00am - 11.00am	Final Exam
	7.00pm	End of Program Dinner
Tuesday 17 to Wednesday 18 July		End of academic program Relax in Cairns Optional trips to Great Barrier Reef diving/snorkelling, white water rafting, bungy jumping and skydiving.

Thursday 19 July	5.30am	Depart Cairns on QF 799 to Brisbane (ETA 7.30am, Brisbane International Airport)
	10.55am	Depart Brisbane on QF 15 for Los Angeles (ETA 7.00am, 19 July)

Note: Both this itinerary and accommodation are subject to change

Cultural and Social Activities

During your stay in Australia, UNSW Study Abroad will be coordinating a range of cultural and social activities for you to do in your free time. These are optional. UNSW Study Abroad offers all activities at cost price. Students will be given the opportunity to sign up for these activities upon arrival in Darwin and again in Cairns.

Below is a list of some of the activities that may be offered. Prices are given in Australian dollars (US$1.05 = A$1.00 - September 2011) and are based on 2011 prices, so are subject to change.

Darwin

Sailing on the harbour afternoon	$60 - $80
Cinema evening	$12
Fish feeding	$10

Cairns

Day on the Great Barrier Reef	$165
White water rafting day	$140
Day trip to the Daintree Rainforest	$110
Skydiving	$270 - $300
Bungy Jumping	$100

Sydney

Blue Mountains Day Trip	$99
Two-hour "Learn to Surf" lesson at Bondi Beach	$55
Ticket to a Rugby League game	$16
Ticket to an Australian Rules game	$22
Symphony at the Sydney Opera House	$40 - $65
Opera at the Sydney Opera House	$80 - $95
A play/musical in Sydney	$40
Sydney Harbour Bridge Climb	$200 - $300
Wine Tasting trip to the Hunter Valley	$99
Overnight stay at Taronga Zoo on Sydney Harbour	$150

Contact Details

Program Convenors

The program convenors for the UNSW Study Abroad Summer School are Clare Mander, Tom Küffer and Nick Dowd. They can be contacted on:

Clare Mander
Program Coordinator
UNSW Study Abroad Summer School
Ph: +61 2 9385 1656 / mobile 0415 033 101
Email: c.mander@unsw.edu.au

Tom Küffer
Program Coordinator
UNSW Study Abroad Summer School
Ph: +61 2 9385 3178 / mobile 0412 894 282
Email: t.kuffer@unsw.edu.au

Nick Dowd
Senior Short Course Manager
UNSW Study Abroad Summer School
Ph: +61 2 9385 1445 / mobile 0414 262 214
Email: n.dowd@unsw.edu.au

Fax: +61 2 9385 1265

Contacting Students

At any time during the program students can be reached by mail at the following address:

Student's Name
c/o UNSW Study Abroad Summer School
UNSW Study Abroad Office
Level 16, Mathews Building
The University of New South Wales
Sydney NSW 2052
Australia

Messages can also be left for students using the contact details above for Clare or Tom.

Hotel/hostel contact details appear in the Course Itinerary section of this pack. They are, however, subject to change.

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

Prof. Gerald Cecil
The University of North Carolina at Chapel Hill
Department of Physics and Astronomy
College of Arts and Sciences

CB 3255, Phillips Hall
Chapel Hill, NC 27599-3255
(919) 962-7209

March 18, 2013

Study Abroad Advisory Board

Dear Board members,

Emily Marlton asked me to explain why I think that the UNSW program fills an important gap at UNC, why it lacks a textbook, and why the sample assigned readings are appropriate. I'm happy to do so.

It definitely fills a void. Here energy is introduced ad hoc in the occasional freshman seminar offered by physics and chemistry professors who recognize that the ongoing energy transition is a defining phase of our civilization, and as a policy — not technical — problem in our Environmental Sciences program. It is also the subject of PHYS/ENST/MASC/GEOL/PWAD 108, which has been team taught by 3 professors for several years. In most of these UNC classes energy specific calculations are introduced at various levels of rigor, but the technology is not reviewed in a sophisticated or practical manner to consider how various options scale in both the developed and developing world. I occasionally teach PHYS 131 to detail the technology and physics of energy in more depth than most non-science majors wish to handle. All of our energy courses are "feeders" to advanced treatments that have we have yet to offer! For example, we have two capstones to our physics BA in energy that we cannot teach because of manpower constraints. The UNSW program straddles our introductions and capstones. It delves into practicalities of various energy systems, including trade-offs of using current technology, and visits installations of alternatives such as wind farms that do not exist in NC because most of our power generation is based in stodgy monopolies that aim to maximize shareholder value not longer-term societal benefit.

In my experience, standard energy texts are rarely both precise and passionate. College-level ones trend toward dry engineering texts. Most of the rest seem to be rants. There are only a couple, e.g. *Renewable Energy Without the Hot Air* by McKay, that provide adequate technical background then guide students to think critically about the myriad implications of our energy use. Few dwell on the underlying reason for our unfolding energy/environmental crises: the flat supply of petroleum is constantly bumping into the mobility aspirations of the growing human population in tension with the developed world's inefficient usage patterns. Instead we hear about how e.g. hydro-fracking is a novel game changer (it isn't, it has become viable because of sustained expensive oil caused by scarcity. Those wells will be dry within 5 years), how electric vehicles will soon wean us off petroleum (only if people accept that for the next $\sim$20 years EVs will cost twice what cars do today in current dollars or have short range), and how CO_2 sequestration will solve global warming (it can't from basic thermodynamics and because we generate so much of this waste product).

"Sources" are mostly technical in this subject because it takes considerable background for students to start thinking critically on energy and the impracticality/downsides of scaling up use of our various options. “Original sources” covering the development of energy systems are not particularly interesting because the physics was worked out a century or more ago. It's now all about getting costs of alternatives down with often subtle tweaks while maintaining their ability to scale, both engineering problems.

I reviewed some of the UNSW PDFs and found that they cover topics deeper and at a higher technical level than we do here, yet link to societal choices often by case studies. For example, the UNSW paper on carbon sequestration provides the background context of the issue then examines how to do it and at what cost. This analysis regularly eludes e.g. columnists in the New York Times and Wall Street Journal. There are many references to technical reports in its bibliography that have been chosen carefully and presumably will be assigned. They would make for many stimulating discussions, at a more advanced level than we have at UNC.

Overall the material suggests that this will be a high value program, providing insights that students will not get here or at e.g. NCSU on a broad range of energy topics.

Professor of Astrophysics

Energy Tomorrow

Energy and Sustainable Development

Contents

Introduction

Much of the journey of human development to date has been shaped by our growing expertise in harnessing and transforming new forms of energy to extend our capabilities. Readily available and affordable energy has given many of us near unprecedented material comfort, mobility and opportunity. Energy also has a key role to play in further progress – particularly for the two billion energy poor people amongst us.

The energy systems that support this, however, seem almost certain to have to change. Energy plays a key role in just about every thing that we do so it can be expected to have adverse impacts. Unfortunately, our society's present energy systems appear to have such severe environmental outcomes as to threaten our collective future.

The role of energy in sustainable development therefore is twofold

- Adequate energy to meet our needs and enable ongoing human development and welfare
- The creation of energy systems that don't threaten the prospects of future generations or the integrity of our ecosystem.

Of course, we don't want energy itself, but instead the services that it can provide – food, light, comfort, materials, mobility and communication. The question then is how best to meet these 'energy services' needs.

Engineering is, in essence, the practical application of scientific knowledge *through a systematic process of designing, creating and operating socio-technical systems* in order to meet practical human needs. Energy engineering is therefore the process of developing socio-technical energy systems to deliver necessary energy services for our society.

This unit will first focus on the role of engineering in our energy systems, the energy services our society requires, and the present energy systems – resources, conversion chains and end-use equipment – that are delivering these services. We will then explore the environmental and other sustainability related impacts of our present energy systems, and what if anything can be done to address these problems.

Engineering

The definition of engineering that we will use is *the practical application of scientific knowledge through a systematic process of designing, creating and operating socio-technical systems in order to meet practical human needs.*

Key themes

The three key themes identified in this definition are

- the stated objective of improving societal welfare
- the use of scientific knowledge; certainly knowledge of physics, chemistry, biology, mathematics but also that of the social sciences
- engineering as the practical and systematic application of such knowledge through technology to meet these societal objectives, subject to a range of constraints.

The focus is on meeting practical societal needs with due consideration to the wide possible range of constraints on this task; constraints such as environmental impacts.

Systems methodology

The engineering methodology is required to solve complex and ill-defined community problems which generally don't have unique correct solutions. The answer is to use a 'systems' approach.

A system is a *"...collection of interrelated and interacting components that work together in an organised manner to fulfil a specific purpose or function."* (Dandy and Warner, 1989).

Engineering deals with complexity by breaking the work into fairly autonomous tasks that can be planned and executed largely separately. It's a powerful approach but note the great care required when creating and executing these sub-components. They have to be brought smoothly back together as a complete system that achieves overall system objectives.

It is still unavoidable that the resulting socio-technical systems in our society are complex and not always fully understood, often involving

- many physical components
- many human operators or users
- potential 'emergent' behaviour that is not fully predictable from knowledge of component behaviour.

Engineering process

A process is defined as an activity executed progressively in time. The process or methodology of developing engineering systems can be broadly categorised as (Dandy and Warner, 1989 Chapter 2)

- define the problem clearly – poor problem definition is the cause of many well engineered but poorly targeted system designs
- generate a range of feasible options – its important to explore different possible ways to solve a problem, and the tradeoffs required.
- identify the best of these approaches, and undertake detailed design and planning of a solution
- implementation.

Top-down engineering focuses on overall system objectives, feasible options and the system compromises required in choosing the best approach. **Bottom-up** engineering is focused, instead, more on the sub-systems (and their sub-systems) - their detailed design and implementation. Each is essential, and informs the other.

Some of the major tools in generating options and designing solutions are

- modelling – creating representations of the physical system which allow us to explore the behaviour of the real system
- analysis – the use of models to explore and predict the behaviour of the system under different conditions
- optimisation of system performance to clearly defined goals. Note that optimisation of a system is unlikely to be achieved by independent optimisation of each sub-component because of the interactions between them – this is known as 'error of sub-optimisation'.

Energy systems

In the context of energy systems, the three key engineering themes are

- meeting people's energy needs in the context of wider societal objectives like sustainability - considered through the concept of 'energy services'
- the essential scientific knowledge that frames the provision of energy services – available energy resources and the process of energy conversion
- the systematic design, creation and operation of our energy systems – energy technologies yet, importantly, also the larger integrated 'infrastructure' systems in which these technologies reside.

The key engineering process themes with respect to energy systems are

- the proper definition of the energy services these systems are required to meet: The problem definition for energy systems is often misrepresented in terms of energy supply and use. Also, wider societal objectives appear to be shifting with our growing awareness of environmental issues.
- the development of a range of feasible energy systems options; In particular, our extensive existing energy infrastructure frames many of our short-term options but the potential of numerous new technologies is very great.
- identification and consequent implementation of our best energy system options with regard to both our energy service requirements, yet also the wider environmental, social and economic impacts of different options.

Energy fundamentals

Energy types

A 'physics' based definition for energy is

> (n) the capacity of a physical system to do work WordNet (2002)

One common classification framework for the different forms of energy available is

- mechanical – including the kinetic energy of mass in motion and the potential energy of mass displaced in some type of force field; eg gravity
- heat (thermal) – the kinetic energy of molecules in a material as indicated by the material's temperature;
- electrical – energy in the movement of electrons under the influence of an electrical field;
- light (radiant) – a pure form of energy in the form of photons;
- chemical - a form of microscopic potential energy, which exists because of the electric and magnetic forces within different types of molecules.
- nuclear - the energy within atoms that arises from the structure of their nuclei. With fusion, small nuclei fuse (combine) together to make larger nuclei while releasing energy; with fission, large heavy elements split apart into smaller nuclei, also releasing energy. In both cases, some of the nuclei matter is actually converted into energy in accordance with that famous law $E=MC^2$.

Energy transformation

There are two broad categories of energy – stored (potential) energy and working (kinetic) energy, i.e. energy in use. Energy transformation is the key to energy systems – the types of energy (hence work) that our society requires as energy services are

- derived from a range of different energy sources
- delivered through a range of often different energy forms, and
- provided to users in yet other forms.

There are two fundamental scientific 'laws' that govern the inter-relation between heat, work and internal energy of a system.

> **First Law of Thermodynamics**: Energy can be changed from one form to another, but it cannot be created or destroyed. The total amount of energy and matter in the Universe remains constant, merely changing from one form to another. The First Law of Thermodynamics (Conservation) states that energy is always conserved..
>
> **Second Law of Thermodynamics**: In all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state. This is also commonly referred to as entropy.
>
> Maricopa (2002)

In more straightforward terms

> **Rule 1**: You cannot win (that is, you cannot get something for nothing, because matter and energy are conserved)
>
> **Rule 2**: You cannot even break even (you cannot return to the same energy state, because there is always an increase in disorder; entropy always increases)
>
> (from the British scientist and author C.P. Snow)

These laws define the framework of what is possible in our society's energy systems. We can't create energy; we can merely transform it between its different forms. Also, we can't generally achieve complete transformation of one energy form into another desired and useful form – there will be energy losses at each step. The key concept of efficiency relates to the magnitude of these losses through the various conversion stages of an energy system from supply through to use.

Energy Units

A fixed and widely agreed system of units plays a key role in all forms of communication, including that in science and engineering. There is a wide range of different units for energy and power – many reflecting historical precedent (eg horsepower), cultural origins (eg BTU or British Thermal Units) or convenient reference to particular energy sources (eg MTOE or Megatonnes of Oil Equivalent).

The French metric system was officially launched in 1799 with the declared intent of being 'for all people, for all time'. Le Systeme International d'Unites (SI notation) is derived from the metric system and officially arrived in 1960. It has been adopted by nearly all countries including Australia. The US is a notable exception.

The basic SI units of length (meter), weight (kilogram), force (newton), temperature (Kelvin) and time (second) give us derived units for

- energy - Joule (J)
- power – Watt (W) or 1 Joule per second

The SI notation uses prefixes to manage the great range of energy and power magnitudes that we are interested in ranging from global energy consumption to the power requirements of individual electronic circuits.

yotta [Y] 1 000 000 000 000 000 000 000 000= 10^24

zetta [Z] 1 000 000 000 000 000 000 000= 10^21

exa [E] 1 000 000 000 000 000 000= 10^18

peta [P] 1 000 000 000 000 000= 10^15 - eg. PJ yearly global energy use

tera [T] 1 000 000 000 000 = 10^12

giga [G] 1 000 000 000 - eg. GW of Australian generation capacity

mega [M] 1 000 000 - eg. MW rating for coal fired power stations

kilo [k] 1 000 - eg. KW power rating for car engines

Note that 10^x means 10 to the power x

Convenience still plays a major role in commonly used units, eg. the electricity industry favours KWh and MWh units for energy since generators have KW and MW power ratings.

(RCC, 2002)

Energy Conversions

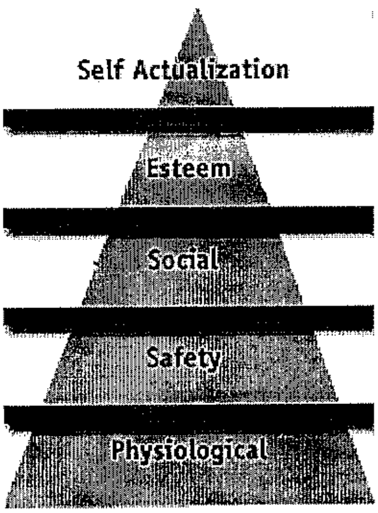
1 British thermal unit (Btu)	=	one match tip
	=	250 cal
	=	0.25 Cal
10 kilocalories (Cal)	=	One peanut
	=	10,000 calories
	=	41,900 joules
1,000 Btu	=	Two 5-ounce glasses of table wine
	=	250 Cal
	=	about 80% of a peanut butter and jelly sandwich
1 million Btu	=	90 pounds of coal
	=	120 pounds of dried hardwood
	=	8 gallons of gasoline
	=	10 therms of dry natural gas
	=	11 gallons of propane
1 barrel of crude oil	=	5,600 cubic feet of dry natural gas
	=	0.26 ton (520 pounds) of coal
	=	1,700 kilowatts of electricity
1 ton of coal	=	3.8 barrels of crude oil
	=	21,000 cubic feet of dry natural gas
	=	7,680 kilowatt-hours of electricity
1 quad (Q)	=	293.17 trillion kilowatt-hours
	=	171.5 million barrels of crude oil
	=	41.7 million tons of coal

Exercise 1

Estimate the distance you might be able to run a car on your typical daily food intake (say 2000 Kilocalories).

Energy services

Our understanding of human needs and motivations remains limited despite considerable work. The Maslow hierarchy of human needs is one possible model. It suggests that the most important needs are physiological; food, water and shelter. Once these are satisfied, safety and security needs are next followed by our social needs, esteem and finally self actualization.



(Accel-team, 2002)

A number of energy systems are required to deliver these services. Food supply, for example, is an energy system. Our individual daily energy (food) needs are around 2000-3000 Kilocalories. However, food often needs to be cooked. Many foods need processing and this takes energy – eg grinding flour. And food has to be transported from where its grown to where its consumed.

Task	Energy consumption
Daily food needs per person	8.4 MJ / day
Firewood for cooking and heating per rural household	80-100 MJ / day

(UNDP, 2002; Chapter 3)

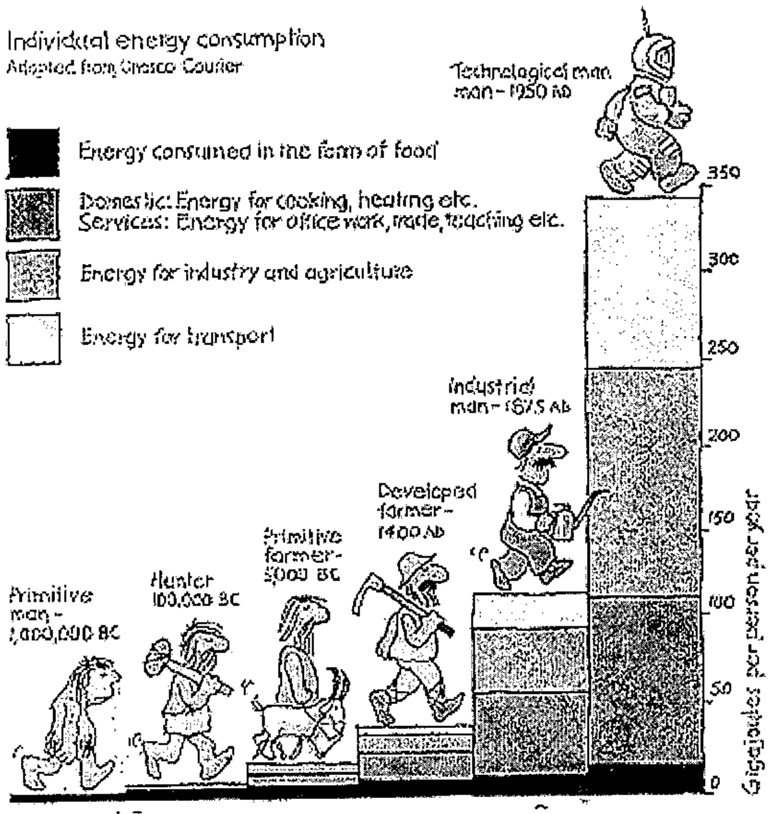
Consideration of energy services for our needs beyond the merely physiological is even more challenging. For example, shelter and mobility serve safety, social and, for many people, even esteem and self-actualisation needs.

We will use two case studies to briefly consider four key issues in understanding energy services:

- the enormous growth, and growing worldwide inequality, in many types of energy services
- the wider context in which society makes decisions about energy services
- how our understanding of energy services are complicated by the widely varying efficiency of the energy systems that currently deliver them and the embodied energy in materials that we use
- the role that new technologies can play not only in helping to deliver desired energy services, but shaping what we consider these needs to be and, in some cases, the entire structure of our society

The two case studies are on mobility and buildings. Both are major contributors to our individual energy consumption as seen in the figure below. Note also that a significant proportion of the 'energy for industry and agriculture' sector gets embodied in materials that we use for transport and buildings.

Keep in mind that not everyone gets to be 'technological man'. According to the WorldBank (2002) high income countries make up 15% of the world's population yet use 50% of the world's commercial energy and 10 times as much per capita as low income countries.



Case study - mobility

This first case study considers mobility. The Cambridge Dictionary considers mobility *"the ability to move freely."* Here, we will consider it the movement of people, their goods and ideas.

By all these measures, the last century has been one of more and faster mobility. The OECD's project on environmentally sustainable transport reports that the motorized movement of people and goods both increased more than one hundredfold over the last 100 years, while our population merely quadrupled. The pace of this travel leapt as well, and in surprising ways. Car sales worldwide went up from some 4000 to now 55 million annually over the century. Powered aircraft flights rose from four in 1903 -all on December 17- to eighteen million in 1998. The average US citizen now travels nearly 30,000 kilometres a year. Note, however, that not all travel options have similarly prospered; its estimated the average distance people walk or cycle each year has fallen by a third over the last century.

Mechanised transportation is now responsible for some 30% of energy use in industrialized countries – perhaps 37% if indirect energy used in vehicle production and transport infrastructure is included.

The accelerating mobility of ideas is, if anything, even more astounding. One in thirteen US households had a telephone in 1900. It took 23 years from 1923 for radios to appear in 90% of US households, only fifteen years from 1948 for televisions to do likewise and its now predicted that home internet will likewise arrive in around 2003.

Exercise 2

There has been extraordinary growth in per capita use of mechanised transport over the last 150 years as shown in the Figure below. How do you imagine these trends might have changed over the last decade (consider issues such as globalisation, amazon.com, SouthWest airlines, the recently expanded airport in Anchorage, Alaska etc)?

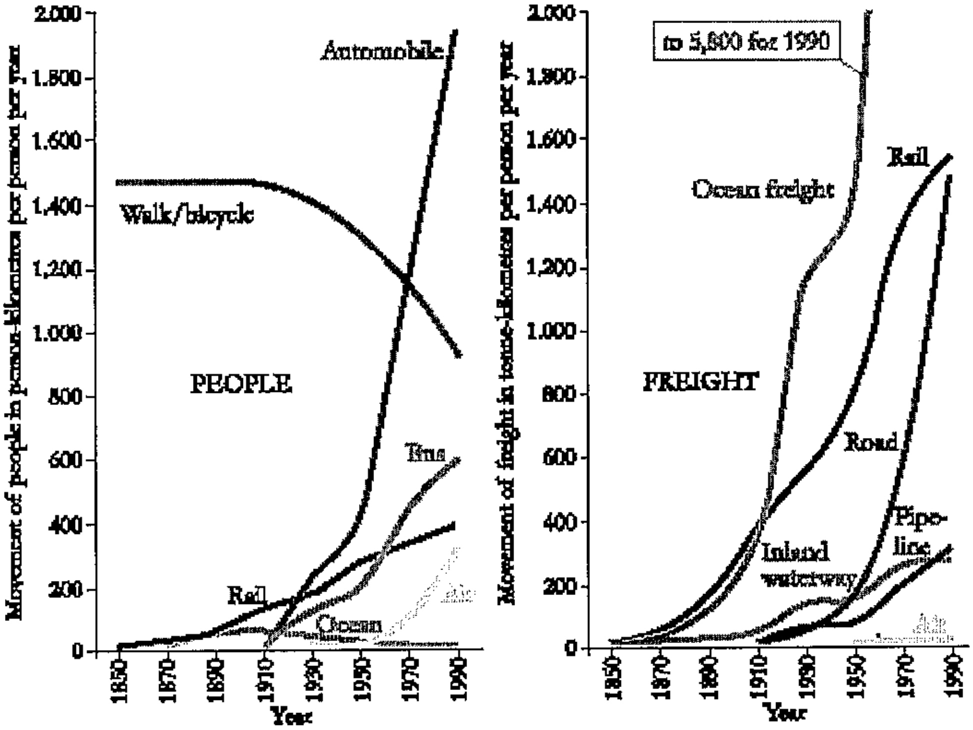


Figure 1. Worldwide per-capita movement of people and freight, 1850–1990

Source: Centre for Sustainable Transportation (Ref. 5)

Case study – buildings

It has been estimated that most Australians spend about 90% of their time in buildings (Environment Australia, 2001). In the industrialised world, buildings are estimated to account for some 42% of society's total energy use. This includes both direct energy use (eg lighting, heating and equipment) and the energy embodied in the materials that the building uses (ISR, 1998).

Building end-use energy services of lighting, cooking, heating (water and space), cooling, refrigeration and appliances can be clearly identified. Note, however, that the relative energy consumptions often presented don't directly represent the energy needs of these services. These proportions depend on the energy source and efficiency of the energy systems currently providing the service.

Consider, for example the task of lighting a standard room – a task that requires around 10W of radiant energy.

Lighting options:	energy source	Approx. energy required
Incandescent globe	electricity	100W (10% efficient wrt electricity)
Compact fluorescent	electricity	25W (40% efficient wrt electricity)
Incandescent globe	Electricity – considering full supply chain	Approx 300W (coal fired electricity is approx 35% efficient (3% efficient wrt coal)
Kerosene lantern	kerosene	530W (2% efficient wrt kerosene)

Exercise 3

There are obviously better, and worse, energy systems for delivering particular services into buildings. There is a potentially even greater problem with using energy consumption tables like that above to analyse the delivery of energy services. What is it? (hint – think of all the possible energy flows into a building)

____

____

____

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____

____

____

What is embodied energy?

There are two forms of embodied energy in buildings:

· ***Initial embodied energy;*** and
· ***Recurring embodied energy***

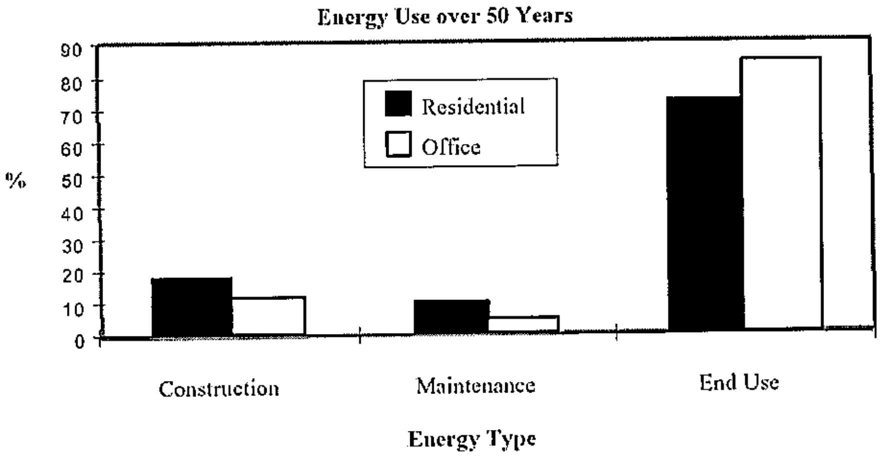
The ***initial embodied energy*** in buildings represents the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction. This initial embodied energy has two components:

Direct energy the energy used to transport building products to the site, and then to construct the building; and

Indirect energy the energy used to acquire, process, and manufacture the building materials, including any transportation related to these activities.

The ***recurring embodied energy*** in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building.

Some New Zealand estimates of embodied versus operating energy consumption over a building's life are given below. Note that such calculations depend greatly on the type of building and its construction materials. Further numerous assumptions are required in such estimates so they should only be taken as a guide.



(Jaques,1996)

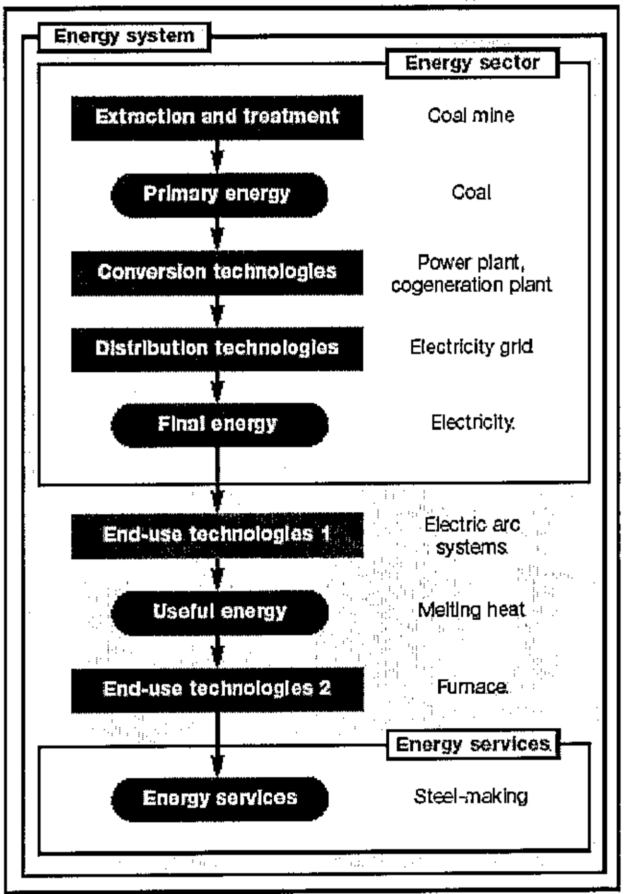
	EMBODIED ENERGY	
MATERIAL	MJ/kg	MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700
NOTE: Embodied energy values based on several international sources - local values may vary.		

(Kesik, 2002)

Energy systems

The energy systems that our society has developed to deliver its energy services are among the largest and most complex systems we have yet devised. They can be usefully modelled as

FIGURE 1. AN EXAMPLE OF THE ENERGY CHAIN FROM EXTRACTION TO SERVICES



Source: Adapted from chapter 6.

(UNDP, 2002) for all tables below unless otherwise noted.

Note that we consider the term 'energy system' to include all parts of this chain leading to the delivery of energy services. We have considered these energy services, and some of the end-use technologies that deliver them – eg cars, light globes.

We can now 'systematically' assess our present energy systems with respect to

- the energy resources available and their current usage
- energy conversion and distribution
- general end-use technologies.

Energy resources

The energy resources available for our energy systems can be broadly classified as non-renewable and renewable. The non-renewable, depletable resources were laid down at the planet's creation (eg Uranium) or over very long time periods (fossil fuels).

The outstanding feature of all fossil fuels is that they contain a lot of carbon. Coal is especially rich, with up to 95%. The others are mainly hydrocarbons, compounds of carbon with hydrogen, sometimes with other elements present, but even in these the proportion of carbon is high, around 75% or more by weight.

The earth's renewable energy resources are ongoing energy flows driven mainly by the sun (solar, wind, hydro, biomass) but also the earth's internal heat (geothermal). The potential size of these are more than three orders of magnitude greater than present global energy use.

TABLE 5.26. SUMMARY OF THE RENEWABLE RESOURCE BASE (EXAJOULES A YEAR)

Resource	Current use[a]	Technical potential	Theoretical potential
Hydropower	9	50	147
Biomass energy	50	>276	2,900
Solar energy	0.1	>1,575	3,900,000
Wind energy	0.12	640	6,000
Geothermal energy	0.6	5,000	140,000,000
Ocean energy	n.e.	n.e.	7,400
Total	56	>7,600	>144,000,000

n.e. Not estimated.
a. The electricity part of current use is converted to primary energy with an average factor of 0.385. *Source: Author's calculations from previous chapter tables.*

Nevertheless, it is fossil fuels that supply some 80% of the world's primary energy consumption, as shown below. The use of coal, has grown four-fold in the last century, oil use is up 160 fold and gas use 240 fold.

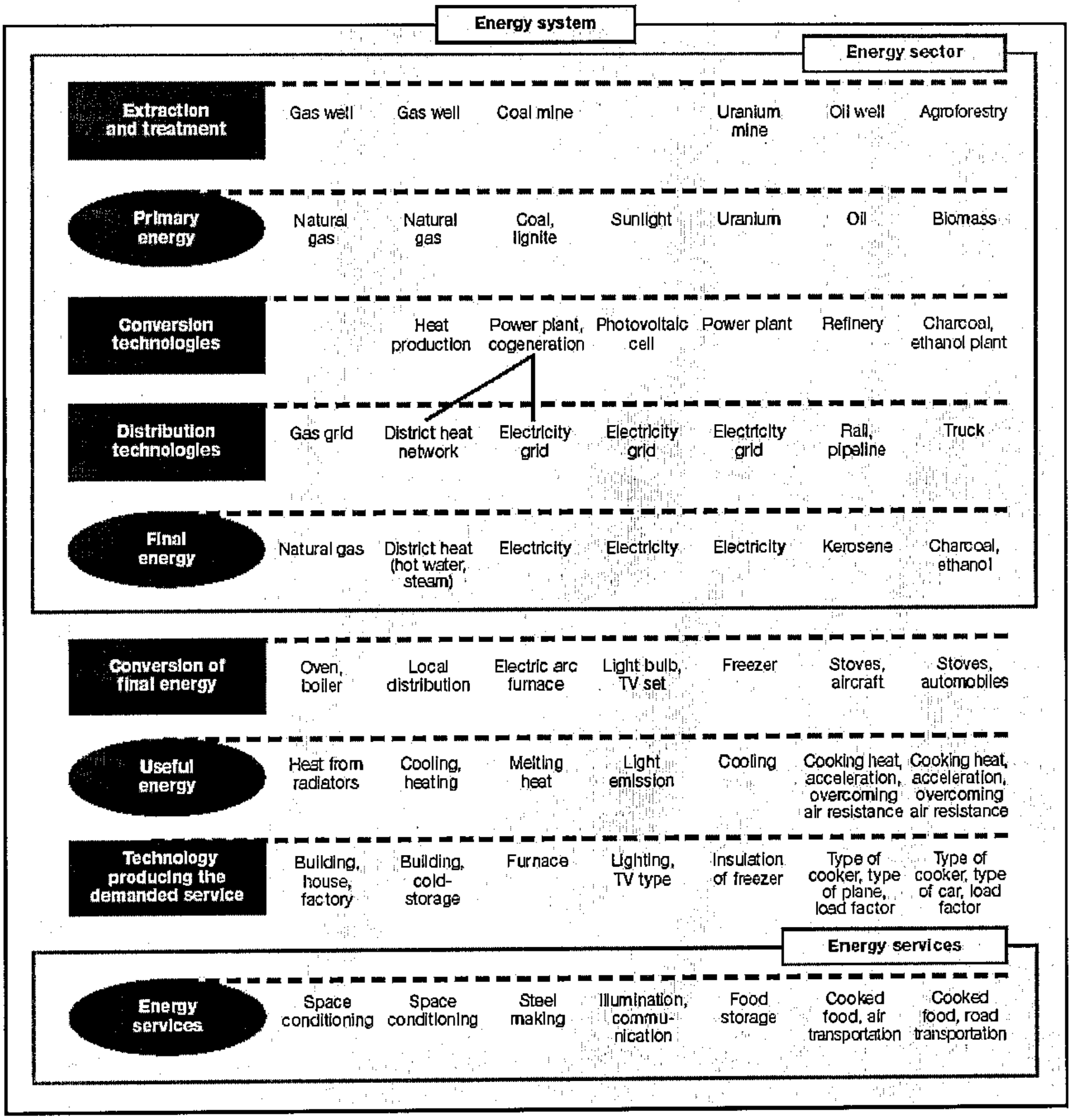
TABLE 1. WORLD PRIMARY ENERGY CONSUMPTION, 1998

Source	Primary energy (exajoules)	Primary energy (10^9 tonnes of oil equivalent)	Percentage of total	Static reserve-production ratio (years)[a]	Static resource base-production ratio (years)[b]	Dynamic resource base-production ratio (years)[c]
Fossil fuels	320	7.63	79.6			
Oil	142	3.39	35.3	45	~ 200	95
Natural gas	85	2.02	21.1	69	~ 400	230
Coal	93	2.22	23.1	452	~ 1,500	1,000
Renewables	56	1.33	13.9			
Large hydro	9	0.21	2.2	Renewable		
Traditional biomass	38	0.91	9.5	Renewable		
'New' renewables[d]	9	0.21	2.2	Renewable		
Nuclear	26	0.62	6.5			
Nuclear[e]	26	0.62	6.5	50[f]	>> 300[f]	
Total	402	9.58	100.0			

a. Based on constant production and static reserves. b. Includes both conventional and unconventional reserves and resources. c. Data refer to the energy use of a business-as-usual scenario—that is, production is dynamic and a function of demand (see chapter 9). Thus these ratios are subject to change under different scenarios. d. Includes modern biomass, small hydropower, geothermal energy, wind energy, solar energy, and marine energy (see chapter 7). Modern biomass accounts for about 7 exajoules, and 2 exajoules comes from all other renewables. e. Converted from electricity produced to fuels consumed assuming a 33 percent thermal efficiency of power plants. f. Based on once-through uranium fuel cycles excluding thorium and low-concentration uranium from seawater. The uranium resource base is effectively 60 times larger if fast breeder reactors are used. *Source: Chapter 5.*

Energy conversion

Our energy systems utilise a number of intermediate energy forms between the primary energy resource and its delivery to end-use equipment. The objectives are generally to provide energy in a form that is easier to deliver and to use in this equipment. The figure below (taken from the World Energy Assessment) illustrates some of the energy conversion paths used in our society's energy systems.



Gas requires relatively almost no transformation. It is easy to distribute through pipe networks, and straightforward to use in end-use equipment providing heat service (eg hot water, space heating, cooking.)

Electricity is clearly the most important intermediate energy form. This largely relates to the wide range of end-use equipment that can efficiently and cleanly convert electricity into a very diverse range of services. For example, electric motors are around three times more efficient than the internal combustion engine, while the growing amount of IT equipment we use is all based upon electricity through electronics and microelectronics systems.

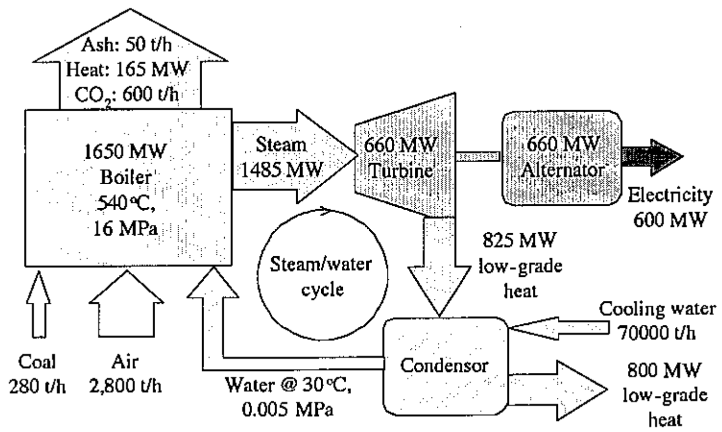
Conversion technologies

There is an enormous range of these in our energy systems and they vary greatly in terms of

- types of energy input and output
- scale
- efficiency

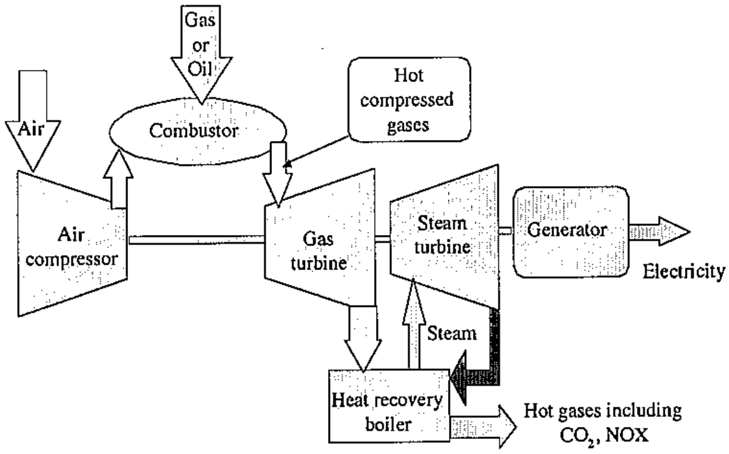
For the example of electricity generation; these vary from coal fired power stations of 1000MW or more operating at around 35% efficiency, gas turbines from the tens to hundreds of MW operating at around 30-40%, combined cycle gas generation in the hundreds of MW with 55-60% efficiency, through to small renewable home power systems in the KW range.

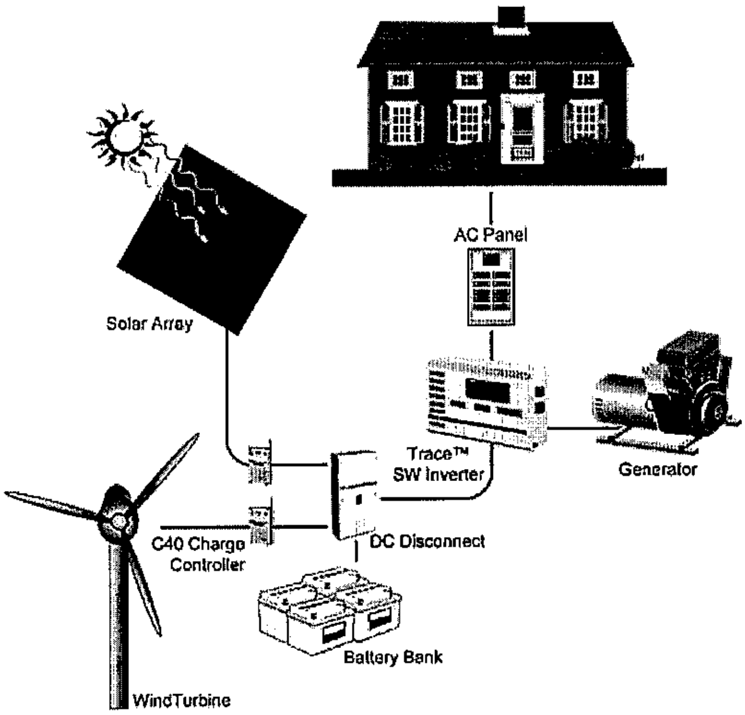
Coal-fired steam-cycle generator



Courtesy Hugh (Outhred, 2001)

Combined cycle gas turbine (CCGT)





(Trace, 2002)

Exercise 4

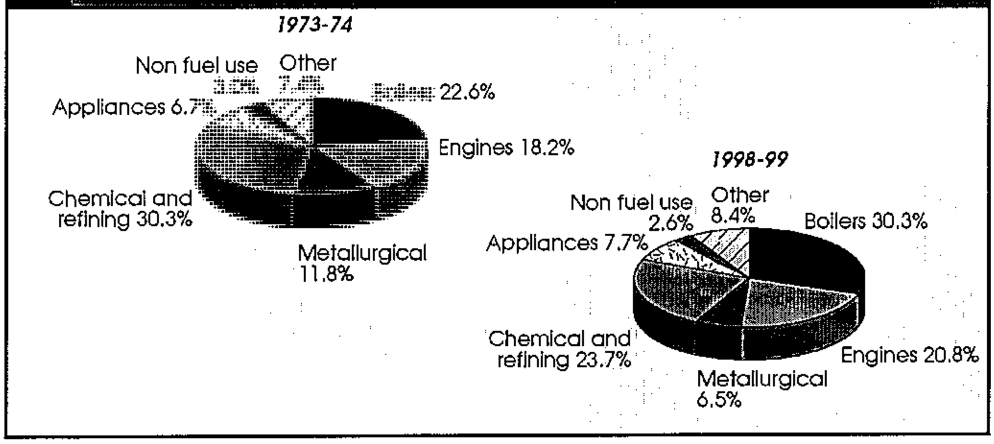
One important feature of energy conversion chains is the losses that occur at each conversion. Describe the energy conversions that turn buried oil into a car trip and the types of losses at each stage.

End-use equipment

We have already considered end-use equipment in the context of particular end-use services. It can be more generally classified in a number of ways.

Estimated Australian energy consumption by overall economic sector (ABARE, May 2001) is as follows. Note that the 'industry' sector covers a wide range of activities and materials that are used in the other sectors.

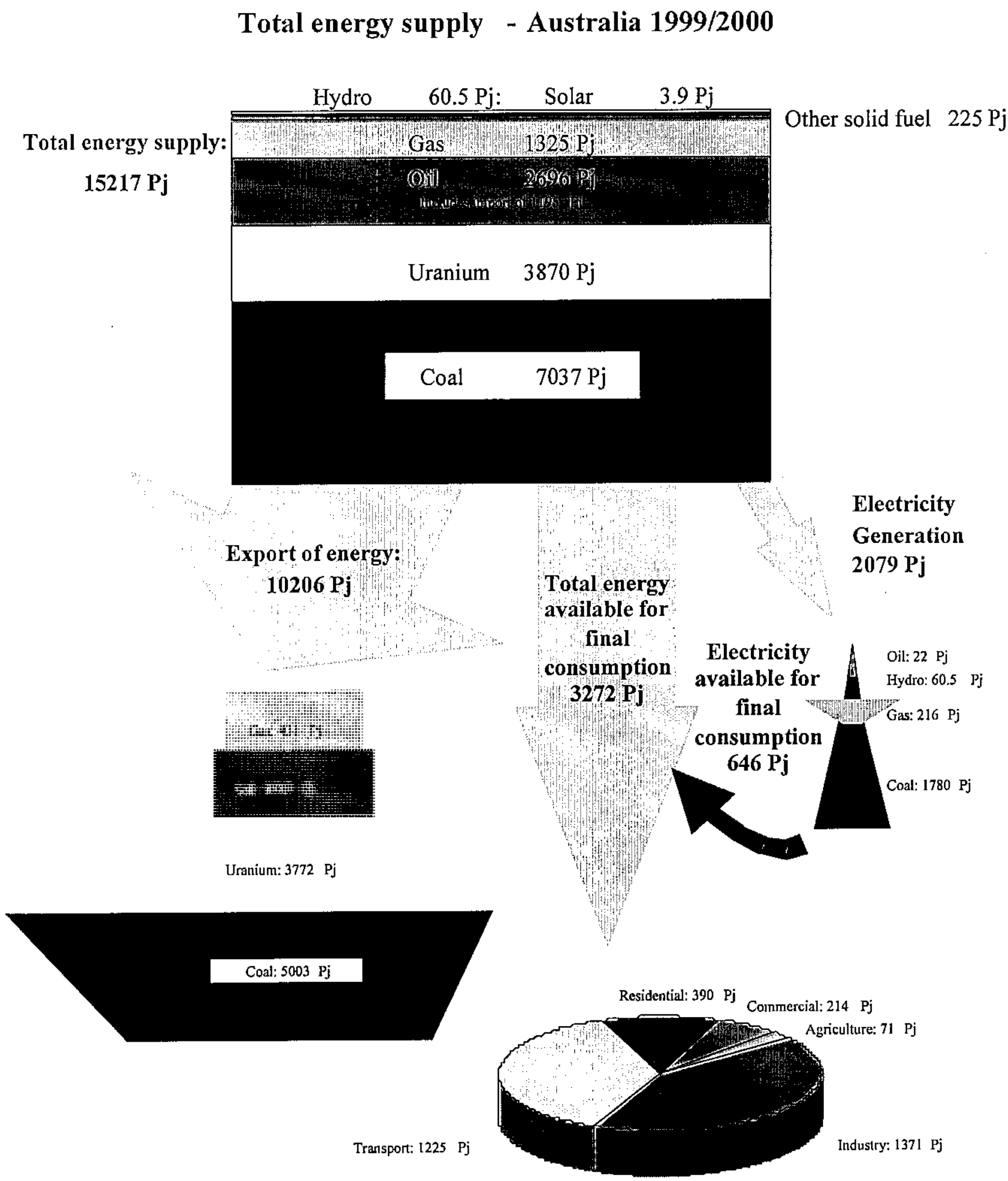
D Shares of Australian energy consumption, by equipment type



Estimated Australian energy consumption by general end-use equipment is as follows. Boilers are the largest single energy consumer but note that these include the boilers for coal fired electricity generation. The engines component is largely internal combustion engines in motorised transportation.

Australia's energy systems

(ESAA, 2002)



Sustainability of energy systems

In this section we assess global energy systems with regard to two key sustainability criteria

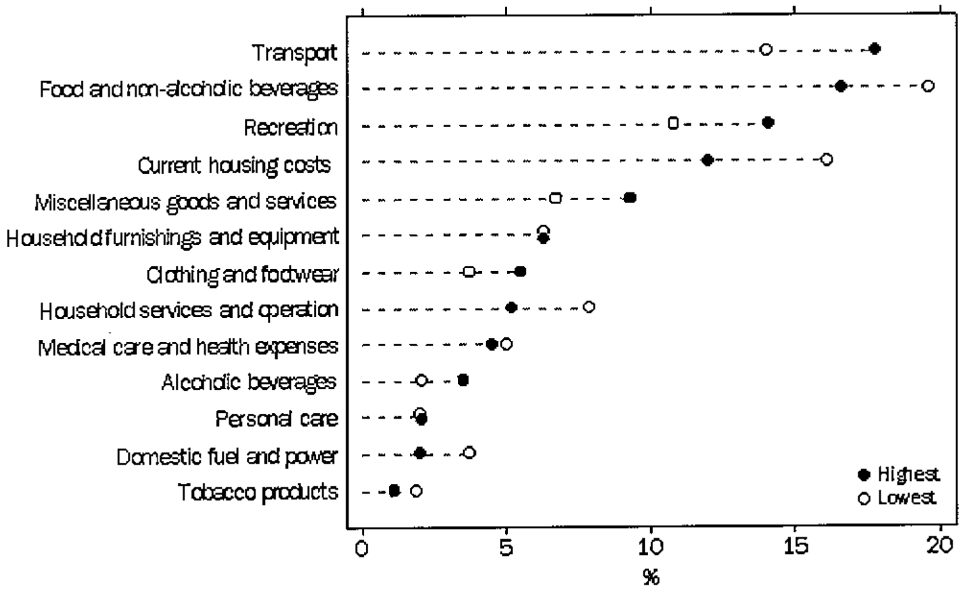
- delivery of adequate energy to meet societal needs and enable ongoing human development and welfare
- the need for energy systems that don't threaten the prospects of future generations or the integrity of our ecosystem.

Energy services

The energy rich

For those of us lucky enough to live in the industrialised world and the privileged of the developing world, the energy services we are able to enjoy are consuming perhaps 100 fold more energy than was available to humans before we mastered fire.

Furthermore, this energy appears very affordable. The direct costs of this energy are certainly often low, as shown below for Australian households. The situation is similar for many industries and commercial enterprises as well, and is part of the reason we see such poor decision making in energy.



Expenditure by highest and lowest Australian income groups; ABS (1998)

The energy poor

There are, however, well over a billion people who don't have access to commercial energy; most of them poor and living in rural areas of the developing world. This inequity is unsustainable.

DMSP (2002)

> The energy dimension of poverty—energy poverty—may be defined as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development. The numbers are staggering: 2 billion people are without clean, safe cooking fuels and must depend on traditional biomass sources; 1.7 billion are without electricity. Increased access to such energy services will not, in itself, result in economic or social development. But lack of adequate energy inputs can be a severe constraint on development.
>
> Universally accessible energy services that are adequate, affordable, reliable, of good quality, safe, and environmentally benign are therefore a necessary but insufficient condition for development.

UNDP (2002); Chapter 2.

Exercise 5

What is actually meant by 'commercial' energy and do you, yourself, ever use non-commercial energy?

Environmental impacts of our energy systems

The environmental impacts of our present energy systems can be broadly categorized into

- major land-use changes in obtaining energy resources
- the release of pollutants.

Land use change

The fossil fuel industries (coal, oil and gas) all contribute to major land use changes from their mining and drilling operations. For example, over the last 10 years the petroleum industry worldwide

> ...has been awarded 4,040 new contracts for exploration activities. These awards have covered a total licensed area of 13,755,000 square kilometers, or the size of both the United States (including Alaska) and Europe together"
> In the last decade, 14,979,795 kilometers of 2D (or standard) seismic lines have been cut globally. To put this into perspective, this is more than twice the total distance of the entire road network of the United States.
>
> Project Underground (1999)

Much of this activity is in relatively unperturbed land areas, for example, in South America. It is not, however, only fossil fuel extraction that impacts on land-use and ecosystems. Large hydro projects can have very significant impacts, as can mono-culture biomass for energy production. An example of the latter is Brazil's use of large-scale sugar plantations to make ethanol as a liquid fuel alternative to petroleum.

Nevertheless, it is probably the enormous quantities of a wide range of environmentally active chemicals emitted by our present energy systems that are of greater concern.

Pollutants

Our energy systems are responsible for enormous material flows through the economy and into our ecosystem, as outlined in the table below. It is clear that energy systems are, with other societal activities, markedly changing the global cycles of numerous important chemicals. Note that the separation between 'commercial energy supply' and 'manufacturing, other' is not always clear – in many cases, the latter can represent embodied energy or waste streams from commercial energy supply. While the potential adverse impacts of these chemical emissions aren't necessarily clear the magnitude of these flows highlights the potential risks.

Impacts of pollutants

The environmental impacts of such materials flows can be categorized in terms of

- direct effects on human health; also termed 'environmental health impacts'
- impacts on ecosystems that indirectly affect, more generally, human welfare.

Another useful 'socio-technical' model for exploring these impacts is in terms of their scale

- the individual and household level
- the community, regional, level
- global impacts

TABLE 3. ENVIRONMENTAL INSULTS DUE TO HUMAN ACTIVITIES BY SECTOR, MID-1990s

Insult	Natural baseline (tonnes per year)	Human disruption index[a]	Share of human disruption caused by: Commercial energy supply	Traditional energy supply	Agriculture	Manufacturing, other
Lead emissions to atmosphere[b]	12,000	18	41% (fossil fuel burning, including additives)	Negligible	Negligible	59% (metal processing, manufacturing, refuse burning)
Oil added to oceans	200,000	10	44% (petroleum harvesting, processing, and transport)	Negligible	Negligible	56% (disposal of oil wastes, including motor oil changes)
Cadmium emissions to atmosphere	1,400	5.4	13% (fossil fuel burning)	5% (traditional fuel burning)	12% (agricultural burning)	70% (metals processing, manufacturing, refuse burning)
Sulphur emissions to atmosphere	31 million (sulphur)	2.7	85% (fossil fuel burning)	0.5% (traditional fuel burning)	1% (agricultural burning)	13% (smelting, refuse burning)
Methane flow to atmosphere	160 million	2.3	18% (fossil fuel harvesting and processing)	5% (traditional fuel burning)	65% (rice paddies, domestic animals, land clearing)	12% (landfills)
Nitrogen fixation (as nitrogen oxide and ammonium)[c]	140 million (nitrogen)	1.5	30% (fossil fuel burning)	2% (traditional fuel burning)	67% (fertiliser, agricultural burning)	1% (refuse burning)
Mercury emissions to atmosphere	2,500	1.4	20% (fossil fuel burning)	1% (traditional fuel burning)	2% (agricultural burning)	77% (metals processing, manufacturing, refuse burning)
Nitrous oxide flows to atmosphere	33 million	0.5	12% (fossil fuel burning)	8% (traditional fuel burning)	80% (fertiliser, land clearing, aquifer disruption)	Negligible
Particulate emissions to atmosphere	3,100 million[d]	0.12	35% (fossil fuel burning)	10% (traditional fuel burning)	40% (agricultural burning)	15% (smelting, non-agricultural land clearing, refuse)
Non-methane hydrocarbon emissions to atmosphere	1,000 million	0.12	35% (fossil fuel processing and burning)	5% (traditional fuel burning)	40% (agricultural burning)	20% (non-agricultural land clearing, refuse burning)
Carbon dioxide flows to atmosphere	150 billion (carbon)	0.05[e]	75% (fossil fuel burning)	3% (net deforestation for fuelwood)	15% (net deforestation for land clearing)	7% (net deforestation for lumber, cement manufacturing)

Note: The magnitude of the insult is only one factor determining the size of the actual environmental impact.
a. The human disruption index is the ratio of human-generated flow to the natural (baseline) flow. b. The automotive portion of human-induced lead emissions in this table is assumed to be 50 percent of global automotive emissions in the early 1990s. c. Calculated from total nitrogen fixation minus that from nitrous oxide. d. Dry mass. e. Although seemingly small, because of the long atmospheric lifetime and other characteristics of carbon dioxide, this slight imbalance in natural flows is causing a 0.4 percent annual increase in the global atmospheric concentration of carbon dioxide. *Source: Chapter 3.*

UNDP (2002); Overview.

Households

Our oldest energy technology, the cooking fire, actually remains our most common fuel-using technology worldwide.

The direct health impacts of the home cooking fire depend greatly on people's typical cooking arrangements – eg outside or inside the home, ventilation and, critically, the type of fuel. Clean combustion of solid fuels like wood, crop residues and coal is difficult in simple, small devices. Wood is actually a clean energy source if burned properly but this is rarely achieved in a poor household. Coal is generally far worse while liquid and gas for cooking offers both cleaner fuels and higher efficiency, causing far less direct harm.

> The direct health impacts of home cooking on solid fuels are difficult to estimate but very great. The best estimates of such effects for developing countries have been done for India… These indicate that household solid fuel use causes about 500,000 premature deaths a year in women and children under 5. This is 5–6 percent of the national burden of ill health, or 6–9 percent of the burden for these two population groups. This is comparable to, though somewhat less than, the estimated national health impacts of poor water and sanitation at the household level— UNDP (2002); Chapter 3

The indirect impacts of home cooking fires on ecosystems include the widespread use of trees and crop residues in the developing world, although the direct impacts of this with regard to deforestation is disputed.

Regional impacts

Many pollutants cause harm at the regional level. Urban air quality in both the industrialized and developing world is adversely impacted by fossil fuel use (largely from motorized transportation) causing a range of direct health harms.

Urban air quality

Over 60% of Australians live in coastal capital cities. High radiation levels, high summer temperatures and location in coastal basins surrounded by hills, make Australian urban areas susceptible to photochemical smog and to its recycling or concentration over areas of the airshed… Motor vehicles are the major emitters of air pollutants in urban Australia, contributing more than 75% of the carbon monoxide emissions and most of the oxides of nitrogen and organic compounds. Emissions include very fine particles that contribute to urban haze and adverse health. The phase-out of leaded petrol (complete by 2002) means that lead in air is no longer a concern for any major urban area.

During 1980 to 1999, the eight-hour Air NEPM Standard for carbon monoxide has been exceeded in areas of high traffic density and low traffic flow, but the problem is not widespread. For nitrogen dioxide, only Sydney has shown exceedences and then on only one day per year. In urban Australia, ambient sulfur dioxide concentrations rarely exceed Air NEPM values except near petroleum refineries, or petrochemical or chemical industries. Emissions of oxides of nitrogen and hydrocarbons react with sunlight to eventually form ozone, whose concentrations provide an estimate of photochemical smog. Since the 1980s, the maximum value of hourly ozone concentrations has declined steadily in the biggest cities. However, for the maximum amount averaged over four hours, there has been no decline, and hence no real drop in the level of photochemical smog. This indicates that the stricter vehicle emission limits proposed for the future will be needed to reach and maintain the Air NEPM standards.

Airborne dust is often the only significant air quality issue in regional Australia. Strong winds influence levels of dust which can be attributed to natural sources as well as wind-blown erosion in cultivated or stocked areas and to mining. Particulates also arise from bushfires, burning off and domestic wood fires. Maximum PM10 concentrations vary greatly. The Air NEPM allows five exceedences per year of the 24-hour average of 50 µg/m3. Most regions comply, but wood burning in Launceston (Tas.) and Armidale (NSW) results in obvious exceptions. In Armidale, there were many days in 1997 and 1999 when 'local visual distance' was below 2 km. *Environment Australia (2001)*

Estimating the health costs of air quality issues in the industrialised developed world is fraught with difficulties. One set of estimates from the European ExternE program is shown below.

UNDP (2002); Chapter 3

TABLE 3.8. AIR POLLUTANT EMISSIONS AND ESTIMATED HEALTH COSTS FOR EUROPEAN POWER PLANTS EQUIPPED WITH THE BEST AVAILABLE CONTROL TECHNOLOGIES

Siting	Unit health cost (cents per gram)			Emission rate (grams per kilowatt-hour): Pulverised coal steam-electric			Emission rate: Natural gas combined cycle	Unit health cost (cents per kilowatt-hour): Pulverised coal steam-electric				Unit health cost: Natural gas combined cycle
	Sulphur dioxide	Nitrogen oxides	PM_{10}	Sulphur dioxide	Nitrogen oxides	PM_{10}	Nitrogen oxides	Sulphur dioxide	Nitrogen oxides	PM_{10}	Total	Nitrogen oxides
Typical	1.0	1.6	1.7	1.0	2.0	0.2	0.1[a]	1.0	3.2	0.3	4.6	0.16
Urban	1.6	2.3	5.1	1.0	2.0	0.2	0.1[a]	1.6	4.6	0.5	6.7	0.23
Rural	0.7	1.1	0.5	1.0	2.0	0.2	0.1[a]	0.7	2.2	0.1	3.0	0.11

Note: These calculations were carried out as part of the European Commission's ExternE Program. Studies under the program have estimated the economic values of health impacts by assessing people's willingness to pay to avoid adverse health effects. The health cost estimates shown are median values; the 68 percent confidence interval is 0.25–4.0 times the median cost.

Source: Rabl and Spadaro, 2000.

The indirect regional impacts of our energy systems, ie those impacts on our ecosystems that effect human welfare, are widespread. They include the impacts of poor air quality on agriculture and regions of great conservation value.

Global impacts

> The environmental transition of the 20th century—driven by more than 20-fold growth in the use of fossil fuels and augmented by a tripling in the use of traditional energy forms such as biomass—has amounted to no less than the emergence of civilisation as a global ecological and geochemical force.

UNDP (2002); Chapter 3.

The term 'global impacts' refers to both the enormous individual and regional impacts summed over the planet, but also the emergence of impacts that are truly global in terms of potential impact and the common role of pollutants regardless of where they are emitted.

Acid rain caused transnational pollution impacts in Canada (from US coal fired generation) and the Nordic countries (from UK coal fired generation).

Global warming, however, represents a new type and scale of problem. GHG emissions from the United States contribute to global warming in exactly the same way as those from China or India. Similarly, the projected impacts of global warming leave few countries unaffected in any way, although the extent of GHG related problems may vary greatly.

Furthermore, CO2 from fossil fuel use isn't a pollutant in the traditional sense; an unwanted and harmful by-product of a process. It's integral to the release of potential chemical energy stored in fossil fuels. Note the range of roles that fossil fuels play in the warming effect – obviously through CO2 emissions but also methane (more commonly known as natural gas) and even via the cooling effect of aerosols - the more traditional pollutants of power generation and car use.

TABLE 3.5. CHANGES IN EARTH'S ENERGY BALANCE, PRE-INDUSTRIAL TIMES–1992

Effect	Global average watts per square metre
Direct effect of increasing carbon dioxide	1.6 ± 0.2
Direct effect of increasing methane	0.5 ± 0.1
Direct effect of increasing halocarbons	0.25 ± 0.04
Direct effect of increasing tropospheric ozone	0.4 ± 0.2
Direct effect of decreasing stratospheric ozone	0.1 ± 0.02
Direct effect of tropospheric aerosols	-0.5 ± 0.3
Indirect effect of tropospheric aerosols	-0.8 ± 0.8
Direct effect of natural changes in solar output (since 1850)	0.3 ± 0.1

Source: IPCC, 1996b. UNDP (2002)

Sustainability trends

Energy services

> In 1993 there were nearly 1.8 billion people in the world without access to commercial energy. Despite efforts to connect roughly 300 million people to electricity grids or to provide them with modern biomass and other commercial energy over the last eight years, there are still an estimated 1.6 billion people in such a situation. Four to five hundred million people out of the 1.4 billion to be born between now and 2020 will join them. Most of these people are in rural areas and shanty towns in developing countries.
>
> *World Energy Council (2002)*

In summary, commercial power is reaching more people, yet is struggling to keep up with population growth in developing countries.

Energy services for people in the industrialized continue to expand, as outlined below for the case of the United States.

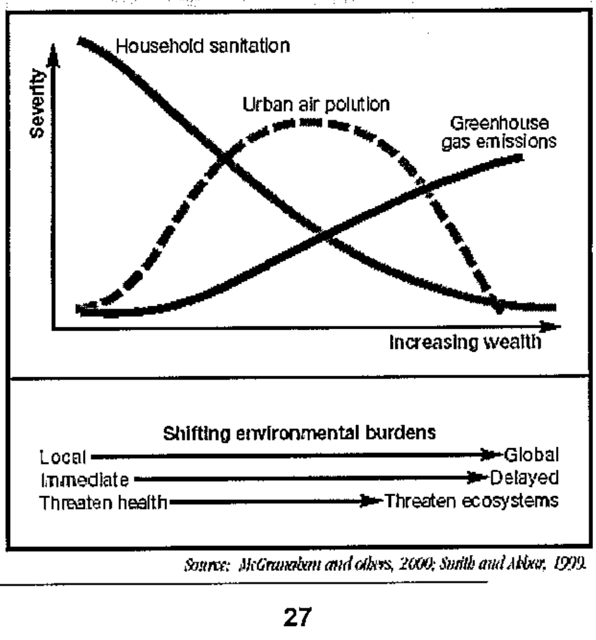
> **Energy use in the United States**
> **Houses.** In 1973 the average new home was 1,600 square feet for the average family of 3.6 people; by 1998 the average size had increased to 2,100 square feet even though the average family had shrunk to 3.0 people.
> **Appliances.** The penetration of energy-intensive appliances has increased. For example, in 1973 fewer than 40 percent of homes had central air conditioning. But in 1998 more than 80 percent had it. Forty percent of homes had two or more television sets in 1970; by 1997, the percentage was 85 percent. And homes with dishwashers increased from 19 percent in 1970 to 57 percent in 1996.
> **Transport.** Americans are driving automobiles more than ever, primarily because there are more wage earners per family and more urban sprawl. Households with three or more cars increased from 4 percent in 1969 to 20 percent in 1998. From 1983–95 average commuting distance increased by one-third, from 9.72 to 11.6 miles. And only 15 percent of commuters use public transit. *UNDP (2002); Chapter 2*

Environmental impacts

The trends for the environmental impacts of our energy systems is mixed, as demonstrated in the graph below. What we are seeing, with increasing wealth, is a transition from direct household impacts towards global impacts. The air pollution hump is the response of wealthier urban societies to act on the health impacts of such pollution. Some of the worst air quality is found in the large cities of the developing world.

With respect to global warming emissions, CO_2 is responsible for some 60% of warming, and fossil fuel use for about 75% of CO_2 emissions. Emissions continue to grow as shown below. Fossil fuel production also contributes, in a less significant way, to methane and Nitrous Oxide emissions.

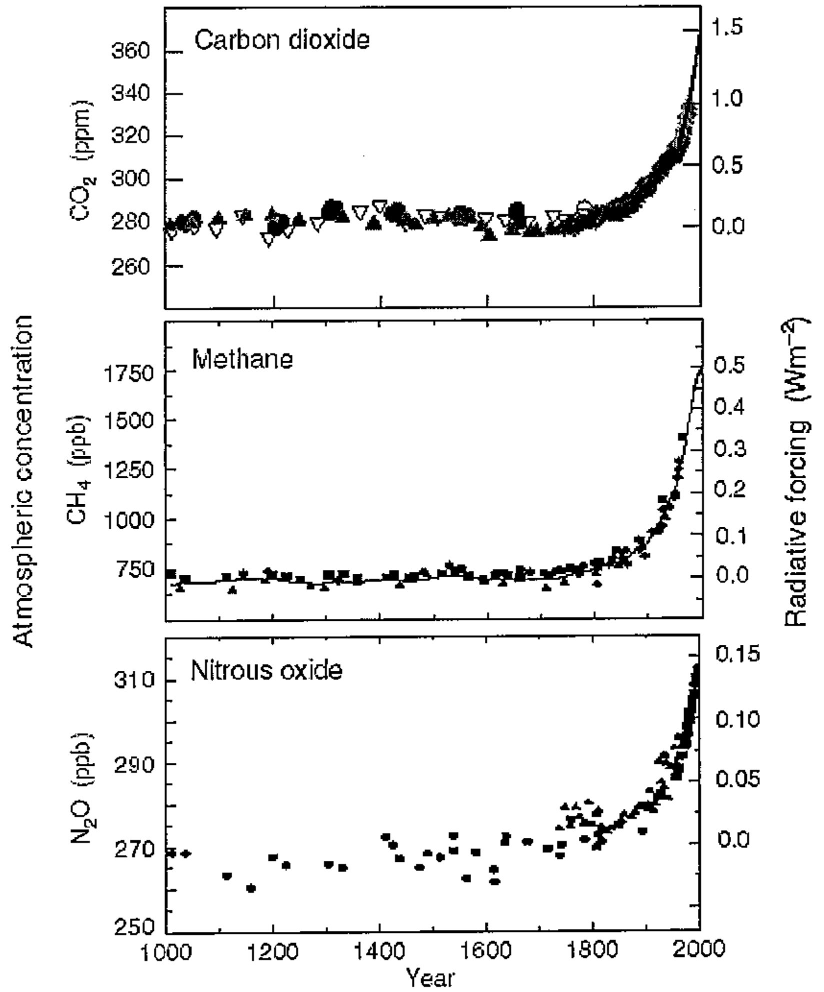
FIGURE 3.10. ENVIRONMENTAL RISK TRANSITION



Source: McGranahan and others, 2000; Smith and Akbar, 1999.

Indicators of the human influence on the atmosphere during the Industrial Era

(a) Global atmospheric concentrations of three well mixed greenhouse gases

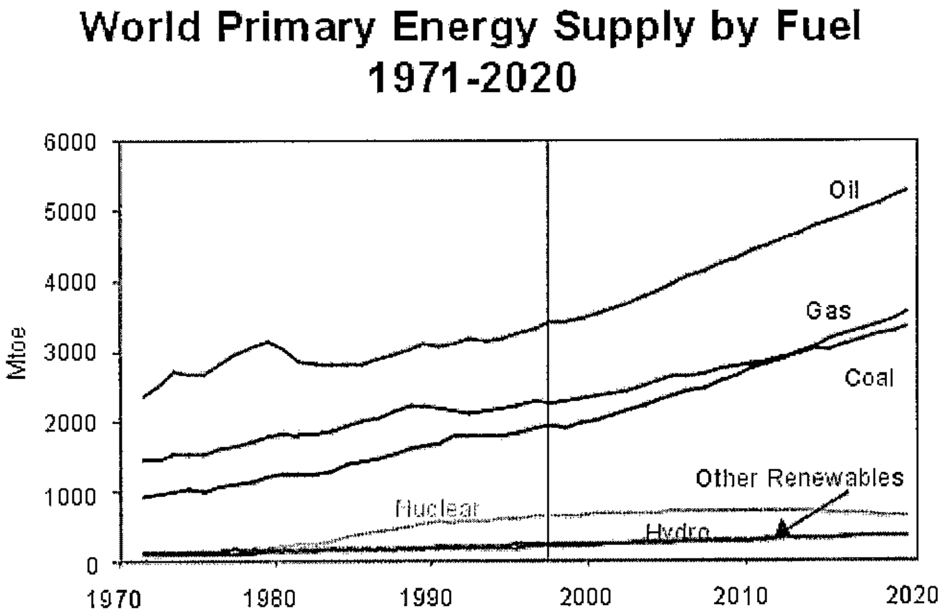


IPCC (2000)

Projections

We should first briefly consider the differences between projections, forecasts or predictions, and scenarios. While the terms are often used interchangeably, a projection is just that – a projection from current data and historical trends into the future. A prediction or forecast on the other hand represents a best guess about the future based, perhaps, on projections but with added judgments. Scenario planning differs again in being a process of generating hypothetical alternative futures to help explore decision making.

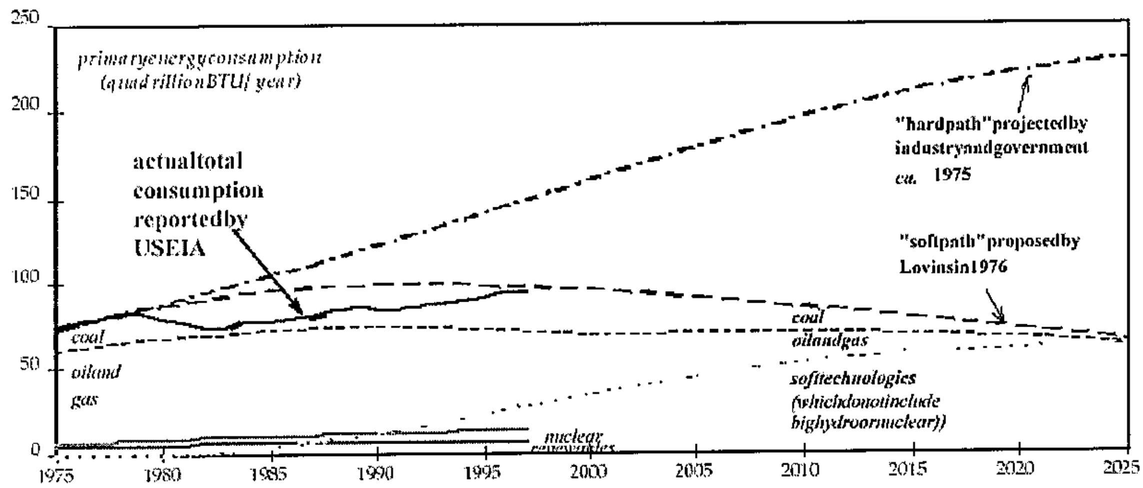
There are a range of projections available according to how historical trends are analysed. The International Energy Agency projections are shown below



IEA (2000)

The history of projections, however, gives some reasons to doubt them. See for example Amory Lovin's scenario of a soft energy path which shows the actual growth in energy consumption over the last 25 years compared to projections made at the time.

Lovins (2001)



Present Energy Drivers

It was physicist Niels Bohr who said that "Prediction is always difficult, especially about the future." Is trend necessarily destiny? This is what the Australian Treasury has to say

> Forecasts… "should be seen as no more than approximate outcomes centred on a range of plausible possibilities, conditional on a number of assumptions"

Commonwealth of Australia, 1985

Another approach looks at the present drivers in energy system development, and how they may have changed over recent times. The major drivers in global energy systems at present are often classified in terms of

- rapid technological development – particularly in small-scale, power conversion devices
- widespread market restructuring – particularly the introduction of competition into previously government or monopoly owned service providers
- increasing environmental concerns, particularly with regard to global warming.
- growing energy security concerns.

These represent significant shifts from earlier drivers in the time periods from which projections often draw up. Note the mix of 'means' and 'ends' in this list. The potential for our society to act on global warming is explored in the next section. All of these drivers can contribute to transformation of our energy systems towards greater sustainability. Whether they do depends on how we, as a society, decide on our 'ends', that is objectives.

Future sustainable energy systems

What has to be done

The two key sustainability issues that have to be addressed by society are, as noted earlier,

- delivery of adequate energy to meet societal needs and enable ongoing human development and welfare
- the need for energy systems that don't threaten the prospects of future generations or the integrity of our ecosystem.

Energy services

The first issue is key and has two steps – the near term provision of essential energy services to the poor of developing countries, and in the longer term, the potential for all people to enjoy the same energy services as those of the rich industrialised world.

This will necessarily affect patterns of global energy consumption, and adds to the challenge of the second key issue of sustainability – reduced environmental impacts, particularly from the use of fossil fuels. Note, however, that providing the poor with decent energy services doesn't necessarily have to add greatly to overall energy consumption.

> If all developing countries achieved a level of energy services comparable to that of Western Europe in the 1970s, and if they deployed the most efficient energy technologies and energy carriers available in the 1980s, what would be the per capita energy consumption corresponding to this vastly improved standard of living?
> The surprising answer was that, provided that the most energy efficient technologies and energy carriers available are implemented, a mere 1 kilowatt per capita—that is, a 10 percent increase in today's energy per capita—would be required for the populations of developing countries to enjoy a standard of living as high as that of Western Europe in the 1970s. [note that Africa currently averages per capita energy of 0.8 kW]. In other words, dramatic increases in living standards in developing countries can theoretically be achieved with small inputs of energy.

UNDP (2002); Chapter 2.

The longer-term question of equal worldwide opportunity to enjoy energy services equivalent to the present energy rich is, however a different question. If everyone on earth lived like Americans, global GHG emissions would be some five times present levels.

GHG emissions

The question of acting on GHG emissions is really one to initially be asked of the energy rich, mainly to be found in the industrialised world. The Kyoto Protocol calls for general emission reductions from industrialised nations of an average 5% or so, over the period 1990 to 2008-12. Stabilising GHG concentrations, however, has been estimated to require emission reductions of the order of 60% or more for industrialised countries, given equity concerns with the developing world. If, as some argue, the Kyoto targets are unachievable without casting the entire world into economic doom and gloom, then what hope is there for the more meaningful emissions required?

Scenarios

The most common framework for exploring action on global warming has been that of scenarios – a range of possible futures given different societal directions on a wide range of issues The Intergovernmental Panel on Climate Change uses scenarios to explore possible carbon emissions, most recently in their Third Assessment Report or TAR which was released in 2001.

The UNDP World Energy Assessment uses scenario analysis and uses three particular scenarios to explore possible energy futures, as shown in the table below.

Exercise 6

a) Implicit in both the high growth and ecologically driven scenarios is rapid technological development. They represent, however, two different views of what drives technological development – explain.

TABLE 5. SUMMARY OF THREE ENERGY DEVELOPMENT CASES IN 2050 AND 2100 COMPARED WITH 1990

		Case A High growth	Case B Middle growth	Case C Ecologically driven
Population (billions)	1990 2050 2100	5.3 10.1 11.7	5.3 10.1 11.7	5.3 10.1 11.7
Gross world product (trillions of 1990 dollars)	1990 2050 2100	20 100 300	20 75 200	20 75 220
Gross world product (annual percentage change)	1990-2050 1990-2100	High 2.7 2.5	Medium 2.2 2.1	Medium 2.2 2.2
Primary energy intensity (megajoules per 1990 dollar of gross world product)	1990 2050 2100	19.0 10.4 6.1	19.0 11.2 7.3	19.0 8.0 4.0
Primary energy intensity improvement rate (annual percentage change)	1990-2050 1990-2100	Medium -0.9 -1.0	Low -0.8 -0.8	High -1.4 -1.4
Primary energy consumption (exajoules)	1990 2050 2100	379 1,041 1,859	379 837 1,464	379 601 880
Cumulative primary energy consumption, 1990-2100 (thousands of exajoules)	Coal Oil Natural gas Nuclear energy Hydropower Biomass Solar energy Other Global total	8.9 – 30.7 27.6 – 15.7 18.4 – 28.7 6.2 – 11.2 3.7 – 4.2 7.4 – 14.3 1.8 – 7.7 3.0 – 4.7 94.0 – 94.9	17.6 15.3 15.8 10.5 3.6 8.3 1.9 4.3 77.2	7.1 – 7.2 10.9 12.2 – 12.9 2.1 – 6.2 3.6 – 4.0 9.1 – 10.1 6.3 – 7.4 1.4 – 2.2 56.9
Energy technology cost reductions (through learning)	Fossil Non-fossil	High High	Medium Medium	Low High
Energy technology diffusion rates	Fossil Non-fossil	High High	Medium Medium	Medium High
Environmental taxes (excluding carbon dioxide taxes)		No	No	Yes
Sulphur dioxide emissions (millions of tonnes of sulphur)	1990 2050 2100	58.6 44.8 – 64.2 9.3 – 55.4	58.6 54.9 58.3	58.6 22.1 7.1
Carbon dioxide emission constraints and taxes		No	No	Yes
Net carbon dioxide emissions (gigatonnes of carbon)	1990 2050 2100	6 9 – 15 6 – 20	6 10 11	6 5 2
Cumulative carbon dioxide emissions (gigatonnes of carbon)	1990-2100	910 – 1,450	1,000	540
Carbon dioxide concentrations (parts per million by volume)	1990 2050 2100	358 460 – 510 530 – 730	358 470 590	358 430 430
Carbon intensity (grams of carbon per 1990 dollar of gross world product)	1990 2050 2100	280 90 – 140 20 – 60	280 130 60	280 70 10
Investments in energy supply sector (trillions of 1990 dollars)	1990-2020 2020-50 2050-2100	15.7 24.7 93.7	12.4 22.3 82.3	9.4 14.1 43.3
Number of scenarios		3	1	2

The three cases unfold into six scenarios of energy system alternatives: three case A scenarios (A1, ample oil and gas; A2, return to coal; and A3, non-fossil future), a single case B scenario (middle course), and two case C scenarios (C1, new renewables; and C2, new renewables and new nuclear). Some of the scenario characteristics, such as cumulative energy consumption, cumulative carbon dioxide emissions, and decarbonisation, are shown as ranges for the three case A and two C scenarios. *Source: Nakićenović, Grübler, and McDonald, 1998.*

Exercise 7

The example of the IT and communications industries has been used to support the potential of one of the above approaches. Do you see fundamental differences between these, and the energy sector in the developed world that might make it hard for clean and green energy to take off in the same way?

What is clear from all of these scenarios is that to create sustainable energy systems that help us avoid dangerous global warming we will have to change just about everything that we are currently doing. Although we don't know exactly what all these changes will be, we do know where to look and where to start.

A framework for action

This section will consider the two major engineering, systematic approaches for reducing the environmental impacts of society's energy systems

- improved efficiency throughout the energy conversion chain through to delivery of energy services
- a transition to lower emission fossil fuels and renewable energy resources.

Key to both of these, however, is innovation.

Innovation and the role of technology

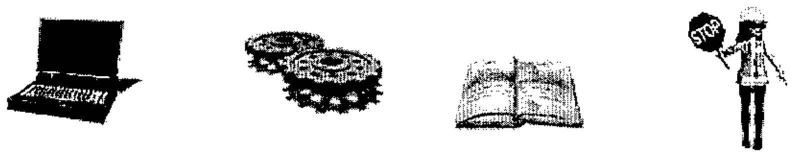
The term 'innovation' is used in many different ways and contexts. We take it to mean the *practical application of new ideas*. If we accept that we have to change just about everything with respect to our present energy systems then innovation is clearly essential. Its key themes are, from our definition above, *invention* and *application*.

What do we mean by 'technology' and technical innovation? Again, these terms are used in widely different ways. We will take it to mean the following:

The Art of Knowing and Doing

The study of **technology** concerns *what* things are made and *how* things are made. Technology, from the Greek *science of* (practical) *arts,* has both a *material* and an *immaterial* aspect.

Technology = Hardware + Software + "Orgware"



Hardware

Software

Orqware

Hardware: Manufactured objects (artifacts)

Software: Knowledge required to design, manufacture, and use technology hardware

"Orgware": Institutional settings and rules for the generation of technological knowledge and for the use of technologies

IIASA (2002)

Note that the word technology also has a Latin root 'technologia', meaning a systematic treatment – systems thinking arises yet again!

The critical role of technology innovation in finding solutions to societal problems is widely acknowledged. The Intergovernmental Panel on Climate Change has identified "technology as a more important determinant of future greenhouse gas emissions and possible climate change than all other driving forces put together" (IIASA, 2002).

Some key themes to keep in mind when thinking about technology and innovation

- Its not just about widgets, but integrated socio-technical systems and societal change.
- Change can be at the scale of components of existing systems (evolutionary) or involve the development of entirely new systems (revolutionary).
- Existing infrastructure often shapes our options, particularly in the short term.
- Note the difference between operational changes (ie how do we operate the systems that we have) versus investment changes (ie how do we change the systems that we have).

Energy efficiency

The term energy efficiency is used in a number of ways. It has a technical meaning, yet also a more broad subjective concept. The technical concept relates to the efficiency with which a level of service is provided.

> Energy efficiency is the relative thrift or extravagance with which energy inputs are used to provide goods or services. Increases in energy efficiency take place when either energy inputs are reduced for a given level of service or there are increased or enhanced services for a given amount of energy inputs. EIA (2002)

A broader view of efficiency gives more thought to the types of energy services involved.

Exercise 8

The US Energy Information Agency might well argue that taking the stairs rather than the lift up to your office is not more energy efficient but, rather, means that you are receiving less energy services. What do you think?

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Technical efficiency

There are technical efficiency options and opportunities in our energy systems at

- end-use; eg more fuel efficient cars, high efficiency home appliances
- energy distribution – eg more efficient transformers within the electricity distribution system
- energy conversion at the supply side – eg the latest coal fired generating plant can have 40% efficiency in comparison with the 35% of conventional plant, the latest Combined Cycle Gas Turbine generating plant can have 55-60% efficiency, while Cogeneration can have even greater efficiency measured by electricity and heat generation.

Beyond the environmental outcomes considered here, energy efficiency has all the other advantages that come with using less of something, i.e.

- cost savings on energy
- the potential to avoid having to upgrade infrastructure capacity given energy consumption growth from other factors like population growth
- increased security of supply where non-renewable resources are being used.

Lower emission fossil fuels and renewable energy resources

To accompany greater energy efficiency, our society is going to have to begin a transition to lower emission fossil fuels and renewable sources.

'Cleaner' fossil fuels

For fossil fuels

- Coal is almost all carbon and releases around 93-100 gCO2/MJ of energy
- Oil is a mix of liquid hydrocarbons and releases 72-80 gCO2/MJ
- Natural gas is the simplest hydrocarbon (CH4) and releases approximately 55 gCO2/MJ.

Again, a systems view is required to more carefully evaluate the options. For example, the efficiency of combined cycle gas fired generating plant is also considerably higher than that of coal fired units leveraging even greater advantages. However, natural gas that leaks from gas supply infrastructure is an extremely potent global warming gas and some argue that this may counteract its advantages as a fuel source.

Gas has reduced emissions of many of the other pollutants associated with fossil fuels – some would go so far as to call it the 'clean' fossil fuel. That is somewhat controversial, however, the importance of moving from 'dirty' fossil fuels like coal towards a greater role for gas is widely accepted and appears to be underway – world coal consumption has fallen over the last decade while gas is the fastest growing energy source. Well, except for a number of renewable technologies as you'll see in the next section.

Example – hot water services

Consider the options for hot water heating here in Australia. Many households, and the great majority of rental properties, have electric hot water systems. Our electricity is about 90% coal fired, so the energy conversion chain is remarkably inefficient. Gas fired generation is more efficient than coal. Even better, however, is a hot water system which burns gas directly. Or you can get a solar hot water system. The key question in its environmental performance is the boosting energy source. Electricity boosted hot water in many parts of Australia can actually cause more GHG emissions than a non-solar gas fired unit. A gas boosted solar hot water heater is the most environmentally friendly option, or is it?

Renewables

Renewable energy resources can be generally categorised as

- Solar – incorporating solar thermal and photovoltaics, also wind, biomass and hydropower
- Geothermal – driven by the internal heat of the planet
- Marine energy – with solar energy a major indirect contributor to this resource

The overall size of the resource is very large for many, although not all, of these resources as shown earlier. The categories of conversion technologies are shown in the table below.

TABLE 7.1. CATEGORIES OF RENEWABLE ENERGY CONVERSION TECHNOLOGIES

Technology	Energy product	Application
Biomass energy		
Combustion (domestic scale)	Heat (cooking, space heating)	Widely applied; improved technologies available
Combustion (industrial scale)	Process heat, steam, electricity	Widely applied; potential for improvement
Gasification/power production	Electricity, heat (CHP).	Demonstration phase
Gasification/fuel production	Hydrocarbons, methanol, H_2	Development phase
Hydrolysis and fermentation	Ethanol	Commercially applied for sugar/ starch crops; production from wood under development
Pyrolysis/production of liquid fuels	Bio-oils	Pilot phase; some technical barriers
Pyrolysis/production of solid fuels	Charcoal	Widely applied; wide range of efficiencies
Extraction	Biodiesel	Applied; relatively expensive
Digestion	Biogas	Commercially applied
Wind energy		
Water pumping and battery charging	Movement, power	Small wind machines, widely applied
Onshore wind turbines	Electricity	Widely applied commercially
Offshore wind turbines	Electricity	Development and demonstration phase
Solar energy		
Photovoltaic solar energy conversion	Electricity	Widely applied; rather expensive; further development needed
Solar thermal electricity	Heat, steam, electricity	Demonstrated; further development needed
Low-temperature solar energy use	Heat (water and space heating, cooking, drying) and cold	Solar collectors commercially applied; solar cookers widely applied in some regions; solar drying demonstrated and applied
Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and applications; no active parts
Artificial photosynthesis	H_2 or hydrogen rich fuels	Fundamental and applied research
Hydropower	Power, electricity	Commercially applied; small and large scale applications
Geothermal energy	Heat, steam, electricity	Commercially applied
Marine energy		
Tidal energy	Electricity	Applied; relatively expensive
Wave energy	Electricity	Research, development, and demonstration phase
Current energy	Electricity	Research and development phase
Ocean thermal energy conversion	Heat, electricity	Research, development, and demonstration phase
Salinity gradient / osmotic energy	Electricity	Theoretical option
Marine biomass production	Fuels	Research and development phase

Renewables make a relatively minor contribution to energy supply in much of the developed world although this may be changing. Wind and solar photovoltaics have been the fastest growing energy sources over the last decade – growing at a rate an order of magnitude higher than that of fossil fuels, as shown in the table below. It's important to note that this is from a small base, however, oil only contributed 2% of world energy supply in 1900 at the beginning of what was to become the oil century.

TABLE 4. CURRENT STATUS AND POTENTIAL FUTURE COSTS OF RENEWABLE ENERGY TECHNOLOGIES

Technology	Increase in installed capacity in past five years (percent a year)	Operating capacity, end 1998	Capacity factor (percent)	Energy production, 1998	Turnkey investment costs (U.S. dollars per kilowatt)	Current energy cost	Potential future energy cost
Biomass energy							
Electricity	≈ 3	40 GWe	25–80	160 TWh (e)	900–3000	5–15 ¢/kWh	4–10 ¢/kWh
Heat[a]	≈ 3	> 200 GWth	25–80	> 700 TWh (th)	250–750	1–5 ¢/kWh	1–5 ¢/kWh
Ethanol	≈ 3	18 billion litres		420 PJ		8–25 $/GJ	6–10 $/GJ
Wind electricity	≈ 30	10 GWe	20–30	18 TWh (e)	1100–1700	5–13 ¢/kWh	3–10 ¢/kWh
Solar photovoltaic electricity	≈ 30	500 MWe	8–20	0.5 TWh (e)	5000–10000	25–125 ¢/kWh	5 or 6–25 ¢/kWh
Solar thermal electricity	≈ 5	400 MWe	20 – 35	1 TWh (e)	3000–4000	12–18 ¢/kWh	4–10 ¢/kWh
Low-temperature solar heat	≈ 8	18 GWth (30 million m²)	8–20	14 TWh (th)	500–1700	3–20 ¢/kWh	2 or 3–10 ¢/kWh
Hydroelectricity							
Large	≈ 2	640 GWe	35–60	2510 TWh (e)	1000–3500	2–8 ¢/kWh	2–8 ¢/kWh
Small	≈ 3	23 GWe	20–70	90 TWh (e)	1200–3000	4–10 ¢/kWh	3–10 ¢/kWh
Geothermal energy							
Electricity	≈ 4	8 GWe	45–90	46 TWh (e)	800–3000	2–10 ¢/kWh	1 or 2–8 ¢/kWh
Heat	≈ 6	11 GWth	20–70	40 TWh (th)	200–2000	0.5–5¢/kWh	0.5–5 ¢/kWh
Marine energy							
Tidal	0	300 MWe	20–30	0.6 TWh (e)	1700–2500	8–15 ¢/kWh	8–15 ¢/kWh
Wave	–	exp. phase	20–35	Unclear	1500–3000	8–20 ¢/kWh	Unclear
Current	–	exp. phase	25–35	Unclear	2000–3000	8–15 ¢/kWh	5–7 ¢/kWh
OTEC	–	exp. phase	70–80	Unclear	Unclear	Unclear	Unclear

Note: The cost of grid-supplied electricity in urban areas ranges from 2-3 (¢/kWh (off-peak) to 15-25¢/kWh) (peak). See chapter 11.
a. Heat embodied in steam (or hot water in district heating), often produced by combined heat and power systems using forest residues, black liquor, or bagasse.

Source: Chapter 7.

UNDP (2002); Overview.

Exercise 9

It can be seen from the table above that wind power and photovoltaics are currently growing at some 30% a year. What do you think are the main factors that determine how fast an industry can grow – for example limits on financial resources, existence of a skilled workforce, size of the industry etc etc) Consider examples of other industries that have grown at a very fast rate.

In the Australian context, three renewable technologies seem particularly important

- Biomass – because of the large resources available, the potential to create both electricity and liquid and gas fuels, the inherent energy storage of the biomass fuel and the potential to integrate biomass energy generation into existing activities.
- Wind – the great global renewable success story of the last decade. It is a large resource and the technology has advanced significantly. Many countries are currently installing very large wind farms - Denmark now obtains more than 15% of its electricity from wind. Australia has a very large resource and a growing number of wind farms.
- Photovoltaics – although the contribution of this technology to current energy usage is very low the technology is very clean, has a wide range of possible applications, can be easily integrated into the built environment and promises significant cost reductions with increased production.

Some of the key issues to consider with renewables are

- Many renewable resources are variable and somewhat unpredictable – this has implications for their integration into existing energy systems, and energy storage
- Some renewables can be associated with significant land use issues – for example the burning of residues from native forest logging operations to generate electricity. Other examples of potentially undesirable impacts might be the visual intrusion of large wind farms in areas of scenic beauty. The key point is that you have to assess the sustainability of particular renewable technologies and particular applications in terms of systems and projects.
- Renewable technologies are generally responsible for far less GHG emissions than fossil fuels. Note, however, that there are questions with some biomass resources given the energy inputs required to grow, collect and use them.
- Renewables generally create less other pollution than fossil fuels. Note, however, that some forms of biomass use can create very significant air pollution.
- Many types of renewable energy are delivered 'free' to the place of use. This can greatly reduce the length of the energy conversion and supply chain, and this can have important benefits in terms of energy security. Consider that a solar hot water system will deliver a hot (well, perhaps only warm) shower even if your electricity and gas has been cut off.
- For many renewable technologies, the great expense is in up-front investment as the fuel is free and the equipment requires little maintenance. This is very different from most fossil-fuel plant where fuel costs over the plant's life are far more than the capital cost of the equipment. This has important implications for financing renewables.
- The different renewable technologies are in very different phases of the technology development cycle. Some are quite mature and it might be expected that cost reductions can arise from up-scaled manufacturing but not technical breakthroughs. Others are still undergoing rapid innovation with the potential for technological breakthroughs and rapidly falling costs.

Exercise 10

Does the use of residues from native forest logging operations to fuel small power stations actually create renewable energy? Explain your reasoning.

Summary

In this unit we have considered the present status and trends of our society's energy systems with regard to two key measures of sustainability – the provision of energy services to all, and the environmental impacts of the systems.

We then considered what would need to be achieved in order to make our energy systems more sustainable, and outlined a framework for taking action. The two key tools are energy efficiency and a transformation towards cleaner fossil fuels and renewables.

Finally, always keep in mind the role of systems thinking in getting our energy systems right

> Systems thinking. In today's complex world, designers and decision-makers too often define problems singly, without due attention to their causes or connections, and devise narrow "solutions" that merely shift the problem or create new ones in its place.
>
> RMI (2002)

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An Introduction to Solar Energy

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In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy.

Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000[1] tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions.

Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun.

Much of the world's required energy can be supplied directly by solar power. More still can be provided indirectly. The practicality of doing so will be examined, as well as the benefits and drawbacks. In addition, the uses solar energy is currently applied to will be noted.

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received. At night or during heavy cloudcover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container.

Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator. In general, there are three types of collectors and many forms of storage units.

The three types of collectors are flat-plate collectors, focusing collectors, and passive collectors.

Flat-plate collectors are the more commonly used type of collector today. They are arrays of solar panels arranged in a simple plane. They can be of nearly any size, and have an output that is directly related to a few variables including size, facing, and cleanliness. These variables all affect the amount of radiation that falls on the collector. Often these collector panels have automated machinery that keeps them facing the sun. The additional energy they take in due to the correction of facing more than compensates for the energy needed to drive the extra machinery.

Focusing collectors are essentially flat-plane collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collector. Although they can produce far greater amounts of energy at a single point than the flat-plane collectors can, they lose some of the radiation that the flat-plane panels do not. Radiation reflected off the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components.

Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation and convert it to heat naturally, without being designed and built to do so. All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make it worthwhile. Often their natural ability to convert radiation to heat is enhanced in some way or another (by being painted black, for example) and a system for transferring the heat to a different location is generally added.

People use energy for many things, but a few general tasks consume most of the energy. These tasks include transportation, heating, cooling, and the generation of electricity. Solar energy can be applied to all four of these tasks with different levels of success.

Heating is the business for which solar energy is best suited. Solar heating requires almost no energy transformation, so it has a very high efficiency. Heat energy can be stored in a liquid, such as water, or in a packed bed. A packed bed is a container filled with small objects that can hold heat (such as stones) with air space between them. Heat energy is also often stored in phase-changer or heat-of-fusion units. These devices will utilize a chemical that changes phase from solid to liquid at a temperature that can be produced by the solar collector. The energy of the collector is used to change the chemical to its liquid phase, and is as a result stored in the chemical itself. It can be tapped later by allowing the chemical to revert to its solid form. Solar energy is frequently used in residential homes to heat water. This is an easy application, as the desired end result (hot water) is the storage facility. A hot water tank is filled with hot water during the day, and drained as needed. This application is a very simple adjustment from the normal fossil fuel water heaters.

Swimming pools are often heated by solar power. Sometimes the pool itself functions as the storage unit, and sometimes a packed bed is added to store the heat. Whether or not a packed bed is used, some method of keeping the pool's heat for longer than normal periods (like a cover) is generally employed to help keep the water at a warm temperature when it is not in use.

Solar energy is often used to directly heat a house or building. Heating a building requires much more energy than heating a building's water, so much larger panels are necessary. Generally a building that is heated by solar power will have its water heated by solar power as well. The type of storage facility most often used for such large solar heaters is the heat-of-fusion storage unit, but other kinds (such as the packed bed or hot water tank) can be used as well. This application of solar power is less common than the two mentioned above, because of the cost of the large panels and storage system required to make it work. Often if an entire building is heated by solar power, passive collectors are used in addition to one of the other two types. Passive collectors will generally be an integral part of the building itself, so buildings taking advantage of passive collectors must be created with solar heating in mind.

These passive collectors can take a few different forms. The most basic type is the incidental heat trap. The idea behind the heat trap is fairly simple. Allow the maximum amount of light possible inside through a window (The window should be facing towards the equator for this to be achieved) and allow it to fall on a floor made of stone or another heat holding material. During the day, the area will stay cool as the floor absorbs most of the heat, and at night, the area will stay warm as the stone re-emits the heat it absorbed during the day.

Another major form of passive collector is thermosyphoning walls and/or roof. With this passive collector, the heat normally absorbed and wasted in the walls and roof is re-routed into the area that needs to be heated.

The last major form of passive collector is the solar pond. This is very similar to the solar heated pool described above, but the emphasis is different. With swimming pools, the desired result is a warm pool. With the solar pond, the whole purpose of the pond is to serve as an energy regulator for a building. The pond is placed either adjacent to or on the building, and it will absorb solar energy and convert it to heat during the day. This heat can be taken into the building, or if the building has more than enough heat already, heat can be dumped from the building into the pond.

Solar energy can be used for other things besides heating. It may seem strange, but one of the most common uses of solar energy today is cooling. Solar cooling is far more expensive than solar heating, so it is almost never seen in private homes. Solar energy is used to cool things by phase changing a liquid to gas through heat, and then forcing the gas into a lower pressure chamber. The temperature of a gas is related to the pressure containing it, and all other things being held equal, the same gas under a lower pressure will have a lower temperature. This cool gas will be used to absorb heat from the area of interest and then be forced into a region of higher pressure where the excess heat will be lost to the outside world. The net effect is that of a pump moving heat from one area into another, and the first is accordingly cooled.

Besides being used for heating and cooling, solar energy can be directly converted to electricity. Most of our tools are designed to be driven by electricity, so if you can create electricity through solar power, you can run almost anything with solar power. The solar collectors that convert radiation into electricity can be either flat-plane collectors or focusing collectors, and the silicon components of these collectors are photovoltaic cells.

Photovoltaic cells, by their very nature, convert radiation to electricity. This phenomenon has been known for well over half a century, but until recently the amounts of electricity generated were good for little more than measuring radiation intensity. Most of the photovoltaic cells on the market today operate at an efficiency of less than 15%[2]; that is, of all the radiation that falls upon them, less than 15% of it is converted to electricity. The maximum theoretical efficiency for a photovoltaic cell is only 32.3%[3], but at this efficiency, solar electricity is very economical. Most of our other forms of electricity generation are at a lower efficiency than this. Unfortunately, reality still lags behind theory and a 15% efficiency is not usually considered economical by most power companies, even if it is fine for toys and pocket calculators. Hope for bulk solar electricity should not be abandoned, however, for recent scientific advances have created a solar cell with an efficiency of 28.2%[4] efficiency in the laboratory. This type of cell has yet to be field tested. If it maintains its efficiency in the uncontrolled environment of the outside world, and if it does not have a tendency to break down, it will be economical for power companies to build solar power facilities after all.

Of the main types of energy usage, the least suited to solar power is transportation. While large, relatively slow vehicles like ships could power themselves with large onboard solar panels, small constantly turning vehicles like cars could not. The only possible way a car could be completely solar powered would be through the use of battery that was charged by solar power at some stationary point and then later loaded into the car. Electric cars that are partially powered by solar energy are available now, but it is unlikely that solar power will provide the world's transportation costs in the near future.

Solar power has two big advantages over fossil fuels. The first is in the fact that it is renewable; it is never going to run out. The second is its effect on the environment.

While the burning of fossil fuels introduces many harmful pollutants into the atmosphere and contributes to environmental problems like global warming and acid rain, solar energy is completely non-polluting. While many acres of land must be destroyed to feed a fossil fuel energy plant its required fuel, the only land that must be destroyed for a solar energy plant is the land that it stands on. Indeed, if a solar energy system were incorporated into every business and dwelling, no land would have to be destroyed in the name of energy. This ability to decentralize solar energy is something that fossil fuel burning cannot match.

As the primary element of construction of solar panels, silicon, is the second most common element on the planet, there is very little environmental disturbance caused by the creation of solar panels. In fact, solar energy only causes environmental disruption if it is centralized and produced on a gigantic scale. Solar power certainly can be produced on a gigantic scale, too.

> Among the renewable resources, only in solar power do we find the potential for an energy source capable of supplying more energy than is used.[5]
>
> Suppose that of the $4.5\text{x}10^{17}$ kWh per annum that is used by the earth to evaporate water from the oceans we were to acquire just 0.1% or $4.5\text{x}10^{14}$ kWh per annum. Dividing by the hours in the year gives a continuous yield of $2.90\text{x}10^{10}$ kW. This would supply 2.4 kW to 12.1 billion people.[6]

This translates to roughly the amount of energy used today by the average American available to over twelve billion people. Since this is greater than the estimated carrying capacity of the Earth, this would be enough energy to supply the entire planet regardless of the population.

Unfortunately, at this scale, the production of solar energy would have some unpredictable negative environmental effects. If all the solar collectors were placed in one or just a few areas, they would probably have large effects on the local environment, and possibly have large effects on the world environment. Everything from changes in local rain conditions to another Ice Age has been predicted as a result of producing solar energy on this scale. The problem lies in the change of temperature and humidity near a solar panel; if the energy producing panels are kept non-centralized, they should not create the same local, mass temperature change that could have such bad effects on the environment.

Of all the energy sources available, solar has perhaps the most promise. Numerically, it is capable of producing the raw power required to satisfy the entire planet's energy needs. Environmentally, it is one of the least destructive of all the sources of energy. Practically, it can be adjusted to power nearly everything except transportation with very little adjustment, and even transportation with some modest modifications to the current general system of travel. Clearly, solar energy is a resource of the future.

Footnotes

1. figure from Asimov, Isaac; *Understanding Physics: The Electron, Proton, and Neutron*; pg. 208
2. figure from Moore, Taylor; "Opening the Door for Utility Photovoltaics"; *EPRI Journal*, Jan./Feb.

1987; pg. 7

3. Ibid.; pg. 8
4. Ibid.; pg. 6
5. Kuecken, John A.; *How to Make Home Electricity From Wind, Water & Sunshine*; pg. 154
6. Ibid.; pp. 154-155

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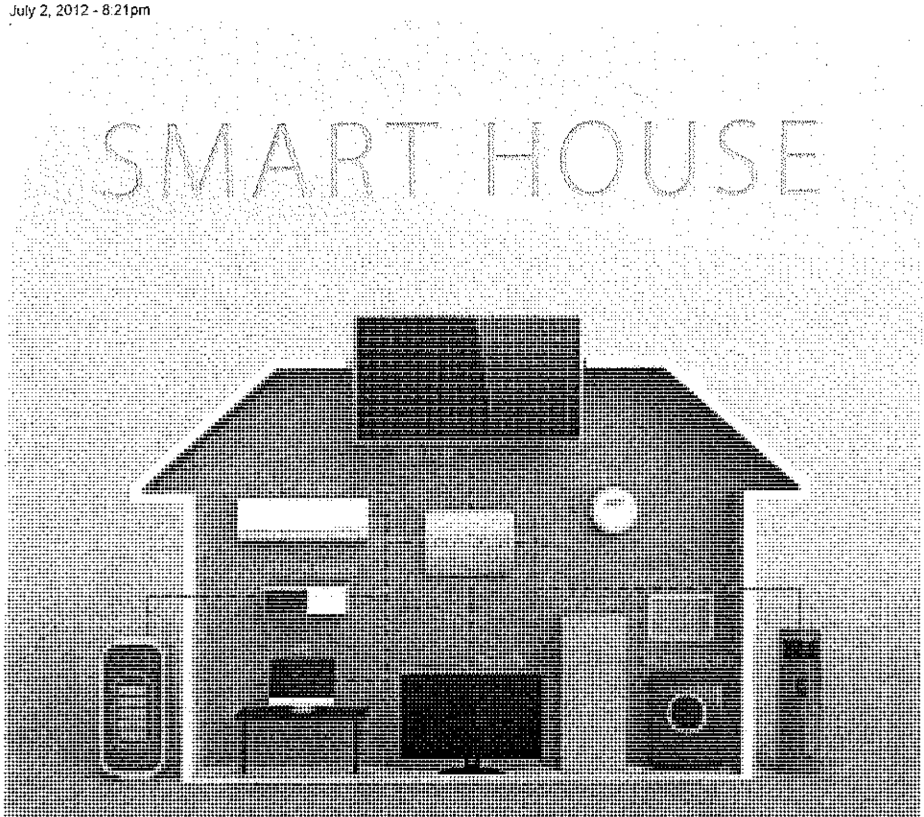
Note that Feneric is now more apt to be found through either Saugus.net or BU

Balance-of-System Equipment Required for Renewable Energy Systems

July 2, 2012 - 8:21pm



Both grid-connected and off-grid home renewable energy systems require additional "balance-of-system" equipment.

RELATED ARTICLES


Off-Grid or Stand-Alone Renewable Energy Systems


Grid-Connected Renewable Energy Systems


Planning for Home Renewable Energy Systems

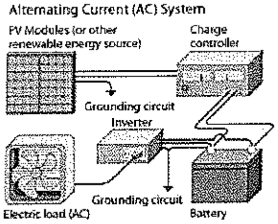
HOW DOES IT WORK?

- With a stand-alone system, depending on your needs, balance-of-system equipment could account for half of your total system costs.
- For both stand-alone and grid-connect systems, you will need power conditioning equipment, safety equipment, and meters and instrumentation.
- For stand-alone systems, you will also want batteries and charge controllers.

Whether you decide to connect your home renewable energy system to the electric grid or not, you will need to invest in some additional equipment (called "balance-of-system") to condition the electricity, safely transmit the electricity to the load that will use it, and/or store the electricity for future use.

With **stand-alone systems** -- those not connected to the electric grid -- the amount of equipment you will need to buy depends on what you want your system to do. In the simplest systems, the current generated by your system is connected directly to the equipment that it is powering (load). However, if you want to store power for use when your system isn't producing electricity, you will need to purchase batteries and a charge controller.

Alternating Current (AC) System



Depending on your needs, balance-of-system equipment for a stand-alone system could account for half of your total system costs. Your system supplier will be able to tell you exactly what equipment you will need for your situation, but typical balance-of-system equipment for a stand-alone system includes batteries, charge controller, power conditioning equipment, safety equipment, and meters and instrumentation.

A **grid-connected system** – one that is connected to the electric grid – requires balance-of-system equipment that allows you to safely transmit electricity to your loads and to comply with your power provider's grid-connection requirements. You will need power conditioning equipment, safety equipment, and meters and instrumentation.

BATTERIES FOR STAND-ALONE SYSTEMS

Batteries store electricity for use during times that your system is not producing electricity (the resource is not available). Batteries are most effective when used in wind and photovoltaic systems (variations in microhydropower resources can be more seasonal in nature, so batteries may be less useful).

The "deep-cycle" (generally lead-acid) batteries typically used for small systems last 5 to 10 years and reclaim about 80% of the energy channeled into them. In addition, these batteries are designed to provide electricity over long periods, and can repeatedly charge and discharge up to 80% of their capacity. Automotive batteries, which are shallow-cycle (and therefore prone to damage if they discharge more than 20% of their capacity), should not be used.

The cost of deep-cycle batteries depends on the type, capacity, climate conditions under which they will operate, frequency of maintenance, and chemicals used to store and release electricity. Wind or photovoltaic stand-alone system batteries need to be sized to store power sufficient to meet your needs during anticipated periods of cloudy weather or low wind. An inexpensive fossil fuel-powered back-up generator can be used to cover unanticipated or occasional slumps in the renewable resource.

For safety, batteries should be located in a space that is well ventilated and isolated from living areas and electronics, as they contain dangerous chemicals and emit hydrogen and oxygen gas while being charged. In addition, the space should provide protection from temperature extremes. Be sure to locate your batteries in a space that has easy access for maintenance, repair, and replacement. Batteries can be recycled when they wear out. Contact your system supplier for information on sizing your battery pack to meet your specific needs.

CHARGE CONTROLLERS FOR STAND-ALONE SYSTEMS

This device regulates rates of flow of electricity from the generation source to the battery and the load. The controller keeps the battery fully charged without over-charging it. When the load is drawing power, the controller allows the charge to flow from the generation source into the battery, the load, or both. When the controller senses that the battery is fully (or neerly fully) charged, it reduces or stops the flow of electricity from the generation source, or diverts it to an auxiliary or "shunt" load (most commonly an electric water heater).

Many controllers will also sense when loads have taken too much energy from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature can greatly extend the battery's lifetime.

The cost of controllers generally depends on the empere capacity at which your renewable system will operate and the monitoring features you want.

POWER CONDITIONING EQUIPMENT

For both stand-alone and grid-connected systems, you will need power conditioning equipment.

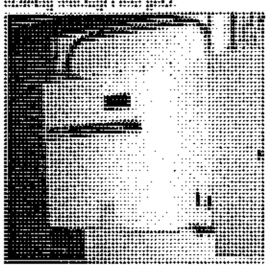
Most electrical appliances and equipment in the United States run on alternating current (AC) electricity. Virtually all the available renewable energy technologies, with the exception of some solar electric units, produce direct current (DC) electricity. To run standard AC appliances, the DC electricity must first be converted to AC electricity using inverters and related power conditioning equipment.

There are four basic elements to power conditioning:

- Conversion -- of constant DC power to oscilleting AC power
- Frequency of the AC cycles -- should be 60 cycles per second
- Voltage consistency -- extent to which the output voltage fluctuates
- Quality of the AC sine curve -- whether the shape of the AC wave is jagged or smooth.

Simple electric devices, such as hair dryers and light bulbs, can run on fairly low-quality electricity. A consistent voltage and smooth sine curve are more important for sensitive electronic equipment, such as computers, that cannot tolerate much power distortion.

Inverters condition electricity so that it matches the requirements of the load. If you plan to tie your system to the electricity grid, you will need to purchase conditioning equipment that can match the voltage, phase, frequency, and sine wave profile of the electricity produced by your system to that flowing through the grid.



A series of requirements for grid-interactive inverters have been developed by Underwriters Laboratories, a leading safety-testing and certification organization. These requirements, referred to as UL 1741, apply to power-producing stand-alone and grid-connected renewable energy systems. Either you or your installer should contact your power provider to see which models they accept for grid-connection; most simply require a grid-interactive inverter listed by an organization such as Underwriters Laboratories.

These factors affect the cost of inverters:

- Application (utility-interconnected, stand-alone, or both)
- Quality of the electricity it needs to produce for stand-alone
- Voltage of the incoming current
- AC wattage required by your loads (for stand-alone systems only)
- Power required for the starting surge of some equipment
- Additional inverter features such as meters and indicator lights.

When you size your inverter, be sure to plan for any future additional loads you might have. In the case of a grid-tied system in which you want to enlarge your renewable energy system, it is often cheaper to purchase an inverter with a larger input and output rating than you currently need than to replace it with a larger one later.

SAFETY EQUIPMENT

Safety features protect stand-alone and grid-connected small renewable energy systems from being damaged or harming people during events like lightening events, power surges, or malfunctioning equipment.

- Safety disconnects -- Automatic and manual safety disconnects protect the wiring and components of your small renewable energy system from power surges and other equipment malfunctions. They also ensure that your system can be shut down safely for maintenance and repair. In the case of grid-connected systems, safety disconnects ensure that your generating equipment is isolated from the grid, which is important for the safety of people working on the grid transmission and distribution systems.
- Grounding equipment -- This equipment provides a well-defined, low-resistance path from your system to the ground to protect your system against current surges from lightening strikes or equipment malfunctions. You will want to ground both your wind turbine or photovoltaics unit itself and your balance-of-system equipment. Be sure to include any exposed metal (such as equipment boxes) that might be touched by you or a service provider.
- Surge protection -- These devices also help protect your system in the event that it, or nearby power lines (in the case of grid-connected systems), are struck by lightening.

A local electrician or your installer should be able to provide you with more information on the safety features required for your particular situation. For additional information on safety and electrical installation requirements, consult the National Electric Code NFPA 70.

METERS AND INSTRUMENTATION

Meters end other instruments allow you to monitor your small renewable energy system's battery voltage, the amount of power you are consuming, and the level at which your batteries are charged, for example.

If you are connecting your system to the electricity grid, you will need meters to keep track of the electricity your system produces and the electricity you use from the grid. Some power providers will allow you to use a single meter to record the excess electricity your system feeds back into the grid (the meter spins forward when you are drawing electricity, and backward when your system is producing it).

Power providers that don't allow such a net metering arrangement require that you install a second meter to measure the electricity your system feeds into the grid.

LEARN MORE

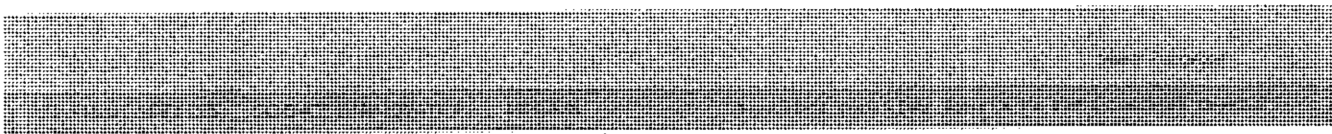
- Reducing Your Electricity Use
- Planning for a Small Renewable Energy System
- Grid-Connected Home Energy Systems
- Stand-Alone Home Energy Systems
- Small Solar Electric Systems
- Small Wind Electric Systems
- Microhydropower Systems
- Hybrid Wind and Solar Electric Systems

EXTERNAL RESOURCES

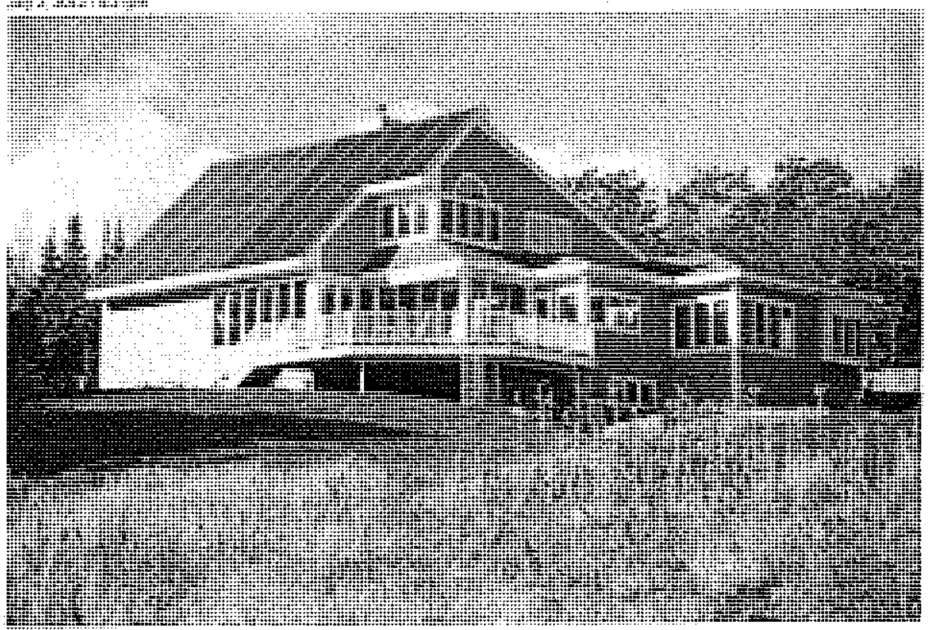
Institute of Electrical and Electronics Engineers

Inverters, Converters, and Controllers for Use in Stand-Alone Independent Power Systems

Database of State Incentives for Renewables and Efficiency



Grid-Connected Renewable Energy Systems



When connecting a home energy system to the electric grid, research and consider equipment required as well as your power provider's requirements and agreements. | Photo courtesy of Solar Design Associates, Inc.

RELATED ARTICLES

Balance-of-System Equipment Required for Renewable Energy Systems

Planning a Home Solar Electric System

Planning for Home Renewable Energy Systems

WHAT ARE THE KEY FACTS?

- While renewable energy systems are capable of powering houses and small businesses without any connection to the electricity grid, many people prefer the advantages that grid-connection offers.
- Aside from the major small renewable energy system components, you will need to purchase some additional equipment to connect your system to the electric grid.
- Grid-connection requirements vary widely, but regulations usually have to do with safety and power quality, contracts (which may require liability insurance), and metering and rates.

While renewable energy systems are capable of powering houses and small businesses without any connection to the electricity grid, many people prefer the advantages that grid-connection offers.

A grid-connected system allows you to power your home or small business with renewable energy during those periods (daily as well as seasonally) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, eliminating the expense of electricity storage devices like batteries.

In addition, power providers (i.e., electric utilities) in most states allow net metering, an arrangement where the excess electricity generated by grid-connected reneweble energy systems "turns back" your electricity meter as it is fed back into the grid. If you use more electricity than your system feeds into the grid during a given month, you pay your power provider only for the difference between what you used and what you produced.

Some of the things you need to know when thinking about connecting your home energy system to the electric grid include:

- Equipment required to connect your system to the grid
- Grid-connection requirements from your power provider
- State and community codes and requirements

EQUIPMENT REQUIRED FOR GRID-CONNECTED SYSTEMS

Aside from the major small renewable energy system components, you will need to purchase some additional equipment (called **"balance-of-system"**) in order to safely transmit electricity to your loads and comply with your power provider's grid-connection requirements. You may need the following items:

- Power conditioning equipment
- Safety equipment
- Meters and instrumentation.

Because grid-connection requirements vary, you or your system supplier/installer should contact your power provider to learn about its specific grid-connection requirements before purchasing any part of your renewable energy system. See our page on balance-of-system equipment requirements for small renewable energy systems.

GRID-CONNECTION REQUIREMENTS FROM YOUR POWER PROVIDER

Currently, requirements for connecting distributed generation systems—like home renewable energy or wind systems—to the electricity grid vary widely. But all power providers face a common set of issues in connecting small renewable energy systems to the grid, so regulations usually have to do with safety and power quality, contracts (which may require liability insurance), and metering and rates.

You will need to contact your power provider directly to learn about its specific requirements. If your power provider does not have an individual assigned to deal with grid-connection requests, try contacting your state utilities commission, state utility consumer advocate group (represents the interests of consumers before state and federal regulators and in the courts), state consumer representation office, or state energy office.

ADDRESSING SAFETY AND POWER QUALITY FOR GRID CONNECTION

Power providers want to be sure that your system includes safety and power quality components. These components include switches to disconnect your system from the grid in the event of a power surge or power failure (so repairmen are not electrocuted) and power conditioning equipment to ensure that your power exactly matches the voltage and frequency of the electricity flowing through the grid.

In an attempt to address safety and power quality issues, several organizations are developing national guidelines for equipment manufacture, operation, and installation (your supplier/installer, a local renewable energy organization, or your power provider will know which of the standards apply to your situation, and how to implement them):

- The Institute of Electrical and Electronics Engineers (IEEE) has written a standard that addresses all grid-connected distributed generation including renewable energy systems. IEEE 1547-2003 provides technical requirements and tests for grid-connected operation. See the IEEE Standards Coordinating Committee on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage for more information.
- Underwriters Laboratories (UL) has developed UL 1741 to certify inverters, converters, charge controllers, and output controllers for power-producing stand-alone and grid-connected renewable energy systems. UL 1741 verifies that inverters comply with IEEE 1547 for grid-connected applications.
- The National Electrical Code (NEC), a product of the National Fire Protection Association, deals with electrical equipment and wiring safety.

Although states and power providers are not federally mandated to adopt these codes and standards, a number of utility commissions and legislatures now require regulations for distributed generation systems to be based on the IEEE, UL, and NEC standards.

In addition, some states are now "pre-certifying" specific models of equipment as safe to connect to the state electricity grid.

CONTRACTUAL ISSUES FOR GRID-CONNECTED SYSTEMS

When connecting your small renewable energy system to the grid, you will probably need to sign an interconnection agreement with your power provider. In your agreement, power providers may require you to do the following:

- Carry liability insurance -- Liability insurance protects the power provider in the event of accidents resulting from the operation of your system. Most homeowners carry at least $100,000 of liability through their homeowner insurance policies (although you should verify that your policy will cover your system), which is often sufficient. Be aware, however, that your power provider may require that you carry more. Some power providers may also require you to indemnify them for any potential damage, loss, or injury caused by your system, which can sometimes be prohibitively expensive.
- Pay fees and other charges -- You may be asked to pay permitting fees, engineering/inspection fees, metering charges (if a second meter is installed), and stand-by charges (to defray the power provider's cost of maintaining your system as a backup power supply). Identify these costs early so you can factor them into the cost of your system, and don't be afraid to question any that seem inappropriate.

In addition to insurance and fees, you may find that your power provider requires a great deal of paperwork before you can move ahead with your system. However, power providers in several states are now moving to streamline the contracting process by simplifying agreements, establishing time limits for processing paper work, and appointing representatives to handle grid-connection inquiries.

METERING AND RATE ARRANGEMENTS FOR GRID-CONNECTED SYSTEMS

With a grid-connected system, when your renewable energy system generates more electricity than you can use at that moment, the electricity goes onto the electric grid for your utility to use elsewhere. The Public Utility Regulatory Policy Act of 1978 (PURPA) requires power providers to purchase excess power from grid-connected small renewable energy systems at e rate equel to what it costs the power provider to produce the power itself. Power providers generally implement this requirement through various metering arrangements. Here are the metering arrangements you are likely to encounter:

- Net purchase and sale -- Under this arrangement, two uni-directional meters are installed: one records electricity drawn from the grid, and the other records excess electricity generated and fed back into the grid. You pay retail rate for the electricity you use, and the power provider purchases your excess generation at its avoided cost (wholesale rate). There may be a significant difference between the retail rate you pay and the power provider's avoided cost.
- Net metering -- Net metering provides the greatest benefit to you as a consumer. Under this arrangement, a single, bi-directional meter is used to record both electricity you draw from the grid and the excess electricity your system feeds beck into the grid. The meter spins forward as you draw electricity, and it spins backward as the excess is fed into the grid. If, at the end of the month, you've used more electricity than your system has produced, you pay retail price for that extra electricity. If you've produced more than you've used, the power provider generally pays you for the extra electricity at its avoided cost. The real benefit of net metering is that the power provider essentially pays you retail price for the electricity you feed back into the grid.

Some power providers will now let you carry over the balance of any net extra electricity your system generates from month to month, which can be an advantage if the resource you are using to generate your electricity is seasonal. If, at the end of the year, you have produced more than you've used, you forfeit the excess generation to the power provider.

LEARN MORE

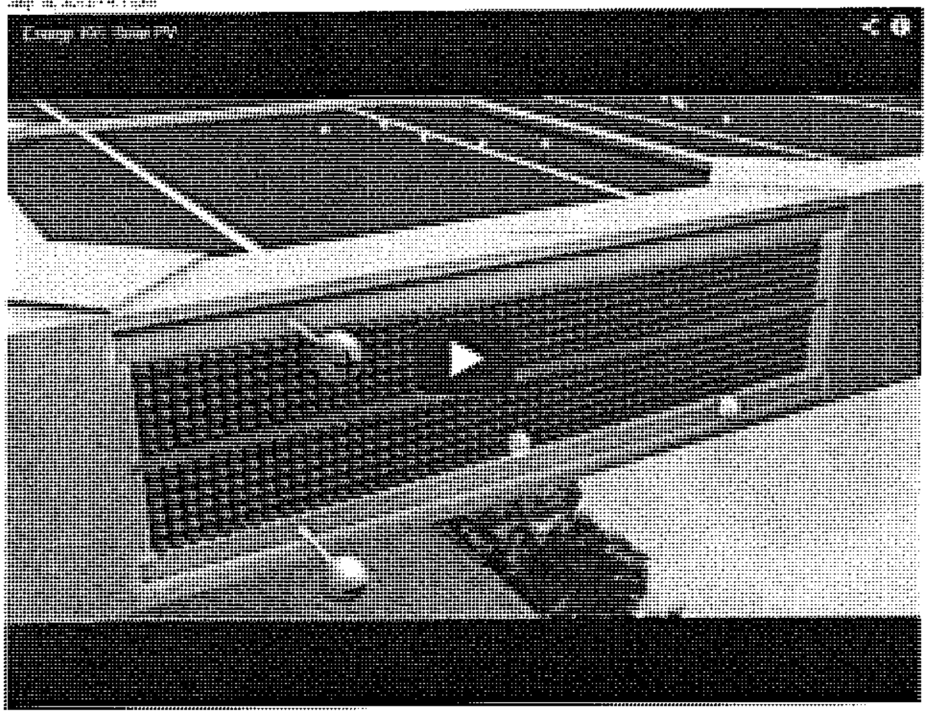
- **Reducing Your Electricity Use**
- **Planning for a Small Reneweble Energy System**
- **Balance-of-System Equipment Required for Renewable Energy Systems**
- **Stand-Alone Home Energy Systems**
- **Small Solar Electric Systems**
- **Small Wind Electric Systems**
- **Microhydropower Systems**
- **Hybrid Wind and Solar Electric Systems**

EXTERNAL RESOURCES

Database of State Incentives for Renewables and Efficiency

Green Power Network's Net Metering Policies Page

Small Solar Electric Systems



A small solar electric or photovoltaic system can be a reliable and pollution-free producer of electricity for your home or office.

RELATED ARTICLES

NREL's PV Incubator: Where Solar Photovoltaic Records Go to be Broken

Installing and Maintaining a Home Solar Electric System

Department of Energy Official in Newark, Delaware, to Highlight $168 Million for Solar Energy Projects

WHAT ARE THE KEY FACTS?

- Because PV technologies use both direct and scattered sunlight to create electricity, the solar resource across the United States is ample for home solar electric systems.
- Solar cells—the basic building blocks of a PV system -- consist of semiconductor materials.
- A typical home solar electric, or PV, system consists solar cells, modules or panels (which consist of solar cells), arrays (which consist of modules), and balance-of-system parts.

A small solar electric or photovoltaic (PV) system can be a reliable and pollution-free producer of electricity for your home or office. Small PV systems also provide a cost-effective power supply in locations where it is expensive or impossible to send electricity through conventional power lines.

Because PV technologies use both direct and scattered sunlight to create electricity, the solar resource across the United States is ample for home solar electric systems. However, the amount of power generated by a solar system at a particular site depends on how much of the sun's energy reaches it. Thus, PV systems, like all solar technologies, function most efficiently in the southwestern United States, which receives the greatest amount of solar energy.

Because of their modularity, PV systems can be designed to meet any electrical requirement, no matter how large or how small. You can connect them to an electric distribution system (**grid-connected**), or they can **stand alone** [10610](off-grid). You can also use PV technology to provide **outdoor lighting**.

See our other pages for more information on **Planning A Home Solar Electric System** and **Installing and Maintaining A Home Solar Electric System**.

TYPES OF SOLAR CELLS

Solar cells—the basic building blocks of a PV system -- consist of semiconductor materials. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms. This phenomenon is called the "photoelectric effect." These free electrons then travel into a circuit built into the solar cell to form electrical current. Our **Solar Power Basics animation** shows a simulation of the photoelectric effect. Only sunlight of certain wavelengths will work efficiently to create electricity. PV systems can still produce electricity on cloudy days, but not as much as on a sunny day.

The performance of a solar (or PV) cell is measured in terms of its efficiency at converting sunlight into electricity. There are a variety of solar cell materials available, which vary in conversion efficiency.

SEMICONDUCTOR MATERIALS

Silicon remains the most popular material for solar cells, including these types:

- Monocrystalline or single crystal silicon
- Multicrystalline silicon
- Polycrystalline silicon
- Amorphous silicon.

The absorption coefficient of a material indicates how far light with a specific wavelength (or energy) can penetrate the material before being absorbed. A small absorption coefficient means that light is not readily absorbed by the material. Again, tha absorption coefficient of a solar cell depends on two factors: the material making up the cell, and the wavelength or energy of the light being absorbed.

The bandgap of a semiconductor material is an amount of energy. Specifically, the bandgap is the minimum energy needed to move an electron from its bound state within an atom to a frea state. This free state is where the electron can be involved in conduction. The lower energy level of a semiconductor is called the "valance band." The higher energy level where an electron is free to roam is called the "conduction band." The bandgap (often symbolized by Eg) is the energy difference between the conduction band and valence band.

Solar cell material has an abrupt edge in its absorption coefficient; because light with energy below the material's bandgap cannot free an electron, it isn't absorbed.

THIN FILM

Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film technology has made it possible for solar cells to now double as these materials:

- Rooftop or solar shingles
- Roof tiles
- Building facades
- Glazing for skylights or atria.

Thin-film rooftop or solar shingles, made with various non-crystalline materials, are just now starting to enter the residential market. The following are benefits of these solar shingles:

- Attractive integration into homes
- Dual purpose -- serves as both roofing material and pollution-free electricity producer
- Durability.

Current issuas with commercially available solar shingles include their lower efficiencies and greater expense compared with the standard home solar electric system.

SMALL SOLAR ELECTRIC MODULES

The basic PV or solar cell typically produces only a small amount of power. To produce more power, solar cells (about 40) can be interconnected to form panels or modules. PV modules range in output from 10 to 300 Watts. If more power is needed, several modules can be installed on a building or at ground-level in a rack to form a PV array.

In addition to solar cells, a typical PV module or solar panel consists of these components:

- A transparent top surface, usually glass
- An encapsulant -- usually thin sheets of ethyl vinyl acetate that hold together the top surface, solar cells, and rear surface
- A rear layer -- a thin polymer sheet, typically Tedlar, that prevents the ingress of water and gases
- A frame around the outer edge, typically aluminum.

Energy performance ratings for PV modules include the following:

- Peak Watt -- Measures the maximum power of a module under laboratory conditions of relatively high light level, favorable air mass, and low cell temperature. These conditions are not typical in the real world.
- Normal operating cell temperature -- Measures a module's nominal operating cell temperature after the module first equilibrates with a specified ambient temperature. It results in a lower Watt value than the peak-Watt rating, but it is probably more realistic.

- AMPM Standard -- Measures the performance of a solar module under more realistic operating conditions. It considers the whole day rather than "peak" sunshine hours, based on the description of a standard solar global-average day (or a practical global average) in terms of light levels, ambient temperature, and air mass.

HOME SOLAR ELECTRIC SYSTEM ARRAYS

For home solar electric systems, the most common array design uses flat-plate PV modules or panels. These panels can either be fixed in place or allowed to track the movement of the sun.

The simplest PV array consists of flat-plate PV modules in a fixed position. These are some advantages of fixed arrays:

- No moving parts
- No need for extra equipment
- A lightweight structure.

These features make them suitable for many locations, including most residential roofs. Because the panels are fixed in place, their orientation to the sun is usually at an angle that is less than optimal. Therefore, less energy per unit area of array is collected compared with that from a tracking array. This drawback, however, must be balanced against the higher cost of the tracking system.

ENERGY PERFORMANCE

Solar arrays are designed to provide specified amounts of electricity under certain conditions. The following factors are usually considered when determining array energy performance:

- Characterization of solar cell electrical performance
- Determination of degradation factors related to array design and assembly
- Conversion of environmental considerations into solar cell operating temperatures
- Calculation of array power output capability.

The amount of electricity required may be defined by any one or a combination of the following performance criteria:

- Power output -- power (Watts) available at the power regulator, specified either as peak power or average power produced during one day.
- Energy output -- the amount of energy (Watt-hour or Wh) produced during a certain period of time. The parameters are output per unit of array area (Wh/m²), output per unit of array mass (Wh/kg), and output per unit of array cost (Wh/$).
- Conversion efficiency -- defined as "energy output from array" ÷ "energy input from sun" × 100%.

This last parameter is often given as a power efficiency, equal to "power output from array" ÷ "power input from sun" × 100%. Power is typically given in units of Watts (W), and energy is typically in units of Wh, or the power in Watts supplied during an hour.

To ensure the consistency and quality of PV systems and increase consumer confidence in system performance, various groups -- such as the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), and the American Society for Testing and Materials (ASTM) -- are working on standards and performance criteria for PV systems.

HOME SOLAR ELECTRIC COMPONENTS

A typical home solar electric system consists of these components:

- Solar cells
- Modules or panels (which consist of solar cells)
- Arrays (which consist of modules)
- Balance-of-system parts.

The balance-of-system equipment required depends on whether the system is a stand-alone system, connected to the electric grid, or a hybrid system. Balance-of-system equipment can include:

- Mounting racks and hardware for the panels
- Wiring for electrical connections
- Power conditioning equipment, such as an inverter
- Batteries for electricity storage (optional)
- Stand-by gasoline electric generator.

LEARN MORE

- Planning a Home Solar Electric System
- Installing and Maintaining a Home Solar Electric System
- Reducing Your Electricity Use
- Planning for a Small Renewable Energy System
- Balance-of-System Equipment Required for Renewable Energy Systems
- Grid-Connected Home Energy Systems
- Stand-Alone Home Energy Systems
- Hybrid Wind and Solar Electric Systems

EXTERNAL RESOURCES

PV Watts Evaluation Tool - National Renewable Energy Laboratory

In My Backyard Solar and Wind Estimator - National Renewable Energy Laboratory

Photovoltaic Basics

Wind Energy

Paul N. Rowley

Introduction

A wind turbine is designed to extract the wind's kinetic energy and convert this to electricity as efficiently as possible. This course examines aspects of material and component design, along with principles of aerodynamics, mechanical and electrical engineering.

Course Aims and objectives

Aims:

- To describe the components of a wind turbine
- To examine the interaction of the wind with the rotor
- To relate the loadings on the turbine to its fatigue response
- To examine the process of electricity generation and its supply to a grid system

Objectives:

After completing this course, you should;

- Have an overall understanding of the structure of a wind turbine, its components and their function
- Realise how the wind's energy is extracted and the principles involved
- Know the principles of electricity generation, the hardware required and the technical factors involved in supplying electricity to a grid

Section 1 - System Design and Components

Introduction

Wind turbine technology is advancing rapidly as lessons are learned from two decades of operational experience, and as advances in materials take effect. This section describes the individual components of a horizontal axis wind turbine, and examines the materials aspects of its design.

The section comprises of a collection of relatively detailed resources regarding the hardware of wind energy technology. There is information on the design and a description of all the major turbine components, from the rotor to the tower foundations.

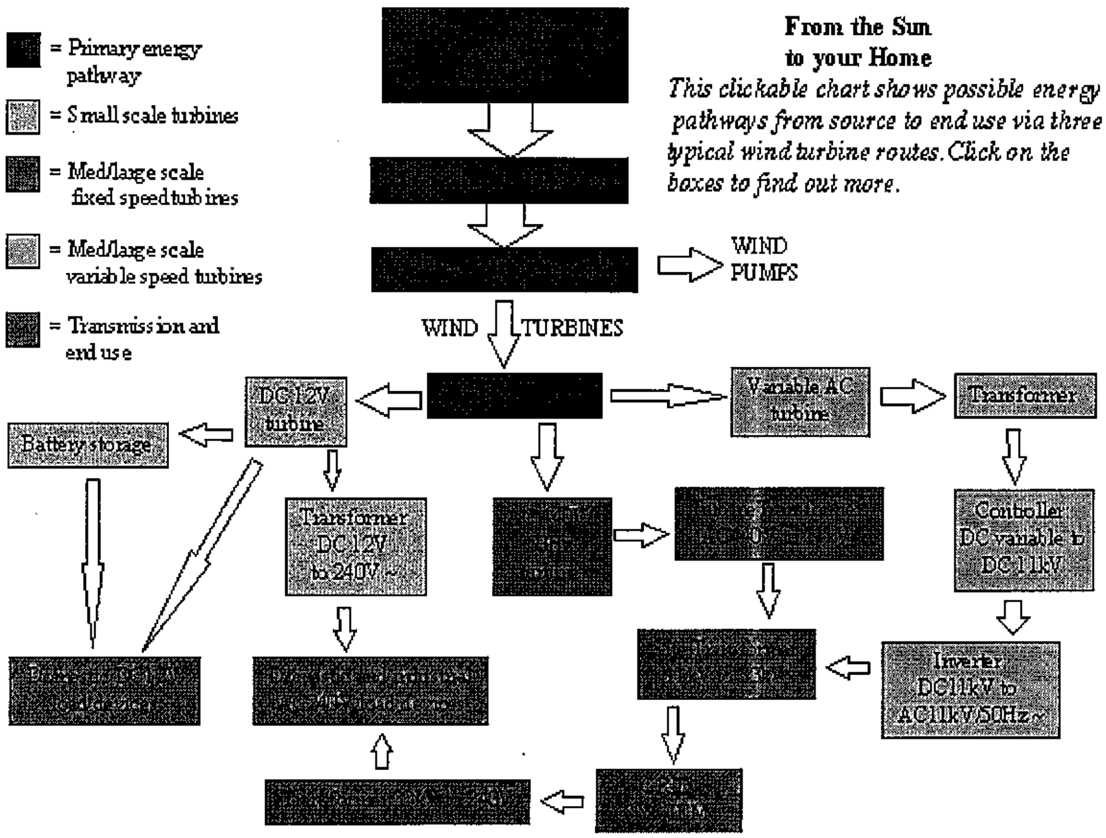
OVERVIEW

Firstly, we shall study the methods by which the kinetic energy of the wind is converted into electrical energy by a wind turbine system. This course deals predominantly with large scale (200kW per unit and up) grid connected systems, such as are seen on modern wind farms. However, small scale domestic and stand alone systems are important, and many of these resources are relevant to smaller systems.

The sequence of events in the production and transmission of wind generated electricity can be summarised as follows:

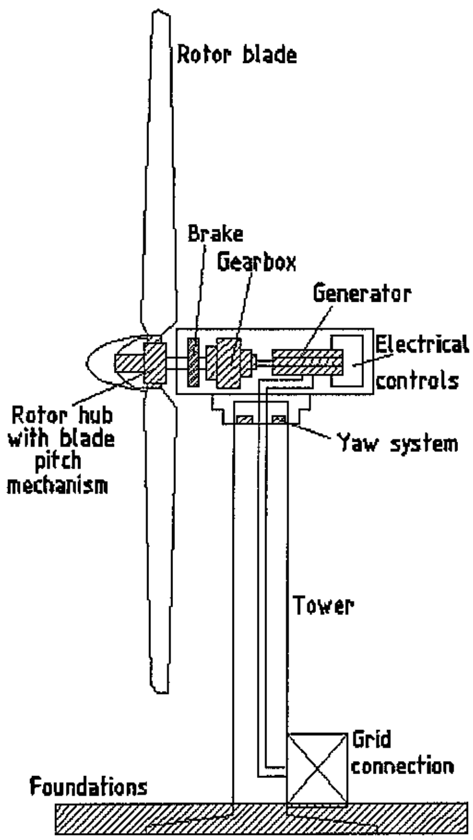
1. A torque is produced as the wind interacts with the rotor.
2. The relatively low rotational frequency of the rotor is increased via a gearbox.
3. The gearbox output shaft turns a generator.
4. The electricity produced by the generator passes through the turbine controller and circuit breakers and is stepped up to an intermediate voltage by the turbine transformer.
5. The site cabling system delivers the electricity to the site transformer via the site control and circuit breaker system.
6. The site transformer steps up the voltage to the grid value.
7. The grid system transmits the electricity to the locality of its end use.
8. Transformer substations reduce the voltage to domestic or industrial values.
9. Local low voltage networks transmit the electricity to homes, offices and factories.

The diagram below shows various technological routes for this process:



We shall now examine the hardware required to facilitate the first steps in this chain:

As a starting point, the diagram below shows the main components of a grid-connected medium or large scale wind turbine:



THE ROTOR - MATERIALS AND DESIGN

Rotor blade design has advanced with knowledge from wing technology, and utilises the aerodynamic lift forces that an airfoil experiences in a moving stream of air. The shape of the blade and its angle in relation to the relative wind direction both affect its aerodynamic performance.

The rotor assembly may be placed either

1. upwind of the tower and nacelle, so receiving wind unperturbed by the tower itself or
2. downwind of the tower, which enables self alignment of the rotor with the wind direction (yawing), but causes the wind to be deflected and made turbulent by the tower before arriving at the rotor (tower shadow).

The lifetime of a rotor is related to the variable loads and environmental conditions that it experiences during service. Therefore, the rotor's inherent mechanical properties and design will affect its useful service life.

The materials used in modern wind turbine blade construction may be grouped into three main classes:

1. Wood (including laminated wood composites)
2. Synthetic composites (usually a polyester or epoxy matrix re-inforced by glass fibres)
3. Metals (predominantly steel or aluminium alloys)

Wood Laminates

Wood has a natural composite structure of low density, good strength and fatigue resistance. Many commercial small turbine blades (up to about 5 metres in length) are hand shaped or machined from prepared lengths of solid wood. The blades are then painted or varnished, and the leading edge is protected by an epoxy resin-impregnated tape (the same tape is used on the leading edge of helicopter blades).

An alternative and improved use of wood is to shape blades from bonded layers of wood sheet, using advanced composite construction technology. The blades are made from vacuum bonded sheets glued with epoxy resin, a technique developed for building racing yachts and boats. By varying the type of wood used, and the direction of its grain when laid up, a composite material is produced which has good specific strength, flexural and fatigue properties.

A manufacturer in the USA (Gougen Bros., Michigan) has produced laminated wood blades up to 43m in diameter. In the UK, the technique was pioneered by Howdens Ltd. and is being developed by the Wind Energy Group (WEG).

Synthetic Composites

In recent years, synthetic composite materials have become common in the turbine blade industry, due to;

- their relatively low density compared with metals
- their generally good tensile properties.

Glass reinforced plastic (GRP) blades are cheap, quite strong and have moderate fatigue properties (Module 3.3). However, long term fatigue test data for wind turbines are rare, and so the ultimate fatigue life of blades has been seldom experienced.

GRP is very versatile in forming, and can be laid up in female half-moulds (using glass fibre mats soaked in a polyester or epoxy resin) before the two airfoil halves are glued together.

Blades can also be fabricated using the filament winding process, which developed from military technology to make missile bodies. In this, a resin soaked glass strand is wound around a former to make both the airfoil shape and the box-shaped strengthening spar. This fabrication technique gives good strength and flexibility.

Carbon and aramid (predominantly Kevlar) fibre reinforced composites offer the best all round mechanical properties of all the potential blade materials. Unfortunately, it is their cost, rather than their performance which governs their use in the wind turbine industry, and few manufacturers are actively producing carbon fibre blades.

The aramid group of materials offer a cheaper route than carbon, and give material properties which are somewhat of a compromise between expensive carbon and cheaper glass. The aramids, unlike carbon, are non-electrically conducting, which is an advantage in situations where galvanic corrosion may occur, such as at the blade root/hub junction, and prevents the need for system protection against lightning strikes.

Metals

Steel is a common material, and its mechanical properties are well understood. Although it has good fatigue strength (see Module 3.3), it is relatively dense, and so steel blades tend to be heavy. This results in large oscillating gravity loads on the rotor fixings and bearings as large blades rotate from upwards (pressing down in compression) to downwards (pulling out in tension).

Using the "spar and skin" construction method, steel has traditionally been used for the largest turbine rotors, such as those fitted to the Boeing MOD2 (91m), the MOD 5b (98m) in the USA, and to the 3MW LS1 machine in Orkney (60 m).

Weight for weight, aluminium has better tensile properties than steel, and was once the material of choice for blade manufacturers, especially in the US. It is versatile in construction, and can be extruded, pultruded or used in sheet form. In the most common method of blade fabrication, sheets are supported over ribs or a spar, and riveted into place, as on NASA's early MOD-OA machine. Unfortunately, its fatigue strength deteriorates rapidly in service. This can have serious consequences in situations where stress amplitudes are large, and where the number of cyclic loadings is high. These problems are compounded in cases where component design is flawed.

Novel Materials

As the trend at the present time is toward composite materials, it seems that the development of turbine blade technology will be in this direction.

Hybrid composites are being developed which offer a combination of the constituent materials' separate properties. Wood/fibre/epoxy laminate materials potentially combine excellent strength and fatigue properties with low weight.

ARALL, developed in The Netherlands, is a laminated sheet material which combines aluminium with thin aramid/epoxy layers, and exhibits excellent fatigue crack growth and tensile strength properties. Hybrid composites may become commercially acceptable in the future if production costs can be made competitive with traditional blade materials.

THE NACELLE COMPONENTS

The nacelle houses the turbine's drive train and generator assemblies, plus the yaw mechanism and any control components.

The main (or slow speed) shaft

Transferring the primary torque to the gear train from the rotor assembly, the main shaft is usually supported on journal bearings. Due to its high torque loadings, the main shaft is susceptible to fatigue failure. Thus, effective pre-service non-destructive testing procedures are advisable for this component.

Disc brake

This may be situated either on the main shaft before the gearbox, or on the high speed shaft after the gearbox. The latter arrangement requires a smaller (and cheaper) brake assembly in order to supply the necessary torque to slow the rotor. However, this arrangement does not provide the most immediate control of the rotor, and in the event of a gearbox failure, braking control of the rotor is lost.

Transmission

Th electrical output of wind turbines has to be compatible with the frequency (50 - 60 Hz) and voltage of the local distribution grid. The rotor's frequency is typically about 0.5Hz, and so the increase in frequency is obtained by a combination of a gearbox and a multi-pole generator. Most commercial generators have 4 or 6 pole pairs, and so a step-up gear ratio of about 25:1 is required.

The simplest method to drive the generator is directly via the main shaft from the rotor without a gearbox. Energy conversion efficiency is optimised, due to the elimination of gearbox power losses. However, special slow-speed generators are required, which need large rotor and stator diameters incorporating about 50 poles in order to provide the required frequency. A small number of manufacturers are now offering these systems on a commercial basis.

Most small sized (50 to 150kW) turbines utilise one or two stage parallel shaft transmissions (which use helical gears to minimise noise and power losses). The larger commercial turbines (150 to 750kW) most commonly use epicyclic or planetry transmissions, which have the advantage that the output shaft is in line with the main shaft (thereby reducing stress and power losses in the drive train), with a corresponding reduction in size.

Hydraulic transmissions should, in principle, offer a simple method of power transmission which is well matched to the torque characteristics of the rotor. However, their efficiencies are low, and no manufacturers use hydraulic transmission systems at the present time.

The generator

The generator converts the mechanical energy of the input shaft to electrical energy. It must be compatible at input with the rotor and gearbox assemblies, but at output with the utility's power distribution (if connected to a grid) or to local power requirements (if the turbine is part of a stand alone system).

Very small wind turbines may have generators producing DC power, which may then be used to power low voltage loads (usually at 12 volts), to charge a bank of batteries, or may be passed through an inverter system for the supply of higher voltage AC power to a grid network or local distribution.

If a grid-connected turbine is fitted with an AC generator, this must produce power which is in phase with the utility's grid supply. Many commercial grid-connected turbines use induction A.C. generators, whose magnetising current is drawn from the grid, ensuring that the generator's output frequency is locked to that of the utility and so controlling the rotor speed within limits.

Synchronous generators produce electricity in synchronisation with the generator's rotating shaft frequency. Thus, the rotor speed of grid-connected turbines must exactly match the utility supply frequency. Both capacitor excited induction generators and synchronous generators can operate in stand alone situations, not connected to a grid.

The Yaw Assembly

It is necessary for the rotor axis to be aligned with the wind direction in order to extract as much of the wind's kinetic energy as possible. The smallest upwind machines (up to 25 kW) most commonly use tail vanes to keep the machine aligned with the wind. However, larger wind turbines with upwind rotors require active yaw control to align the machine with the wind. To enable this, when a change in wind direction occurs sensors activate the yaw control motor, which rotates the nacelle and rotor assembly until the turbine is properly aligned.

Downwind machines of all sizes may possess passive yaw control, which means that they can self-align with the wind direction without the need for or a tail vane or yaw drive.

THE TOWER

The tower of a wind turbine supports the nacelle assembly (which may weigh many tonnes), and elevates the rotor to a height at which the wind velocity is significantly greater and less perturbed than at ground level.

Modern towers can be over 50 metres high, and therefore their structure must withstand significant loads, originating from gravitational, rotational and wind thrust loads. In addition, the tower must be able to withstand environmental attack for the design life of the turbine, which may be 20 years or more.

Fixed tubular towers

These are manufactured from tapered steel or concrete. Steel towers may be welded or pressed together in sections on site or in the factory. Spun-concrete towers are generally less flexible than steel towers and so offer improved sound deadening qualities (i.e. they do not transmit or amplify rotationally-induced vibrations)

Fixed latticed (or trussed) towers

These are relatively cheap to erect, and require less substantial foundations than tubular towers due to their spreading of the structure loads over a wider area. Although at one time lattice towers were commonly used for medium and large scale machines, today they have lost favour in the EU, partly due to their lack of aesthetic appeal.

Erectable guyed towers

These towers have a significant cost advantage compared to other types. Guyed towers may be raised or lowered using a gin pole, without the need for a crane. Therefore ground-level rotor and nacelle maintenance is possible. However, they utilise more ground area due to the need to spread the guy cables quite widely, which may be a handicap if machines are used for cultivating crops around the wind turbine bases. Animal farming is not so affected. The mast may be of steel pipe (very small machines) or tube which is assembled on the ground and then winched upright via a gin pole. The diameter of guyed towers is, in practice, much less than fixed towers. Guyed towers, along with latticed designs, give less of a tower shadow effect than tubular towers.

Section 2 - Extracting The Wind's Power

Introduction

The power contained in a moving airstream is proportional to the cube of the wind speed. In order to extract this power, and to convert it to a torque suitable for the generator, the rotor must be carefully designed.

THE WIND'S ENERGY

The purpose of a wind turbine is to extract kinetic energy from the wind and convert this firstly to mechanical energy and then usually to electrical energy. The wind's kinetic energy is expressed in equation 3.3

Equation 3.3

$$KE = \_\ pV^2$$

p = air density in kgm^{-3}
V = volume of air interacting with turbine rotor in m^3

Therefore, the power in a given volume of wind is given by equation 3.4

Equation 3.4

$$P = \_\ pAu^3$$

p = air density in kgm^{-3}
u = wind speed in ms^{-2}
A = swept area of rotor in m^2

Equation 3.4 shows that the maximum power that may be extracted from the wind is proportional to the square of the rotor diameter and the cube of the wind speed. This power is usually expressed in the unit of the watt (joule per second).

ROTOR EFFICIENCY

An airstream moving through a turbine rotor disc cannot give up all of its energy to the blades because some kinetic energy must be retained in order to move the airstream away from the disc area after interaction. In addition there are frictional effects, which produce heat losses. Thus, a turbine rotor will never extract 100% of the wind's energy.

The ability of a turbine rotor to extract the wind's power depends upon its "efficiency". Thus, to express the power output of the turbine, a non-dimensional power co-efficient C_p is included (equation 3.5)

Equation 3.5

$$P = \_\ C_p p\ Au^3$$

p = air density in kgm^{-3}
u = wind speed in ms^{-2}
A = swept area of rotor in m^2
C_p = non-dimensional power co-efficient

This describes the fraction of the wind's power per unit area extracted by the rotor, governed by the aerodynamic characteristics of the rotor and its number of blades.

As the airstream interacts with the rotor disc and power is extracted, the airstream speed is reduced by an amount described by the axial interference factor, *a*. This is the ratio of the upstream to the downstream wind speed. Equation 3.6 expresses the power using the axial interference factor.

Equation 3.6

$$P = 2p\ Au^3\, a(1\text{-}a)^2$$

p = air density in kgm^{-3}
u = wind speed in ms^{-2}
a = dimensionless axial interference factor
P = power in the wind in Watts

thus, by substitution, the power co-efficient *Cp* may be defined (equation 3.7).

Equation 3.7

$$C_p = 4a(1 - a)^2$$

C_p = non-dimensional power co-efficient
a = dimensionless axial interference factor

By differentiating with respect to *a*, the maximum value of C_p occurs when $a = 0.33$. Thus, $C_{p,max}$ = 16/27 = 0.593 *Cp,max* = 16/27 = 0.593

Although this method gives a criterion (known as the Betz criterion) for the maximum amount of power that may be extracted from the wind, it does not tell us anything about the rotor conditions necessary to approach maximum efficiency.

The Tip Speed Ratio

If a rotor turns very slowly, it will allow wind to pass unperturbed through the gaps between the blades. Conversely, a rotor turning very rapidly will appear as a solid wall to the wind. Therefore, it is necessary to match the angular velocity of the rotor to the wind speed in order to obtain maximum efficiency.

The relationship between the wind speed and the rate of rotation of the rotor is characterised by a non-dimensional factor, known as the tip speed ratio *lambda*:

For optimum power extraction, the rotor must turn at a frequency which is related to the speed of the oncoming wind. This rotor frequency decreases as the radius of the rotor increases, and may be characterised by calculating this *optimum* tip speed ratio. Practical results have shown that the optimum tip speed ratio is defined by equation 3.13

Equation 3.13

$$\lambda_0 \approx \frac{4\pi}{n}$$

λ_0 =optimum tip speed ratio
n = number of blades

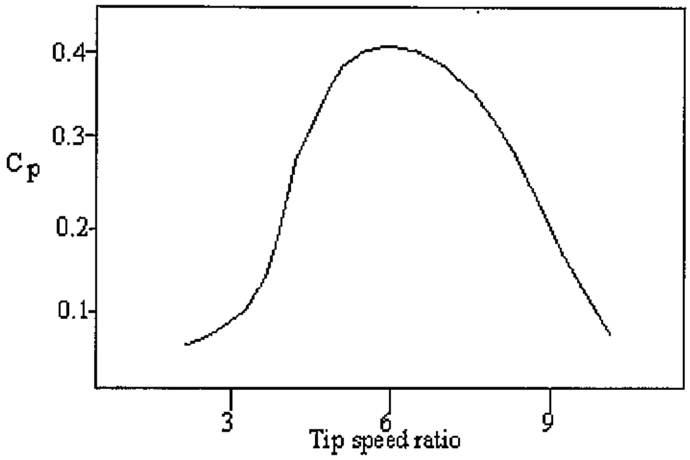
Thus, for a two-bladed rotor, the maximum power extracted from the wind (at *Cp,max*) occurs at a tip speed ratio of about 6, and for a four-bladed machine at a tip speed ratio of about 3. If the aerofoil is carefully designed, the optimum tip speed ratios may be ~30% above these values.

Most modern horizontal axis wind turbine rotors consist of two or three thin blades. These are known as "low solidity" rotors, due to the low fraction of the swept area which is solid. This arrangement gives a relatively high tip speed ratio in comparison to rotors with a high number of blades (such as those used in water pumps, which require a high starting torque), and gives an optimum match to the frequency requirements of modern electricity generators. This minimises the size of the gearbox required and increases efficiency.

Fig 3.2.3 shows the relationship between rotor efficiency and the tip speed ratio for a typical wind turbine. This shows that as the wind speed increases, it is necessary for the rotor to speed up in order to remain near the optimum tip speed ratio. However, this is in conflict with the requirements of most generating systems, which require a constant generator frequency in order to supply electricity of a fixed frequency. Thus, the wind turbine which has a generator directly coupled to the grid operates for much of the time with a tip speed ratio which is not optimised.

The alternative is to decouple the generator from the grid by an intermediate system which facilitates variable speed operation. Some manufactures are now producing variable speed turbines (where the rotor speeds up with the wind velocity), in order to maintain a tip speed ratio near the optimum. These turbines utilise electronic inverter/rectifier based control systems to stabilise the fluctuating voltage from the turbine before feeding into the grid supply.

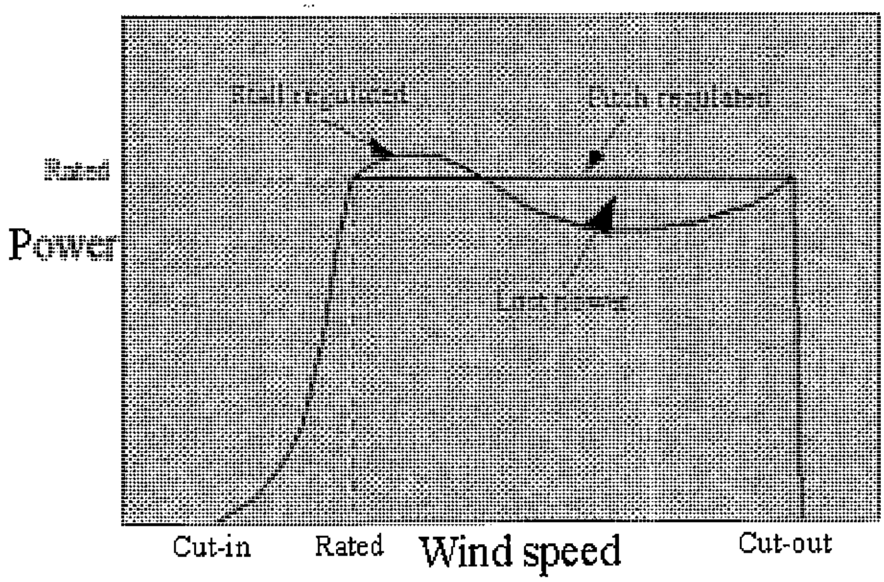
Fig3.2.3 - Power coefficient vs. tip speed ratio



Power Curves

A graph showing the variation of a turbine's power output as a function of wind speed is known as a power curve (fig 3.2.4). This shows the cut-in wind speed (the minimum at which the turbine is controlled to operate), the rated wind speed (at which the turbine reaches its rated power) and the shut down wind speed, at which the turbine shuts down to prevent damage (long periods above rated power would damage the generator and produce excessive mechanical stresses). As the wind speed increases past the turbine's rated speed, the control mechanism of the rotor limits the power drawn from the wind in order to keep the drive train torque constant. The aerodynamic characteristics of stall-regulated machines result in a reduction in power output at higher wind speeds rather than shut-down, in comparison to pitch-regulated turbines.

Fig3.2.4 - Power curves for stall and pitch regulated machines



Section 3 - Fatigue

INTRODUCTION

Due to their complex systems of variable loads, wind turbines are particularly susceptible to fatigue damage. Rotor blades are particularly at risk, and much research effort has been put into assessing the potential for blade fatigue damage whilst in service. Certain drive train failures have also been shown to be due to fatigue, and much effort has gone into alleviating the effects of variable loads on this component.

BASIC FATIGUE THEORY

Cyclic loading of the structure of a wind turbine may cause failure if some critical level of damage is exceeded. Once initiated, damage grows with load cycling until failure, because either

- The net section stress (allowing for the loss of section caused by the damage) exceeds the ultimate strength of the material or
- A critical crack forms by the accumulation of damage.

If the damage growth rate in a component depends on the cyclic stress range, the load ratio R (the ratio of the maximum applied cyclic stress to the material's tensile strength) and the current value of damage D, then

Thus the fatigue lifetime, N_f, is the number of load cycles necessary to raise the initial damage

Equation 3.14

$$\frac{dD}{dN} = f(\Delta\sigma, R, D)$$

$\Delta\sigma$ = cyclic stress range
R = ratio of maximum applied cyclic stress to the material's tensile strength
D = current value of damage (eg. % of section subject to fracture)
N = number of cycles

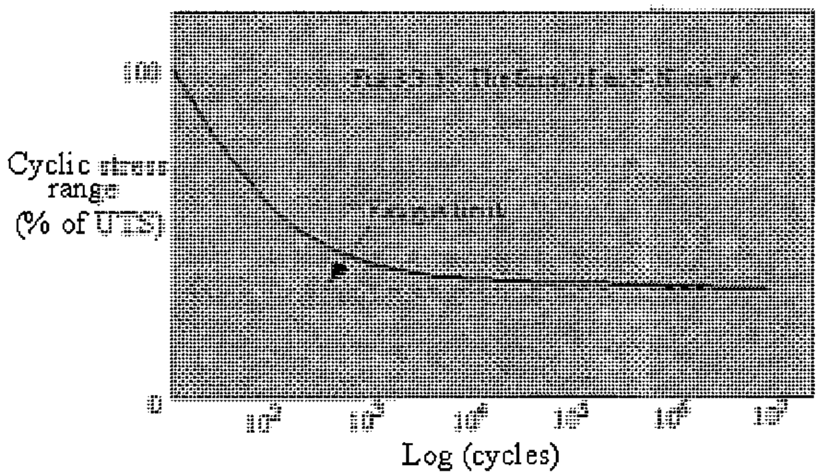
state D_i to the final or critical level of damage D_f, where failure occurs. Therefore, integrating gives

Equation 3.14

$$N_f = \frac{dD}{f(\Delta\sigma, R, D)}$$

$\Delta\sigma$ = cyclic stress range
R = ratio of maximum applied cyclic stress
to the material's tensile strength
D = current value of damage (eg. % of section
subject to fracture)
N_f = number of cycles at failure

Clearly, it is necessary to define the function f in order to quantify N_f. This is commonly carried out empirically by the use of S(stress)-N(cycles) curves (fig 3.3.5). An alternating stress is applied to the material and the number of cycles to failure (N) is determined as a function of the stress amplitude (S). The slope of the S-N curve is a measure of the resistance of the material to fatigue, and the actual shape varies from one material to another.



FORCES RELEVANT TO FATIGUE

Although S-N curves give an indication of relative fatigue properties, they do not take into account the complex effect of the large number of different cyclic forces which act on a turbine blade during operation. These forces arise due to the blade's own mass and the force of the wind acting upon it. They include the following:

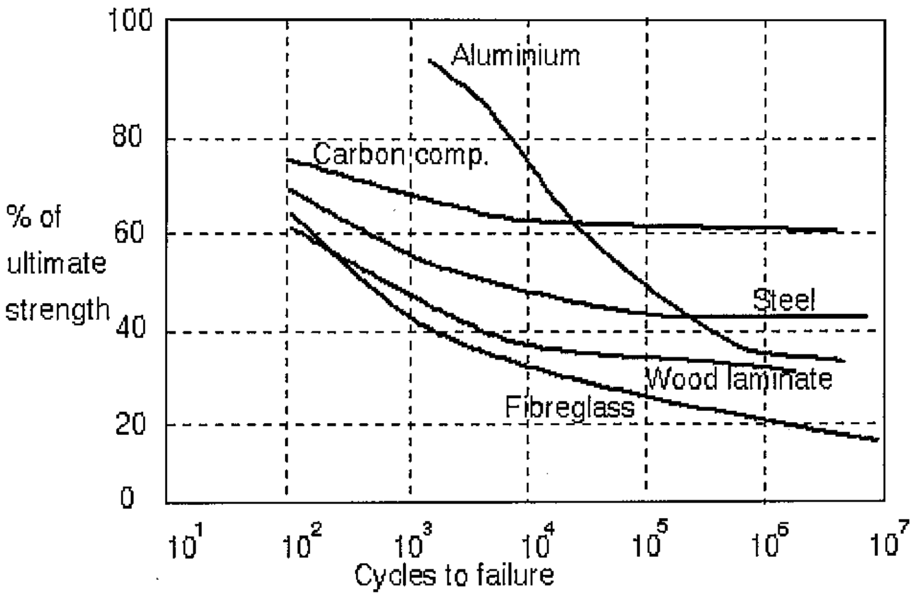
- Gravitational (due to the pull of the earth on the mass of the blade, causing compression and tension in each cycle)
- Centrifugal (due to the rotation of the blade)

- Wind thrust (a force perpendicular to the plane of the blade which varies relatively slowly)
- Rapidly varying forces arising from wind turbulence which increase as stall conditions are approached - Module 3.2)

The research indicates that it is the relatively low frequency high amplitude wind thrust forces which contribute most to fatigue damage.

FATIGUE PROPERTIES OF BLADE MATERIALS

Fig 3.3.6 shows S-N curves for the turbine blade materials examined in Module 3.1. At this point, it should be stressed that data concerning the fatigue life of materials must be regarded with great care, especially in the case of composite materials whe re differences in fibre or mat type, matrix/re-inforcement bond strength or construction methods can introduce significant uncertainties.



The turbine blade materials may be classed into the following groups (see section 3.1.2);

- Metals
- Composites
- Wood Laminates

Metals

Some metals (like mild steel) are relatively fatigue resistant. Provided it is subjected to a cyclic stress below its fatigue threshold (usually less than half its ultimate tensile strength), it may be used for long periods if the component is designed, fabricated and maintained correctly.

Unfortunately, many light alloys, like aluminium, exhibit an S-N curve which falls continuously with time. Thus, failure becomes increasingly likely if the material remains in service under cyclic stress conditions for long enough. This results in the concept of a limited service life for the component after which it must be discarded, regardless of whether any damage is apparent.

Composites

The fatigue properties of composite materials depend on the inherent strength and stiffness of their component materials, and on their structure.

Glass reinforced composites are the most commonly used turbine blade material. Experimental full scale simulations indicate a satisfactory service life under normal conditions. However, laboratory data (fig 3.3.6) show a steadily decreasing S-N curve for GRP's, indicating a finite service life. Careful monitoring of GRP blades currently in service thus seems desirable.

Of the composite materials, those containing higher modulus (stiffer) fibres generally have better fatigue properties, if cyclic stress is applied parallel to the fibre orientation. This is because the matrix epoxy material is constrained by the reinforcing fibres during cyclic loading, subjecting the composite to relatively low strains which do not approach the cracking strain of the matrix. The second phase (such as glass fibre in GRPs) can also act as a crack arresting zone, effectively pinning the growth of fatigue cracks.

Carbon fibre re-inforced composites exhibit outstanding fatigue performance when compared to metals and other composites, especially when subject to tension fatigue in the fibre direction. The advantage of CFRPs is reduced when the matrix material become s the predominant load bearer, but they still offer many times the performance of other composites or metals. At the present time, however, cost constraints mean that carbon fibre composites are rarely used in turbine blade construction.

Wood Laminates

A small number of manufacturers are currently producing wood laminate blades up to 25 metres in length. This material offers good strength to weight properties when compared to GRP. Full-scale tests of Khaya (African mahogany) laminates indicate a favourable fatigue response. This data can be seen on the plot of S-N curves (fig 3.3.6) to give a comparison with other blade materials.

BLADE DESIGN FACTORS

It is important that blade design does not exacerbate the effect of cyclic forces. Certain blade geometries should be avoided in order to reduce the prospect of early fatigue failure. Sharp changes in the blade profile (such as at the blade root/hub junction) can act as stress concentration regions, causing the yield stress of the blade material to be locally exceeded, thus leading to crack initiation. The series of Comet airliner disasters in the early 1960's were due to such a design error, namely too s harp a radius of curvature at the corners of the fuselage window openings.

Design of joints is particularly important in blade construction. For example, it was found that veneer butt joints in wood laminate blades were particularly susceptible to fatigue failure. A simple modification, substituting scarf (angled) joints at the veneer junctions, significantly reduced failure rates.

ENVIRONMENTAL EFFECTS

Even for a fatigue resistant material, environmental attack can rapidly reduce its fatigue strength. This may occur in two main ways:

- The topography of the blade surface may be modified. For example, minute erosive/corrosive pits (from sand or rain impingement) may act as stress concentrators during cyclic loading, causing localised cracking to be initiated. Corrosive attack along g rain boundaries in metals acts in a similar manner, setting up crack initiation sites for intergranular fracture. For larger GRP and wood laminate blades, erosion attack can occur near the blade tips where rotational velocities can reach the equivalent of 100ms-1.

- The bulk material properties may be altered, thus reducing fatigue strength throughout the blade wall thickness or through the surface layers. An example of this is moisture ingress into wood laminate blades in poorly protected regions or at the trail ing edge where debonding can occur.

For these reasons, protective coatings must be applied at manufacture and regularly checked during maintenance. Wood laminate blades are commonly coated with an epoxy skin for environmental protection, in a similar technique to that used in the manufacture of helicopter blades. The leading edge of wind turbine blades always requires a special finish and care.

Section 4 - Electricity Generation and Integration

POWER THEORY

Active and reactive power

In a DC circuit, the power consumed by the circuit is given by the product of the volts and the current. For an AC circuit, the situation is slightly more complicated. If the voltage and current waveforms are in phase with one another, the circuit is said to be purely resistive. When a current i flows through a circuit across which an in-phase voltage v exists, then the instantaneous power associated with the circuit is given by

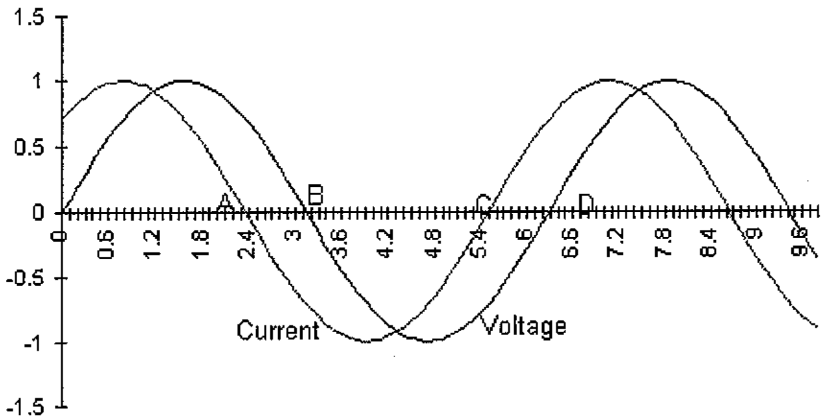
$$p = iv$$

For a purely resistive circuit with an impressed sinusoidal voltage, the power is more easily expressed by an *average*, rather than an instantaneous value;

$$P = IV$$

where I and V are the RMS values of current and voltage respectively, and P is known as the active power.

If the voltage and current are out of phase, the circuit is said to have an inductive component, as seen in fig 3.4.1.1 (below)



In this case, the voltage lags the current by an angle given by the distance A-B. In this interval, we can see that the current is negative, whilst the voltage is positive; the volt-ampere product is therefore negative. Also, in the interval C-D, the volt-ampere product is again negative. Between B and C however, the *V-A* product is positive (because V and A are both negative). Similarly, the *V-A* product before point A and after point D are also positive. What happens in this case is that when the *V-A* product is positive, power is consumed by the load. However, when the *V-A* product is negative, the load consumes a negative power! This means that power is returned to the supply. This is due to energy being released from the magnetic field when the field collapses.

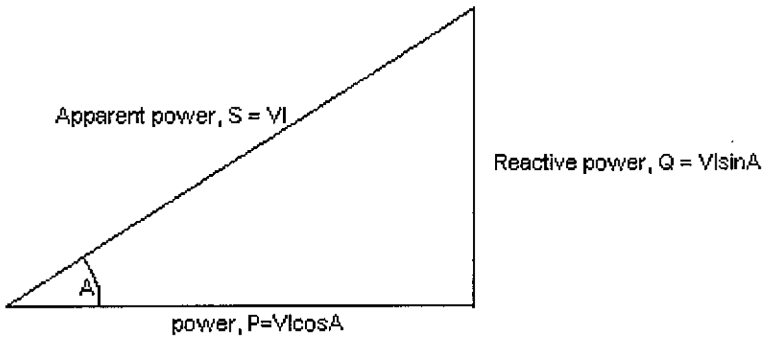
In the case of fig 3.4.1.1, more energy is consumed by the load than is returned, and so the average power consumption over a cycle is positive. However, if the voltage and current are out of phase by 90 degrees, the *V-I* product graph would have equal positive and negative areas, so that the load returns as much power to the supply as it consumes *ie* the average power consumed is zero. In this case, the energy flow oscillates between the generator and inductor and back again at twice the frequency of the voltage.

It is useful to define the peak of this wattless power generation as Q, where

$$Q = IV$$

and is known as the reactive power of the circuit.

To determine the power consumed by an AC circuit, you need to know not just the *V-I* product, but also the phase angle between the two. This is shown scematically in fig 3.4.1.2 (below)



For a utility's A.C. grid system, power is consumed by both resistive (active power) and inductive (reactive power) components, each of which accounts for its own component of the total power, namely P the active component, and Q the reactive component. In this mixed reactive/active case, the average active power component is given by

$$P = VicosA$$

and the peak reactive component is given by

$$Q = VisinA$$

where A is the phase angle between I and V and $cosA$ is the power factor (fig 3.4.1.2 above).

The Power Factor

The power factor of an AC circuit is the ratio of the useful power (W) consumed by a circuit to the apparent power (VA) consumed. This is given by the equation power factor = 'real' power in Watts/apparent power in volt-amperes

$$= VI\cos A / VI = \cos A$$

For an in-phase V and I relationship, the power factor for the circuit is therefore unity.

In practical terms, the voltage stability in a grid network is optimised when P is consumed at minimum I, thus ensuring $\cos A$ approaches unity and Q is kept to a minimum. This may be facilitated by the utility imposing special tariffs that penalise the consumer for a large Q demand.

GENERATORS

In the generation of electricity from fuel sources in thermal processes, the efficiency of conversion is low (described by the 2nd law of thermodynamics). Therefore, the direct conversion of mechanical to electrical energy as occurs in a wind turbine generator should be advantageous. In principle,100% efficiency should be possible. However, in practice there are a number of factors that must be considered in order to supply an A.C. supply suitable for connection to a grid network:

- Wind turbine efficiency is greatest if rotational frequency varies with the wind velocity in order to maintain a constant tip speed ratio (see aerodynamics and power control - module 3.2). However, for most wind turbines the generator must operate at a constant or nearly constant frequency in order to supply grid-compatible electricity.

- Control of turbine speed by flaps etc. is costly and inefficient (see module 3.2), thus rotational frequency is best controlled by varying the electrical load on the turbine.

- The optimum rotational frequencies of all but the smallest wind turbine rotors are much lower than those of existing generators (rotor speed decreases with rotor radius for a constant wind speed).Thus, gearboxes must be used, which absorb energy, can be noisy and may require frequent maintenance (see components - module 3.1).

All generators produce electricity by the Faraday of electro-magnetic induction). A magnetic field cuts a wire with a relative velocity, so inducing an electric potential difference in the wire. If this wire forms a circuit, then an electrical current is produced. The magnitude of the current increases with the strength of the field, the length of wire cut by the field and the relative velocity.

Of the wind turbine systems currently being manufactured, their generating systems may be classed as follows;

D.C machines

Small scale stand alone wind turbines are most commonly used to charge batteries at relatively low voltages. They use simple DC generators similar to that shown in fig 3.11. In these systems, the rotating generator shaft (connected to the turbine blades either directly or through a gearbox) turns the rotor within a magnetic field produced by either the field coil windings or by an arrangement of permanent magnets on the armature. The rotation causes an electric current to be set up in the rotor windings as the coils of wire cut through the magnetic field. This current (whose magnitude depends upon the number of turns in the windings, the strength of the magnetic field and the speed of rotation) is drawn off from the commutator through graphite brushes and fed directly to the battery, sometimes via a voltage regulator which smooths out fluctuations in the generated voltage.

Synchronous A.C. machines

Early alternators, which produce an AC voltage, were developed as a replacement for DC generators. Alternators have a number of advantages. They are generally cheaper and more durable, due to the use of slip rings rather than commutators. A further design improvement is their incorporation of the armature windings in the stator, whilst the rotor provides the magnetic field. If permanent magnets are used, the power is drawn from the alternator through fixed contacts, and wear due to the passage of high currents through moving contacts is eliminated. In excited field alternators, the magnetic field is provided by a supply of relatively low current to the field windings, via slip rings.

The output frequency of the generator depends on

- the input frequency of the drive shaft
- the number of pole pairs in the generator

Thus, in order to be compatible with a utility's grid supply, the machine must be driven at a constant speed by the turbine rotors, to produce power which is in phase with the grid supply. In practice, this may be achieved by altering the pitch of the turbine rotor blades to alter their lift co-efficient as the wind speed varies. More commonly, however, the generator output is small enough in relation to that of the utility supply to allow it to "lock-on" to the grid frequency, ensuring a grid-compatible output frequency despite small variations in wind speed.

Induction A.C. machines

An induction generator differs from a synchronous generator in that its rotor consists in its simplest form of an iron cylinder with slots on its periphery that carry insulated copper bars. These are short-circuited by rings which are positioned on the flat faces of the cylinder. The currents that produce the magnetic field are in short-circuited loops. If positioned on the stator, the field current in these loops is induced from currents in the stator windings, and vice versa. In operational terms, power generation can only occur when the induced closed-loop field currents have been initiated and maintained. This is facilitated in one of three ways;

- reactive power is drawn from the live grid to which the generator is connected
- capacitors connected between the output and the earth enable autonomous self-excited generation (some residual magnetism in the system is necessary)
- a small synchronous generator may be run in parallel, which may (if diesel fuelled, for example) then provide power at times of inadequate wind.

Depending on operating conditions (e.g. wind speed), the generator may act either as a generator, supplying power to the grid, or as a motor (acting as a sink of power from the grid). In either case, there will be a difference in speed between the shaft frequency fs and the output frequency $f1$. This is known as generator slip, and may be expressed as shown in equation 3.4.6:

The slip is defined as negative when the machine is acting as a generator, and positive when acting as a motor.

Equation 3.4.6

$$s = \frac{(f_1 - nf_s)}{f_1}$$

f_1 = AC output power frequency
f_s = shaft frequency
n = number of windings on rotor
s = generator slip

Recent Developments in Generators for Wind Turbines

As well as applying to the basic process of energy conversion, technological development also relates to the design and size of machines used for the generation of electric power from wind energy. Whilst the induction machine is now well established as the most popular generator for reliable, efficient, low-cost power production from the wind, other designs of machines are used and there are several "drivers" for change.

Variations on traditional designs

The 'traditional' Danish design of wind turbine is fixed-speed, using an induction generator. Variations on this theme which are now appearing include

- multiple generators
- two-speed induction generators
- induction machines with variable generator rotor resistance.

Commercial machines generate at low voltage, with no move to voltages above 690 V, though one 1.5 MW turbine has a step-up transformer adjacent to the generator, in the nacelle.

Variable-speed operation

Another major option is variable speed operation, which offers several benefits (along with some disadvantages).

Due to their ability to operate at tip speed ratios closer to the optimum value, variable speed machines can be more efficient than fixed speed systems (depending on the wind speed distribution function - see module 1). However, modification of both the generator and the intermediate electronic control systems are necessary in order to provide a grid-compatible supply. One of the main factors favouring this route is the requirement of some utilities for very smooth output power.

Variable speed drive technology is now being applied to wind turbines to bring various performance benefits to the overall system. These benefits include:

- Increase in energy yield;
- Reduction in loading on mechanical components;
- Reduction in audible noise during low wind speed conditions;
- Smoothing of the energy flow;
- Reducing disturbances on power network.

High power variable speed drives are now being designed into turbines and with them a new set of engineering aspects need to be considered, including:

- Fault level of network;
- Voltage regulation;
- Electromagnetic compatibility;
- Electrical system behaviour during gusting conditions;
- Power converter efficiency.

For variable speed turbines, relatively complex power converter hardware is necessary. The power conversion equipment must provide low harmonics and unity power factor control of the current delivered to the network.

High torque/low speed (direct drive) generators

Direct-drive generators are currently of great interest. As turbine size increases, the relative cost of the gearbox becomes more important. Removing the gearbox could save not only cost, but also mass, losses, acoustic noise and reliability problems. For a doubling of wind turbine diameter, rated power will quadruple, and rotor torque, which is closely related to gearbox cost, will increase by a factor of eight. Another important issue is the integration of the generator into overall nacelle design.

The physical size of any electrical machine is governed by the torque it is required to develop. A direct-drive generator is therefore necessarily a large machine, but it is subject to very tight cost restrictions imposed by the economics of wind power. Low cost is the prime requirement in every aspect of the design, yet high efficiency is vital because of the high capitalised value of losses and because variable-speed capability is increasingly becoming a requirement. Possible routes to fulfill these design pre-conditions include:

- Permanent-magnet excitation for high efficiency.
- Standard parts across a wide range of power and speed ratings to minimise tooling costs and facilitate long production runs.

Designs which incorporate these factors can yield high efficiency and are competitive in cost with the conventional gearbox - induction generator arrangement. Specific design features for such a machine may include:

- Ferrite magnets with flux concentration for low material cost.
- A small number of stator coils pre-fitted to stator core segments.
- Simple stator lamination packs fully prepared prior to assembly of the machine.
- Integration of the ac/dc conversion into the machine to simplify the winding and its connections.
- Structural design which avoids threading a magnetised rotor.

Features such as these mean that similar modules are useable across the whole power and speed range covered by modern wind turbines.

It is likely that future advances in turbine design will incorporate variable speed and direct drive technology. Furthermore, these advances are a clear indication of component development taking place specifically for the wind turbine market.

SITE DISTRIBUTION AND GRID LINKAGE

Site Factors

Wind farm locations and the associated weather conditions have posed engineers with enormous challenges in meeting wind farm design requirements and installing systems. Poor site access can hinder the delivery of large and heavy components, bare rock can make earthing almost impossible and rain and mist can result in water ingress in the cable terminations and joints.

Issues such as transformer location and generator voltage have also become more important as wind turbine size has increased. A particular issue for electrical systems of wind farms is the choice of the site distribution system voltage. Optimisation of wind farm electrical systems is constantly being sought in the effort to reduce component costs and site losses and at the same time increase the flexibility and reliability of the system. Various alternatives to the proven 11 kV site distribution voltages have been investigated including 20kV and 33kV systems. Such systems offer both a reduction in site electrical losses and saving in capitalisation costs.

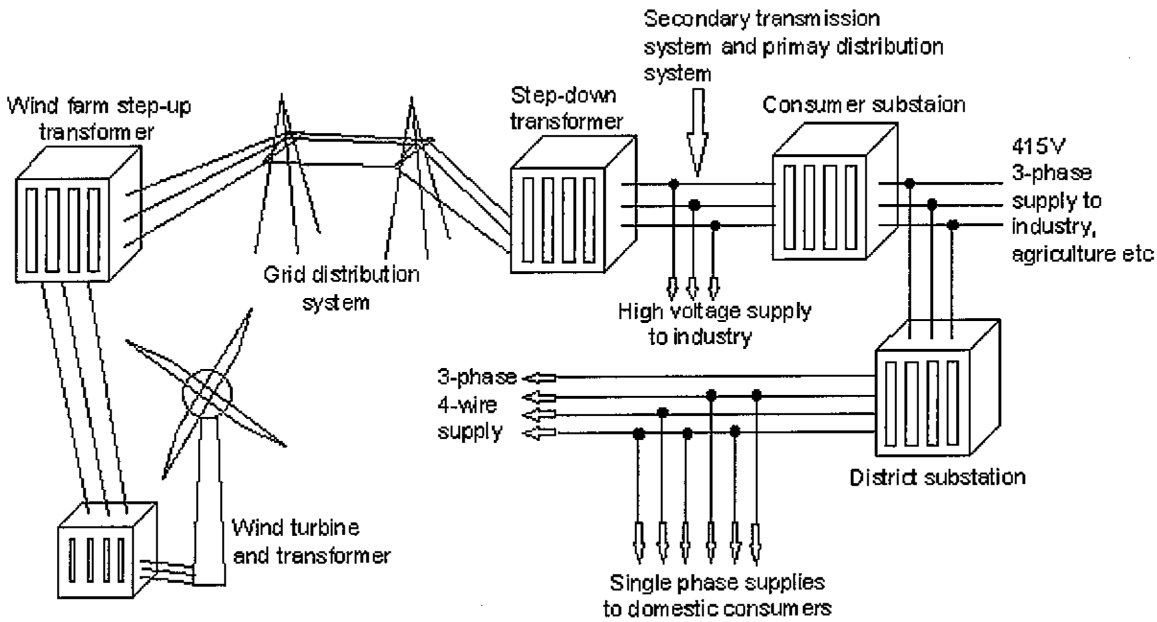
Grid Integration

In simple terms, electrical power is the product of voltage and current (Module 3.4.1 - Power theory). If the power can be transmitted at high voltage, then the current is correspondingly small. This is significant when transmitting electricity over large distances for two reasons:

- the voltage drop in the transmission lines is proportional to the current in the lines
- the power loss in the lines is proportional to (current^2)

Thus, it is desirable to transmit electrical power at the highest voltage possible. As alternating voltages may be easily changed from one value to another via transformers, local and national grid distribution systems utilise a.c. power transmission.

Fig 3.4.2 (below) shows the power distribution system for the U.K



Other countries have similar systems, although the voltage levels may differ slightly.

The voltage levels are typically as follows:

- Wind turbine: 480V, three phase
- Wind farm ring main: 11kv, three phase
- Local grid: 33k or 132 kV, three phase
- Main grid distribution system: 132, 275 or 400kV, three phase

- Secondary transmission system: 33, 66 or 132kV, three phase
- Primary distribution system: 3.3, 6.6, 11 or 33kV, three phase
- Local distribution system: 415 three phase or 240V single phase

Integration of wind turbines on weak rural networks

Lower prices for wind generated electricity tend to concentrate wind farm developments at high wind speed sites, which, in many regions are areas with low population density, remote from a strong electrical connection point. The high capital costs of reinforcing the network, together with the difficulty of obtaining planning permission for new overhead lines, encourage maximum use of the existing network infrastructure.

Rural electricity networks in Europe are characterised by long medium voltage lines to distributed loads, which are predominantly single phase. This leads to a low fault level and low X/R ratio at the point of connection. These conditions, combined with the high wind turbulence intensity which is often associated with upland terrain, provide the least favourable circumstances for the quality of output power from wind turbines.

Problems encountered where the penetration of wind generated power in such a rural network is significant include:

- Surges in reactive power as each wind turbine comes on-line until the turbine is synchronised with the grid. This can lead to a voltage drop of up to 5% on a 33kV line at each start-up
- Voltage flicker, which can be significant due to synchronisations, wind gusting and tower shadow
- Harmonic factors, which can approach 3% for a 33kV grid

The allowable peak output, harmonics, flicker, power factor and switching operations are all clearly stated in relevant engineering recommendations.

Extremely low fault levels and low X/R ratios typical of wind farm grid connections increase the necessity of predicting any potential disturbances to the network. Methods to prevent possible disturbances such as staggering turbine "start ups" and the use of fast acting voltage control equipment, may need to be investigated as the penetration of wind generated electricity into weak networks increases.

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SCHOOL OF ELECTRICAL ENGINEERING + TELECOMMUNICATIONS
ELECTRICITY RESTRUCTURING GROUP

The Australian Electricity Industry and Climate Change: What role for geosequestration?

Iain MacGill

Climate change has become a key driver for technology innovation in the electricity industry. A 50% global reduction in greenhouse emissions over this century appears necessary to avoid dangerous global warming. This will require a far-reaching transformation of our current, primarily fossil-fuel based, energy sector. Present technology options for electricity-related emissions abatement include energy efficiency, low-emission fossil-fuel generation and renewables. There is, however, a clear need for further technical progress in these options given the scale of change required.

There is now growing worldwide, and certainly Australian government, interest in the potential for novel coal-fired electricity generation and geosequestration technologies to reduce greenhouse emissions. This raises the question of how government policy can be used to drive innovation in promising yet unproven abatement technologies. A particular challenge for policy makers is balancing the risks in trying to 'pick winners' against the need to focus publicly funded efforts on the more prospective technology options. Technology assessments are required despite the many challenges, uncertainties and hence risks in attempting to model innovation.

In this paper we outline a simple framework for making such technology assessments. Its evaluation criteria are technical feasibility, delivered energy services (benefits), present and possible future costs, potential scale of abatement, and other possible environmental and societal impacts. These evaluations must factor in risks, the national or regional context facing policy makers – for example, the existing energy sector and R&D capabilities – as well as policy opportunities to drive progress.

We then apply this framework with a preliminary technology assessment for coal-fired generation with geosequestration. This assessment highlights some key remaining questions on the technical feasibility of this approach, its likely high yet uncertain costs, large potential scale of abatement and still significant environmental impacts. These findings are compared against other abatement options including energy efficiency, low-emission gas-fired generation and renewables. In contrast with geo-sequestration, these options have proven technical feasibility, demonstrated and highly competitive abatement costs, varied abatement potential and typically reduced environmental impacts.

Finally, we consider the possible Australian policy implications of these technology assessments. In our view, present innovation policy measures are inadequate and risk being inappropriately focussed on one promising yet unproven option – coal-fired generation with geosequestration. Considerable effort, public investment and time will be required just to determine what, if any, contribution this technology can make. Minimising the risks and maximising our opportunities for innovation in abatement technologies requires instead, a coherent innovation strategy that supports a portfolio of promising options. Policy measures must address the different innovation needs of these options – targeted R&D funding yet, critically, market deployment drivers for near-commercial technologies.

Introduction

Climate change is one of the great policy challenges of our time. We risk causing irreversible damage to vital ecosystems, yet our policy efforts will have to overcome:

- the long time frame and global nature of this problem, and hence our policy response,
- our society's present dependence on low-cost fossil fuels – a far-reaching transformation of these energy systems is clearly required,
- important uncertainties in what this transformation will actually entail, and
- the many other important economic, environmental and societal factors associated with present, and possible future, energy systems.

The likely scale and timeline of required global emissions reductions is 50% over the next century, with developed countries potentially obliged to take greater cuts over a shorter time frame, than this (UK DTI, 2003). Most of these reductions will have to come from fossil fuel emissions (IPCC, 2001).

The IPCC (2001) identifies "technology as a more important determinant of future greenhouse gas emissions and possible climate change than all other driving forces put together." We already have a wide range of technologies for reducing energy related emissions through improved end-use energy efficiency and lower emission and renewable energy supply, (UNDP, 2002; IPCC, 2001). However, technical progress and innovation is essential as present options are almost certainly inadequate for the scale of change required.

The focus of this paper is the potential for novel coal-fired generation and geosequestration technologies to contribute to emissions reductions in the Australian electricity sector.

We first consider the role of government policy in driving technology innovation. A particular challenge for policy makers is balancing the risks of trying to 'pick winners' against the need to appropriately focus policy efforts for different technology options. We outline a simple framework for assessing emission abatement technologies to assist in this.

We then outline Australia's present innovation policy framework for climate change and the electricity sector. Of particular interest is the recent and growing government support for novel coal-fired generation and geo-sequestration technologies as Australia's most promising emissions abatement option.

To explore what rationale might lie behind this focus, we apply our simple technology assessment framework to this geosequestration option. It is then briefly compared against other abatement technology options including energy efficiency, gas-fired generation and renewables.

Finally, we consider how such technology assessments can inform the development of Australian innovation policy for climate change.

Innovation policy for climate change

Our options for emissions abatement now and into the future depend, of course, on what technologies are currently available, yet also on:

- the technical progress that might result from present competitive market pressures, and
- what progress and innovation might be driven by government policy efforts.

Innovation has two key themes, *invention* and *application*. Research and Development (R&D) and Demonstration[1] are key steps of the invention phase. Deployment is the key commercialisation step for moving an invention to possible widespread adoption.[2]

One clear government policy role is supporting socially beneficial 'invention' through publicly funded R&D into sustainable energy technologies.[3]

[1] We use the term R&D&D as shorthand for Research, Development and Demonstration.

[2] Demonstration and Deployment are sometimes used interchangeably but are really quite different. "Demonstration produces results that are necessarily experimental and unreliable since the aim is to try out new techniques. Deployment required the opposite – reliable technologies that can deliver environmental and commercial results." (Watson, 2001).

[3] See for example, UK DTI (2001) "The rationale for Government funding of R&D applied both in the UK and internationally is based on the premise that social rates of return on some R&D, for example energy technologies that can contribute to environmental problems and which involve lengthy development timescales, are higher than private rates of return. Investment in these areas is therefore likely to be to low without Government support or intervention."

However, governments can also play a vital role in taking new sustainable energy technologies from invention (technical feasibility) through to full commercialisation. It is widely agreed that both supply-push (eg. demonstration projects) and demand-pull (market driven deployment) policies are required (Norberg-Bohm, 2000).

Finally, technology can be usefully seen as having 'hardware' (manufactured technology), 'software' (knowledge to use this equipment) and 'orgware' (institutional capacity) dimensions (IIASA, 2002). All of these dimensions are vital for technical progress, although their relative importance may vary with context. For example, new technologies that are radically different in approach from existing technologies (sometimes called "disruptive technologies") may require institutional change to permit successful widespread deployment. At least some greenhouse abatement technologies appear to have this characteristic.

Guidance for policy makers:

Policy makers attempting to drive innovation in greenhouse abatement technologies face some difficult questions, including:

- do particular energy sectors merit special attention – for example, energy efficiency, fossil fuel generation or renewables,
- are there highly promising technologies that merit targeted support – for example, LED lighting, wind power or geosequestration,
- how might different technologies progress in the future – for example, steady progress with established technologies, or potential breakthroughs with novel ones, and *hence*
- what overall policy framework and particular mechanisms are most likely to maximise our abatement capabilities in the longer term.

Innovation policy development must be undertaken in the face of considerable uncertainty. Formal risk management strategies can reduce risks and maximise opportunities for abatement technology innovation. Strategies include technology risk assessments and, critically, diversification (portfolio approaches).

A difficult balance must then be struck between the risks of governments attempting to pick winners against the need to focus limited public resources into our more promising options.

For R&D and demonstration funding, some form of assessment for different technology options will always be required.[4] For commercialisation support, some deployment measures can be made 'technology neutral' to an extent.[5] However, it is still necessary to balance the benefits of competition between options, against the benefits of targeting promising technologies for development support.[6]

Given a climate policy objective of delivering major longer-term emissions abatement, such technology assessments will need to consider:

- technical feasibility,
- delivered energy services (benefits),
- present costs where known, and possible future costs,
- potential scale of abatement delivered, and
- other economic, environmental and societal outcomes with use of the technology.

There are uncertainties and associated risks in all of these considerations. Also, policy makers must make such assessments with regard to their government's particular context – for example, existing national or regional energy sectors, available energy resources and R&D strengths. Perhaps the greatest challenge is that these factors can all respond to policy actions.

A number of tools can help with technology assessments. At their most simple, 'technologies that exist are, by definition, possible' and 'technology trends may continue'. More formally, there are methodologies including:

- bottom-up engineering and economic studies,
- technology road mapping,
- 'experience curves' analysis, and
- scenario analysis.

[4] As noted by Watson and Scott (2001) "In principle, it is essential that the government does not 'pick winners'. A diverse portfolio of basic research, development, demonstration, and technologies should be supported to allow for large uncertainties associated with future directions of technical change, as well as rapidly shifting market conditions. It is, however, equally important that this need for diversity does not dilute public R&D effort because it is thought to be a good idea to do a bit of everything."

[5] For example, MRET gives market-driven support to a diverse range of near-commercial renewable technologies.

[6] The 'price' of particular new energy technologies can be greatly lowered through government support that drives learning from experience and economies of scale in its particular industry (Isoard and Soria, 2001)

Nevertheless, technology assessment remains a difficult challenge, while developing appropriate policies in response to these assessments is probably even harder.[7]

Australian climate change and innovation policy

The Australian Government's stated climate change objectives are to meet our Kyoto target and prepare Australia for the large-scale emissions reductions required over the coming century (Australian Government, 2002).

The Australian electricity sector currently contributes over 32% of national greenhouse emissions and has shown the highest growth in emissions of any sector over the last decade (Commonwealth of Australia, 2002).

While a number of policy measures targeting climate change and the electricity sector have been implemented, emissions are still projected to grow markedly over the coming decades (CoAG, 2002).

The modest target and generous land-use provisions negotiated by Australia in Kyoto mean that our Protocol commitment may actually be met without any significant change in the energy sector (Australia Institute, 2003). However, far greater efforts are clearly needed to achieve the major abatement from this sector required in the longer-term.

Innovation policy for climate change:

Australian policy support for R&D is largely delivered through various general Australian Research Council (ARC) competitive grants programs. There is also funding for Cooperative Research Centres (CRCs). At present, a number of these are directly electricity sector or climate change related – the CRC for Clean Power from Lignite, CRC for Coal in Sustainable Development, CRC for Greenhouse Accounting (largely focused on ecosystem sequestration) and CRC for Greenhouse Gas Technologies (focused on CO_2 capture and its geosequestration). There are, however, no CRCs or dedicated funding for energy efficiency or renewable energy.[8]

Direct Australian policy support for commercialisation of new electricity generation technologies includes the CRCs noted above, and various competitive grant schemes – for example, the Renewable Energy Commercialisation Program (RECP) Deployment support includes grant schemes such as the Photovoltaics Rebate Program and, most importantly, the Mandatory Renewable Energy Target (MRET). There is also some deployment support for energy efficiency including, for ecample, Minimum Energy Performance Standards (MEPS) and energy efficiency 'star rating' schemes (AGO, 2003).

Although there are difficulties in defining and measuring direct government spending in these areas, Australian support for sustainable energy appears to be low compared with many other developed countries (Australia Institute, 2003).

Support for geosequestration:

There is now growing Australian government interest and support for geosequestration of coal-fired electricity generation emissions as an abatement option. This includes (Tarlo, 2003):

- the inclusion of 'capture and sequestration of CO_2' as one of Australia's National Research Priorities,
- recent establishment of the CRC for Greenhouse Gas Technologies which will focus almost exclusively on CO_2 capture and geosequestration,
- leading role of CO_2 capture and geosequestration in the US-Australia Climate Action Partnership,
- strong support for this option given by various Australian Federal Ministers, and
- strong advocacy by a Prime Minister's Science Engineering and Innovation Council (PMSEIC) working group and Australia's Chief Scientist[9] in favour of the technology.

[7] Note that we do not include top-down CGE economic modelling in our list of formal methodologies. They generally have highly stylised and clearly inadequate models for exploring technology innovation (MacGill, 2003b).

[8] The Australian CRC for Renewable Energy was unsuccessful in obtaining additional funding in the latest competitive round.

[9] The PMSEIC Executive Officer is Dr Robin Batterham, Australia's part-time Chief Scientist and also the Chief Technologist for Rio Tinto Corporation.

An important question, then, is whether the Australian government is now attempting to 'pick winners'. Furthermore, what formal assessments of Australia's different technology abatement options justify this apparent focus?

The PMSEIC *Beyond Kyoto* report:

PMSEIC is "the Government's principal source of independent advice on issues in science, engineering and innovation" (PMSEIC, 2003). It was recently given the task of reporting on opportunities to utilise and develop emission reduction technologies appropriate for Australia.

Its (PMSEIC, 2002) report, *Beyond Kyoto – Innovation and Adaptation*, considered a range of generation options for emission abatement including coal-fired Integrated Gasification Combined Cycle (IGCC) plant with geosequestration, Combined Cycle Gas Turbines (CCGT), Distributed Energy Systems (DES) and Renewables. These were classified as current, near-term and longer-term options, and compared on costs and potential abatement.

The report concluded that "within the foreseeable future only carbon capture and geosequestration has the potential to radically reduce Australia's greenhouse signature" and therefore recommended that the Government "establish a national program to scope, develop, demonstrate and implement near zero emissions coal based electricity generation."

Technology assessment of geosequestration:

The authors have previously critiqued this *Beyond Kyoto – Innovation and Adaptation* report (MacGill, 2003). We have particular concerns with its technology assessment of the different abatement options – both in terms of the incomplete criteria used for comparison, and its data estimates for the different technologies. For example, there is little account of the very different risk profiles of the options, and the cost estimates for coal-fired generation with geosequestration are not supported by the international literature.

In this paper, we present some preliminary work on a risk-based assessment of coal-fired electricity generation and geosequestration opportunities for Australia.

We consider, in turn:

- technical feasibility,
- delivered services (benefits),
- present costs, and possible future costs
- potential scale of abatement, and
- other possible societal outcomes.

Technical assessment – coal-fired generation with geosequestration

Technical feasibility:

Coal-fired steam turbines have been one of our major electricity generation technologies for more than 50 years. Some 85% of Australian electricity supply comes from such plant. The 'near zero emission' concept for coal-fired generation involves capturing the CO_2 emissions arising from coal combustion and sequestering it in geological reservoirs.

The key technical steps are capturing CO_2 emissions from the power plant, transporting them to a suitable sequestration site, and then injecting the CO_2 into a stable geological reservoir for long-term storage.

CO_2 Capture:

There are well-established technologies used in the oil and chemical industries for capturing CO_2 from gas streams. Power plant flue gases, however, pose some technical challenges. Most practical experience with CO_2 capture has been from chemically reducing gas streams rather than oxidising flue gases (IEA, 2001).[10] Furthermore, there are the enormous volumes of CO_2 emitted by large coal fired plant – some 20,000 tonnes/day for a 1000MW plant. Small-scale CO_2 capture from conventional power stations has been demonstrated. Large-scale capture, has not, and there are significant cost concerns with present technologies.

R&D efforts are therefore underway in other technical options for large-scale, low cost CO_2 capture – for example, better solvents, membranes and solid adsorbents. Oxygen-blown combustion might also be feasible (IEA, 2001).

[10] There may be particular problems for existing Australian generating plant – our less stringent SOx and NOx emission standards than Europe and the US can adversely impact present solvent scrubbing technologies (Dave, 2000).

Integrated Gasification Combined Cycle (IGCC)

CO_2 capture is far easier with coal-fired IGCC plant. In these plants, the coal is reacted with oxygen and steam to produce a fuel gas. This can then be burned in a Combined Cycle Gas Turbine. Most CO_2 can be captured prior to combustion from the concentrated gas stream.

There is considerable international experience with gasification in the oil and chemical industries, and a number of coal-fired IGCC demonstration plants in operation worldwide. According to the IEA (2001) "IGCC has been successfully demonstrated but the capital cost needs to be reduced and the reliability and operating flexibility needs to be improved to make it widely competitive in the electricity market" (IEA, 2001). 'H_2 rich' gas turbine technologies also have to be proved up.

CO_2 capture from IGCC will certainly be easier than with conventional coal-fired plant. The PMSEIC *Beyond Kyoto* report argues that IGCC shows the greatest potential for cost-effective electricity generation with CO_2 capture.

CO_2 transportation:

There would seem to be few technical problems in transporting CO_2 by pipeline. Such pipelines are already in operation in the US and elsewhere, and the gas is relatively easy to handle (IEA, 2001). Transporting CO_2 long distances does, however, have important cost implications (Allinson, 2003).

Geosequestration:

The main options for storing CO_2 underground over the hundreds of years required for effective emissions abatement are shown in Figure 1.

There is considerable knowledge and experience with CO_2 sequestration in depleted oil and gas reservoirs. Such sequestration is in wide use for Enhanced Oil Recovery (EOR) where it actually provides a net financial benefit. Furthermore, these types of reservoirs are proven traps and have well known geologies. The capture of CO_2 from a lignite (brown coal) IGCC plant and its use for EOR is being demonstrated by the Weyburn project in the US (IEA, 2001).

There is only limited experience with injecting CO_2 into unminable coal seams. The CO_2 is permanently locked up in the coal. Even better, this can release methane bound to the coal and enhance recovery for Coal Seam Bed Methane operations (ECBM) – a growing source of natural gas in countries including Australia. At this time, however, there is only one project using CO_2 sequestration for ECBM recovery, located in the US (IEA, 2001).

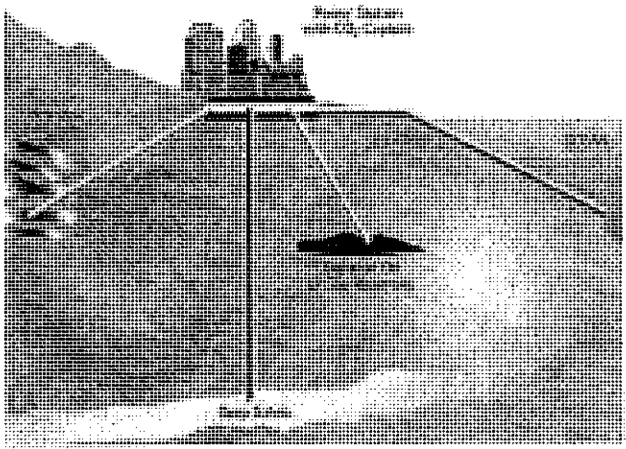

Figure 1: Options for CO_2 sequestration (taken from IEA, 2001).

CO_2 injection into deep saline aquifers potentially offers by far the largest geological storage capacity for geosequestration. Large-scale emissions abatement from the electricity sector will almost certainly require their use. Unfortunately, this type of reservoir is also the least understood in terms of distribution and geology; primarily because they have not had any commercial value until now. Considerable research is still required and there are significant uncertainties and hence risks. There is currently one demonstration project sequestering CO_2 extracted from a natural gas project into a saline aquifer – Sleipner Vest in Norway (IEA, 2001).

In conclusion, the large-scale application of CO_2 capture and geosequestration from coal-fired electricity generating plant has not yet been demonstrated. Most of the key technologies would seem to be commercially available or at least demonstrated at some scale. They have not, however, been integrated and scaled up in a commercial-size demonstration plant. Also, there are still significant uncertainties concerning the risks of re-release of CO_2 from geological storage into the atmosphere. Nevertheless, there is general agreement that at least some geosequestration of coal-fired electricity generation is technically feasible.

Delivered energy services (benefits):

Coal-fired generating plant is the key baseload technology in many electricity industries and offers low-cost, relatively reliable and dispatchable electricity. These plants also create very significant CO_2 emissions – perhaps 6 million tCO_2/year for a typical 1000MW plant.

The ability to add CO_2 capture and sequestration to existing plants would seem to offer very significant emissions abatement yet not require major changes to present electricity infrastructure or operating practice. Much would depend on whether IGCC plant is necessary for cost-effective CO_2 capture, and the availability of geological storage near existing generating regions. If generation must be moved, this could greatly impact on network investment and costs.

Adding CO_2 capture and geosequestration to coal-fired plant will add to costs, so the benefit of the technology in reducing emissions is a primary driver. Although the term 'zero emissions coal' is sometimes used, there will still be significant emissions. This is because of the energy and cost trade-off in how much CO_2 is captured, and the energy required to transport and pump the CO_2 underground.

The IEA (2001) estimates that coal-fired IGCC plant with geosequestration will still emit around 150 $kgCO_2$/MWh in its operation. This is some 40% of existing natural gas-fired CCGT plant, as shown in Figure 2.

There are also upstream greenhouse emissions from coal extraction to consider.[11] These emissions can range from zero to 20% of direct power plant emissions (Gielen, 2003). These overall emission estimates, assume, of course, that the sequestered CO_2 actually remains effectively stored for some hundreds of years.

Costs:

There are many challenges and uncertainties in making cost estimates for coal-fired electricity generation with geosequestration (Freund, 2002; Gielen, 2003). One difficulty, of course, is that no such plants have yet been built. Also, there would seem to be good potential for technical breakthroughs in key steps of the process and, undoubtedly, learning from scale and experience that could reduce costs in the longer-term.

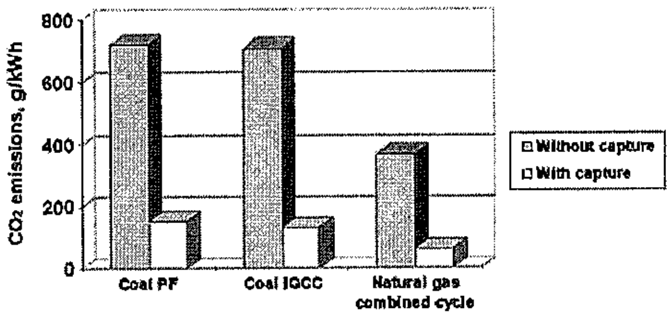

Figure 2: CO_2 emissions from different fossil fuel generation options with, and without, CO_2 capture (taken from IEA, 2001).

Three types of costing studies have generally been undertaken (Gielen, 2003):

- engineering assessments focusing on specific technologies and projects,
- comparative studies that combine different engineering studies, and
- modelling assessments using 'technology learning' concepts and engineering software tools. These are of key importance with novel, unproven technologies.

Engineering assessments offer the highest certainty, yet the least general applicability in terms of future technology development. Such project-specific studies require criteria to be defined including chosen technologies, plant size, fuel costs, CO_2 transport distances, geological reservoir characteristics, project lifetime and financing (Freund, 2002).

More generally, some methodological choices are also critical to cost estimates: (Gielen, 2003)

- the choice of discount rate and use of Net Present or levelised costs (Freund, 2002),
- presentation of results in terms of capital costs ($/MW), electricity costs ($/MWh) or CO_2 abatement ($/$tCO_2$ avoided),
- selection of reference technology against which the plant is compared – for example, the same plant without capture, existing conventional plant or 'best practice' plant,
- energy system boundary – for example, operating or full life-cycle emissions, and
- economic life cycle boundary – for example, including R&D and demonstration costs.

[11] Note,however, that there are also potentially significant upstream CO_2 emissions from natural gas extraction.

Sequestration projects linked with EOR or ECBM can create additional value – potentially sufficient to offset the sequestration costs. Such opportunities are limited however. If significant abatement is to be sought, it can be assumed that most electricity generation projects will not earn such benefits – the value of geosequestration will lie in their 'avoided' emissions. Because CO_2 capture and sequestration is an 'add-on' to generating plant, this abatement will have costs.

Studies to date have differed in type, defined project criteria and methodology, and this makes comparison difficult.[12] With this proviso, we present the cost estimates (with uncertainty ranges) for a number of Australian and International studies in Figure 3.

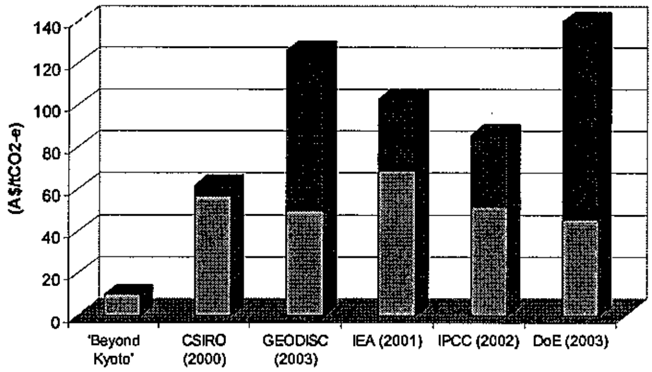

Figure 3: Estimated emission abatement costs[13] (and their uncertainty range) from different Australian and International studies for coal-fired electricity generation with geosequestration.[14]

The cost estimate quoted in the PMSEIC Beyond Kyoto report is drawn from unpublished data by Roam Consulting, so the chosen criteria and methodology in its calculation are unknown. Nevertheless, it is some four to five times less than these other published estimates, which all suggest significant abatement costs.

Possible future costs:

There are opportunities to reduce these costs with time, and experience via: (Freund, 2002)

- technology improvements – perhaps novel R&D breakthroughs or steady progress,
- economies of scale with larger plants, and
- technology learning associated with growing deployment. This is generally described through the use of experience curves.

It is difficult, however, to put numbers to these possible cost reductions, particularly before a technology has been successfully demonstrated.[15] At present, regardless, the cost uncertainties outlined above far outweigh possible learning effects (Gielen, 2003).

Potential scale of abatement:

Global:

Studies to date have confirmed that there is potentially a very large worldwide storage resource. Some theoretical global estimates from the IEA (Gale, 2002) are shown in Table 1. These were derived using general assumptions – actual or realisable storage potential will require regional studies and analysis. Such research is underway worldwide, including Australia.[16]

Table 1: Theoretical global storage potential.

Storage option	Gt CO_2 (% est. global CO_2 emissions to 2050)
Depleted Oil + Gas fields	920 (45%)
Unminable coal beds	40 (2%)
Deep Saline Aquifers	400-10,000 (20-500%)

[12] There are also difficulties in converting US$ estimates to A$. The currency exchange rate has varied over the approximate range A$1 = US$0.50–0.80 over the last ten years. Also, it appears that the capital costs of coal-fired plant in Australia are lower than typical US plant costs – other factors are clearly relevant in making cost conversions.

[13] These results are presented in terms of $/t$CO_2$ emissions avoided. In our view, this is the more relevant for making greenhouse abatement technology comparisons than electricity ($/MWh) costs given the different greenhouse intensities of various low-emission generation options.

[14] The CSIRO study considered two hypothetical projects – a coastal plant using ocean sequestration, and an inland plant sequestering into a depleted gas field. GEODISC base their capture costs on international estimates of US$25-40/t$CO_2$.

[15] Both engineering assessments and experience curve analysis can play a role in estimating possible future costs. Coal-fired electricity generation with CO_2 capture and sequestration has not yet been deployed so experience curves cannot be directly applied. However, some of the likely key components are in use, and can be separately analysed. The mature and widely deployed technology components may not offer great cost reduction opportunities. Nevertheless, there can be considerable 'learning' when integrating such existing technologies (IEA, 2000).

ABARE (2003) comments that "Speculating about renewables costs beyond 2010 is just that – speculation." This is even more applicable to an unproven technology.

[16] See, for example, Bradshaw (2002) "Broad brush style estimates of CO_2 storage potential at the global and continent scale are probably of limited value for future research programmes, and more sophisticated storage capacity estimates are required that integrate economics, source to sink matching and technical viability."

Clearly, the greatest resource potential is that of deep saline aquifers. However, these are also the least understood and potentially expensive type of reservoir. The proximity of suitable storage near large point emission sources is also a critical determinant of the potential storage resource given the costs that would be involved in transporting CO_2 large distances.

Australia:

Australia's GEODISC[17] program has made some preliminary regional estimates of national storage potential (Bradshaw, 2002; Allinson, 2003). This work suggests that Australia's storage potential may be very large – 1600 years or more of present emission levels. However, some 95% of the identified resource is deep saline aquifer and there would seem to be only very limited opportunities for high value EOR and ECBM sequestration.[18]

The great majority of Australia's identified storage potential is located in North Western Australia – an impractical distance from existing coal-fired generation on the east coast.[19] GEODISC results to date suggest that Victoria's brown coal plant may have good sequestration options, Queensland's black coal plant moderate sequestration potential while NSW's black coal generators likely have poor opportunities.

Nevertheless, GEODISC's findings to date suggest that Australia might potentially be able to annually sequester 50-70% of stationary point source emissions (Allinson, 2003).

Other societal factors:

A range of other societal factors and impacts also need to be considered when considering sustainable energy options. These include:

Direct environmental risks:

Geosequestration involves a range of environmental risks that are only poorly understood. Some of the major risks are outlined in Table 2 (adapted from Tarlo, 2003).

Table 2: Environmental risks with geosequestration

Risk	Possible consequences
Slow, long-term escape of CO_2 to atmosphere[20]	Global warming
Sudden large-scale escape of CO_2 to atmosphere[21]	Asphyxiation of humans, animals and plants
Escape of CO_2 to shallow ground waters	Water acidification, mobilised toxic metals, leached nutrients (Bruant,2002)
Displacement of deep brine upward	Contamination of potable water sources
Escape of other captured hazardous flue gases (eg. SOx, NOx)	Range of possible environmental harms

Other environmental impacts:

Coal-fired electricity has a range of adverse environmental impacts other than climate change. These include regional air pollution, water usage and significant land use impacts.

Wider economic impacts:

The coal industry makes an important contribution to the Australian economy and, in particular, national exports. Technologies that allow continued use of coal while meeting Australian and International climate protection objectives might protect this contribution.

There are other wider economic factors to consider as well. For example, the present Australian coal mining, processing, and electricity generation sector is a relatively poor creator of jobs per dollar of investment – largely due to its capital intensity and reliance on imported technologies (MacGill, 2002).

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17 This program commenced in the Australian Petroleum CRC, and now continues in the CRC for GHG Technologies.

18 The IEA (Gale, 2002) notes that GEODISC work to date has concluded "opportunities for CO_2 EOR and CO_2 storage in deep unminable coal seams are limited and only niche opportunities may occur. Also, due to the immaturity of oil and gas production in Australia, storage of CO_2 in depleted gas fields is not a near term opportunity. CO_2 storage in deep saline aquifers is, therefore, likely to be the most likely route for storing large volumes of CO_2 in Australia."

19 The IEA (Gale, 2002) highlights the "clear dichotomy between Eastern Australia (where there are larger CO_2 sources and reservoirs with low storage capacity) and Western Australia (where there are smaller CO_2 sources and larger storage potential)".

20 This is particularly relevant to deep saline aquifers because of our present poor understanding of their geologies.

21 Such a release might result from seismic activity, and there is some suggestion that sequestration activities might cause geomechanical changes of this type.

Energy security:

Australia has very substantial coal reserves – perhaps 300 years or more at present rates of consumption. If secure long-term greenhouse abatement is possible, these coal reserves offer considerable energy supply security.

Comparing abatement options

A range of emission abatement approaches and associated technologies might contribute to longer-term abatement in the electricity sector. These approaches include:

- end-use energy efficiency in appliances, equipment, the built environment and industrial processes,
- lower-emission fossil fuel technologies including CCGT plant and distributed gas-fired generation options like cogeneration,
- renewable generation sources such as PV, wind power and biomass, *as well as*
- ecological or geological sequestration.

While it is beyond the scope of this paper to make a full technical assessment of how these options compare, we will briefly consider the key factors for such comparison.

Technical feasibility:

There are many proven and commercially available energy efficiency, high-efficiency fossil fuel and renewable energy technologies. Some of these technologies are already widely deployed in some regions of the world.

For example, high efficiency household appliances are increasingly available to consumers, highly efficient CCGT is now the preferred electricity plant in many parts of the world while wind power is the fastest growing electricity source in the world.

There are also speculative and as yet unproven technology developments in these fields as well. Nevertheless, the deployed technologies clearly pose far less technical risk than currently unproven approaches including coal-fired generation with geosequestration.

Delivered energy services (benefits):

The different abatement technologies offer different energy services and benefits. Energy efficiency effectively 'delivers' saved energy right where it is required – at the end-user. Distributed renewables and other small-scale generation can also deliver power where it is consumed. This avoids network losses and can potentially defer network upgrades.

For larger-scale generation, CCGT plant has advantageous investment and operational (dispatchability) characteristics compared with coal-fired plant. Some important renewable energy sources, however, have varied and somewhat unpredictable generation and this may impose additional costs on industry operation.

In terms of greenhouse abatement, energy efficiency offers abatement equivalent to the emissions of the electricity supply that is displaced. CCGT has emissions less than half of conventional coal-plant while most renewables have no emissions from operation. Lifecycle emissions can, however, be significant for some renewables – for example, some biomass and PV. In comparison, coal-fired generation with geosequestration seems likely to have emissions some 40% of CCGT, and an order of magnitude greater than promising renewables like wind.

Costs:

The difficulty in cost estimates, and hence comparisons, has been noted above. The costs of proven and commercially available technologies are reasonably well understood, but can vary greatly depending on application specific and methodological factors.

Certainly, end-use energy efficiency offers some of the most cost-effective greenhouse gas emissions reductions available – many energy efficiency options have negative abatement costs (IPCC, 2001). The cost of CCGT generated electricity depends greatly on the fuel cost. In regions with plentiful low cost gas, these plants can offer lower cost generation than coal-fired units. This is not, however, currently the case in much of Australia given very low coal costs. Renewable energy sources generally have higher direct costs than fossil fuel generation. Recent wind power and biomass projects in Australia have generation costs perhaps double coal-fired plant (CoAG, 2002) while PV is an order of magnitude more expensive.

It is difficult to make comparisons between these commercially available and increasingly deployed technology options against coal-fired generation with geosequestration. With this proviso, we present some approximate estimates of their respective abatement costs in Figure 4.

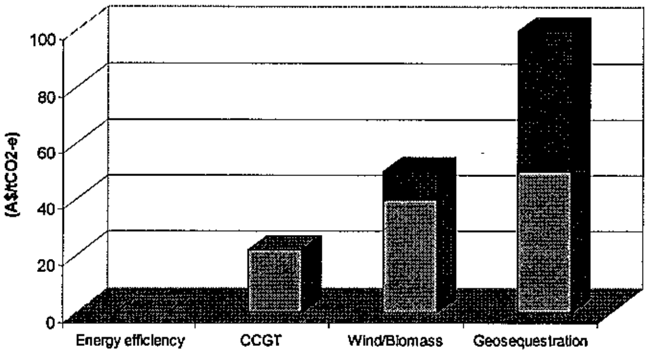

Figure 4: Approximate estimated abatement costs for different options in comparison to conventional Australian coal generation.[22]

These costs are somewhat project dependent, particularly those for wind and biomass projects. CCGT generation costs are very dependent on gas prices and availability at particular locations. Nevertheless, it is clear that coal-fired electricity with geosequestration likely faces severe cost-competition in terms of delivering abatement.

These costs may change markedly with the scale of abatement sought, as discussed in the next section. There is also potential for the costs of all these options to fall with technical progress and greater deployment. For example, the costs of wind power have fallen some 20% in the last five years (EWEA, 2002). The cost of coal-fired electricity with geosequestration is dominated by present uncertainties but could also be expected to fall with R&D, demonstration and eventually large-scale deployment.

Potential scale of abatement:

All the identified abatement options would seem to offer potentially significant abatement opportunities. The IPCC (2001) estimates that global emissions from buildings and industry could be more than halved by 2020, with most of this abatement at net negative direct costs. The UK DTI (2003) *White Paper* estimates that half of the emissions reductions required in the UK by 2020 can come from energy efficiency.

CCGT plant already makes a very significant contribution to electricity supply in some countries. For example, CCGT in the UK now supplies almost the same amount of electricity as conventional thermal plant. In Australia, however, CCGT currently represents less than 5% of installed capacity. Significant expansion will require gas supply and network development but is certainly achievable (CoAG, 2002). This does, however, raise questions about the likely scale of low-cost Australian gas reserves.

The potential scale of renewable energy deployment varies according to technology. Biomass 'fuel' resources from waste streams and agricultural crop residues are necessarily limited. The use of energy crops expands fuel availability but at a cost, and with eventual limitations from agricultural land use.

Australia has a very large potential wind resource. Most of this is in the south of the continent and land-use conflicts may arise for some of this resource. Costs may also rise as the better sites are taken up. There are also questions of how much wind can be accommodated within present electricity networks without imposing substantial costs. Nevertheless, Denmark now gets 20% of its electricity from wind and Germany almost 5% (MacGill, 2003). Many European countries and some US states have set very ambitious renewable energy targets (BCSE, 2003).

In comparison, geosequestration offers a very large but currently uncertain abatement potential. The main limitations would currently seem to lie in storage options for NSW, South Australia and, to a lesser extent, Queensland regions with high emissions.

Other societal factors:

The various abatement options pose varied environmental risks and impacts. Energy efficiency has generally low risks and no additional impacts. CCGT plant causes lower air, water and solid waste environmental harms than coal-fired generation. Some renewable technologies can have regional pollutant impacts – for example, biomass plants. They can also have potentially significant land-use impacts.

[22] Many energy efficiency options have low or even negative abatement costs (IPCC, 2001). Abatement costs for CCGT and wind/biomass projects are calculated from CoAG (2002) estimates of $/MWh costs. Geosequestration costs are averaged from published studies. Costs for all technologies will, of course, change with technical progress and increasing scales of deployment.

Geosequestration poses some rather different environmental risks from CO_2 leakage. In particular, it can never be as safe an abatement as leaving the coal in the ground.

With regard to wider economic impacts, energy efficiency and renewables offer some potentially advantageous investment and job creation opportunities (Greene, 2003; MacGill, 2002).

The energy security impacts of these abatement options also vary. Reducing energy use is one of the best energy security options available. Renewable generation can also offer longer-term energy security advantages through the use of natural renewable energy flows, although short-term variations in their availability can raise short-term energy security challenges.

Some geosequestration scenarios

There are great challenges in determining possible emission abatement futures in the longer-term given the range of present and possible future abatement technologies, and their potential technical feasibility, cost, abatement scale and other impacts. Nevertheless, scenario analysis can be a useful tool for exploring possible futures and guiding policy making.

Australian scenarios:

The PMSEIC *Beyond Kyoto* report presented some electricity sector emission scenarios as shown in Figure 5. From these, it concluded that "although these are extreme scenarios the chart indicates that within the foreseeable future, only carbon capture and geosequestration has the potential to radically reduce Australia's greenhouse signature."

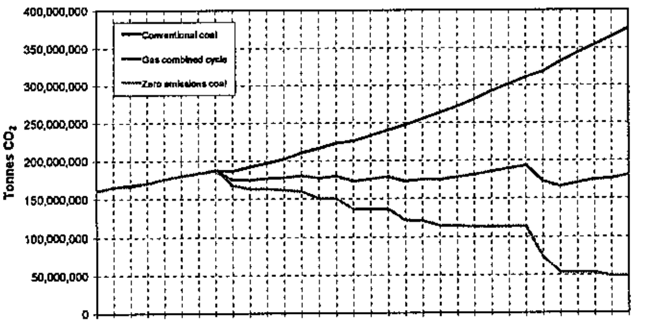

Figure 5: Abatement potential of electricity technology options (taken from PMSEIC, 2002).

It is not clear how such a conclusion was reached. The report's sequestration scenario would seem to assume that electricity use can increase some 130% over the next 30 years while all electricity generation by then comes from 'zero emission coal' Geosequestration starts to contribute to emission reductions in around 2006.

GEODISC scenarios suggest that up to 70% of present stationary sector emissions (the electricity sector presents 70% of this) might be sequestered (Allinson, 2003). Passey (2003) has explored other possible geosequestration scenarios with different assumptions of electricity demand growth and sequestration potential. These suggest generally more modest abatement potential because of the difficulties in matching suitable storage to some regions with high emissions, and likely rates of introduction.

More generally, no PMSEIC scenarios combining the range of available abatement technologies - energy efficiency, high efficiency fossil fuel generation and renewables – are presented for comparison.[23] Furthermore, there is no discussion of the very different risk profiles presented by the different scenarios.

Global scenarios:

Some preliminary global scenario work by the IEA (Gielen, 2003) using their Energy Technology Perspective (ETP) model is showing very different outcomes to those of PMSEIC, as shown in Figure 6. In particular, geosequestration plays almost no role in 2020 and only a minor role in 2040 – renewables make over twice its contribution. Other scenario results also suggest a major decline in global coal-fired electricity whether geosequestration is available or not. There are important caveats with this (and all) scenario modelling. Nevertheless, it suggests other possible technology futures where geosequestration might play a useful but far from dominant role.

There is a broad international consensus including (IPCC, 2001; UNDP, 2002 and UK DTI, 2003) that approaches combining energy efficiency, distributed cogeneration, renewable

[23] See, for example, work by CSIRO (Graham, 2003) modelling Australian energy scenarios with conventional and renewable energy sources.

energy and low-emission fossil fuelled generation hold the greatest potential for large scale emission reductions.

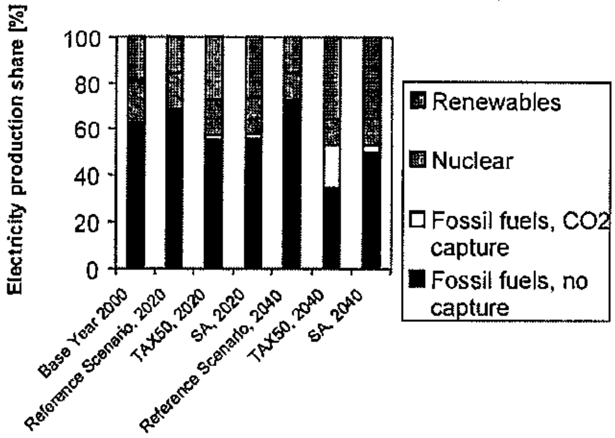

Figure 6: Electricity production from different generation options – some preliminary results from IEA ETP modelling (taken from Gielen, 2003). Note that the reference scenario assumes no CO_2 policies, TAX50 assumes an emission penalty of US$50/t$CO_2$-e from 2010, and a sensitivity analysis (SA) assumes TAX50 yet excluding Solid-Oxide Fuel Cell breakthroughs (which reduce geosequestration costs).

Innovation policy implications

An important question is whether present Australian innovation policy for sustainable energy reflects both:

- the urgent need to drive major innovation in abatement technologies, and
- a risk-based technology assessment of the different abatement options in order to focus R&D and commercialisation (deployment) efforts effectively.

This answer is almost certainly no, with only modest levels of government funding support for R&D and inadequate demand-pull (market development) measures. There is also growing concern that the government is trying to pick winners with its support for geosequestration.

Geosequestration:

The Government's "principal source of independent advice on issues in science, engineering and innovation", PMSEIC, has made only two specific policy recommendations for driving innovation in emission abatement technologies. These are the establishment of a national 'near zero emissions coal generation' development and demonstration program, and the need for market instruments to drive deployment of low emission generation.

We would certainly agree with the IEA (2001) that "In view of the many uncertainties about the course of climate change, further development of CO_2 capture and storage technologies is a prudent precautionary action."

However, considerable uncertainties remain with the technical and economic feasibility of the technology. At the same time, there will be very significant financial risks in large-scale demonstration projects.

For example, 'FutureGen' is a US government led ten-year research project to build the world's first coal-fuel plant to produce electricity and H_2 with zero emissions (DoE, 2003). The capital cost of this 275MW plant and sequestration infrastructure is estimated to be around A$1.3 billion – some four times greater ($/MW) than conventional coal plant. The US government expects the private sector will fund only 20% of this.

There has been very limited success with large-scale demonstration programs of this type. The US Clean Coal Technology program spent around A$1.8 billion of public funds over more than a decade to develop advanced power generation technologies. There has, however, been no commercial uptake of these technologies by US companies (Watson, 2000).

Australia has far less capability in advanced coal-fired generation and geosequestration technologies than the US, and therefore faces an even greater challenge in undertaking such demonstration projects.

There are lower risk approaches. For example, the IEA's Early Opportunities Study is focussing on existing high CO_2 purity emission sources and well understood, high value, EOR and ECBM storage reservoirs (Gale, 2002). Unfortunately, such opportunities are not likely to be available to the Australian Electricity Industry.

There are also important questions on the time required for large-scale demonstration projects to be undertaken, and then, if successful, for wide scale deployment to begin. It is difficult to envisage geosequestration entering such deployment before 2015 even with successful demonstration efforts. Market-based deployment programs only really have a role once technologies are proven and demonstrated.

Some useful innovation policy directions:

While this question lies beyond the scope of this paper, there are some useful guidelines for policy development to consider.

Local deployment delivers local abatement. Also, near commercial abatement technologies have a 'value chain' that goes from manufactured equipment through system integration, project development, installation, operation all the way to on-going maintenance. Even with imported hardware, local deployment programs can deliver local earned value, knowledge ('software') and institutional capacity ('orgware') through most of this chain. Deployment also supports local manufacturing opportunities.

R&D efforts in local technology 'software' and 'orgware' for internationally available 'hardware' can greatly support sustainable local competitive advantage. R&D efforts in novel hardware, however, generally face far greater international competition.

Innovation policy for abatement technologies:

Energy efficiency technologies have important R&D and Demonstration needs. For the many existing technologies, however, the main challenge is to drive wide deployment. This largely requires regulatory, and perhaps targeted market-based, mechanisms given that there are many highly cost-effective options that are still not being adopted by energy users.

CCGT and gas-fired distributed generation options in Australia are highly reliant on the development of gas infrastructure, and governments have an important role in this. Along with regulatory and possible incentive arrangements, there are market-based mechanisms such as the Queensland 13% Gas Scheme, or National Emissions Trading that might be used. Distributed generation also faces a range of barriers from NEM arrangements.

Renewable energy has vital R&D and Demonstration needs to seek novel technologies and breakthroughs. Commercially available renewables, however, mainly require wide scale deployment to drive down costs. MRET is a useful market-based driver for this, but is likely to require an expanded target in order to be effective. Other barriers including present NEM regulatory arrangements also need addressing.

Geosequestration requires R&D efforts. Early demonstration projects are high risk and best based on 'easier' and lower-cost opportunities with high purity CO_2 emission sources (to reduce capture costs) and well-understood sequestration reservoirs (to reduce storage risks). These opportunities are unlikely to lie in Australia's electricity sector.

Conclusions

This paper began with the question of what role geosequestration can play in greenhouse abatement in the Australian electricity industry. The answer is that we don't yet know, and we need to find out as part of a process that:

- reduces risks and maximises our emission reduction opportunities through a portfolio of technology options for abatement, that are
- supported by a coherent innovation strategy, which is
- carefully integrated within a wider energy and climate policy framework.

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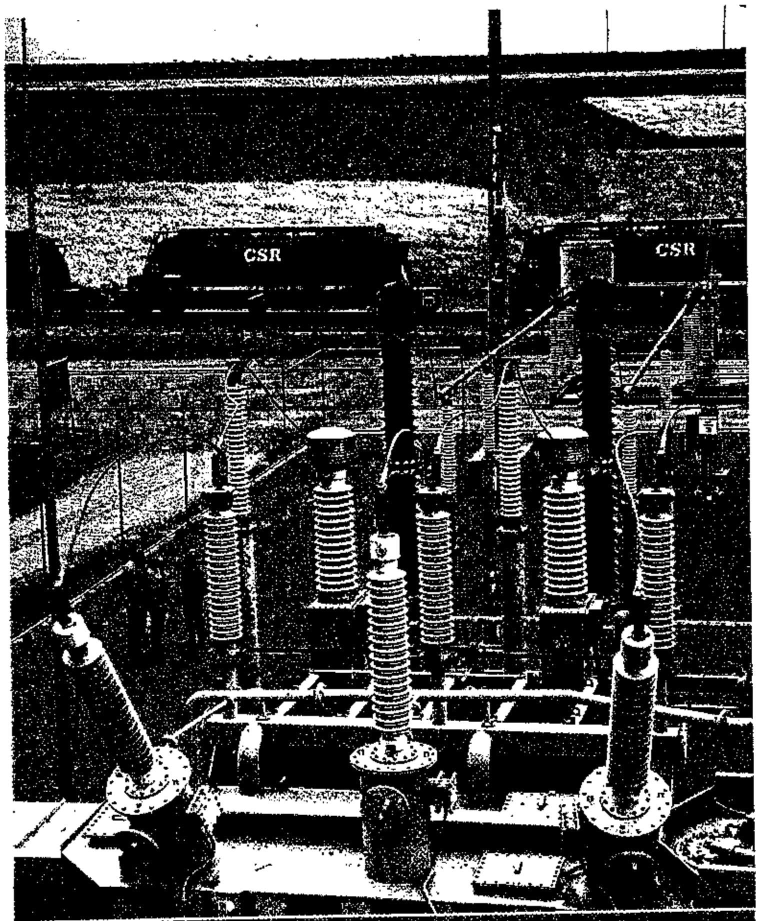
Australia's largest sugar company has unveiled plans to upgrade one of its mills in North Queensland including a new bagasse-fired cogeneration plant. The opening story of this feature looks at how the powerplant will work, as well as how the efficiency of the mill will be improved. The feature also outlines the current use of renewable energy in Australia, visits a new sustainable development in a Sydney suburb and looks at two tidal powerplant proposals in Europe.

More power from bagasse

Australia's largest sugar company, CSR Limited has unveiled plans to upgrade the efficiency of one of its mills in North Queensland and build a $100 million bagasse cogeneration plant at the site.

Shayne Rutherford, CSR Sugar general manager of strategy planning and business development, said the project at CSR's Pioneer raw sugar mill at Brandon, in the Burdekin River District, south of Townsville, will comprise two components of approximately equal capital cost – the mill efficiency works and the powerplant.

"The mill efficiency works will improve the steam generation and consumption efficiency of the sugar mill," he explained.



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"We will do this by upgrading an existing boiler to produce higher pressure higher temperature steam, installing new process vessels, improving process steam efficiency with two new evaporators and replacing the existing mill steam drives with electric drives powered by a new 27.5MW backpressure steam turbine generator.

"The second component of the project will comprise a dedicated export electricity generation powerplant including a new 65 bar boiler, a 35MW steam turbine generator, a cooling tower and associated works.

"The Pioneer mill presently generates the energy required for its own sugar milling operations from bagasse obtained primarily from the sugar cane crushed at the mill. But it does not burn all the bagasse it generates and there is currently an excess of about 70,000t/a. Improving the steam consumption efficiency of the mill will give us another 60t/h of bagasse that will be able to be used for generating electricity in the new powerplant."

When the project is completed, the mill will have a total generation capacity of 63MW. 45MW of this will be sold into the Queensland electricity grid as part of a 10-year power supply agreement between CSR and state-owned electricity retailer Ergon Energy, while the balance will be used to power the upgraded sugar mill.

CSR managing director Alec Brennan said the company is already a significant producer of renewable energy, currently operating a 50MW plant at its Invicta sugar mill, also in the Burdekin District. The Pioneer mill will increase the renewable electricity exported by CSR from 150,000MWh/a to 350,000MWh/a.

CSR expects to shortly finalise which company or companies will be awarded the EPCM (engineering, procurement, construction management) contract to deliver the project. Initial site construction is expected to commence in the noncrushing season of the first half of 2004, with completion scheduled by June 2005, in time for the commencement of crushing operations. ■

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ELEC0390
Energy Tomorrow: An Engineering and Management Perspective

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Contents

COURSE SYLLABUS

Energy Tomorrow: An Engineering and Management Perspective

Course Code: ELEC0390

This five-week course for engineering students explores energy and sustainability, with a focus on new developments in lower-emission fossil fuels, energy efficiency, renewable energy technologies and nuclear power.

The course is available to students who are currently majoring in a tertiary (college or university) engineering course. There are no formal pre-requisite courses given the scope of materials covered in this course. It is, however, assumed that each student has a basic working knowledge of the underlying principles of energy, and one or more energy technologies. Students undertaking related studies in science and design may also be permitted to enrol subject to the approval of the academic course coordinators.

The program is based on a 75-hour combination of lectures, tutorials, laboratory work, demonstrations, site visits, computer simulations, assignments and discussion periods.

The University of New South Wales is recognized as the top university for energy R&D in Australia with many of the research groups among the world leaders in their field. Various UNSW lecturers will cover the topics included in the course.

Energy and Sustainable Development

Our society's energy systems have a critical role to play in driving sustainable development. Key sustainability drivers are energy poverty in the developing world, energy for social welfare and development and the environmental harms of present energy systems. We consider three key issues:

The current status of global energy systems

This topic examines the current status and present international outlook for both traditional and renewable energy sources; energy, economic growth and the environment, implications of the international climate negotiations; and structural change in the electricity supply industry.

Sustainability challenges and options

This topic will consider the current status and trends of existing energy systems with regard to the three sustainability drivers of energy poverty, social welfare and development, and environmental impacts.

A sustainable 'energy services' paradigm

This topic describes an 'energy services' model for designing sustainable energy systems that are highly energy efficient and use cleaner fossil-fuel and renewable energy sources. There is a particular focus on sustainable energy technology innovation.

Energy Storage

Energy storage systems include electrochemical, chemical and thermal. The principles of electrochemical energy systems and fundamentals of electrochemistry, secondary batteries and fuel cells are considered. The latest advanced batteries for stationary and mobile applications, including the vanadium redox flow battery, sodium sulphur, zinc-bromine, sodium metal chloride and nickel-hydride are discussed. Laboratory work includes battery design, testing and performance calculations.

Energy and the Process Industries

Process industries form the basis of modern society and will continue to play a major role. Research initiatives worldwide have paved the way for advancing the development of sustainable processes. Energy efficiency and waste utilisation are some of the key features of many of the sustainable processes that will be discussed.

Renewable Energy technologies

This topic will cover the key renewable energy sources for sustainable energy systems:

Biomass

Considers biomass and agricultural wastes in the production of alternative fuels. Ethanol production technology, from both yeasts and bacteria including genetically engineered micro-organisms (GMOs) and all the issues that this raises for large-scale ethanol production; methane via biogas technology; and other fuels via pyrolysis and combustion.

Photovoltaic Devices and Systems

Will examine the basics of converting sunlight into electricity; the behaviour of solar cells; cell properties; system components; applications; grid connection; system design, including for RAPS (remote area power supply) applications. Experimental work will be carried out at the Photovoltaic Centre teaching laboratories where there are operating PV systems connected to the grid, solar pumping systems and where development work has taken place on the solar powered car.

Wind Energy

Will describe the components of a wind turbine; examine the interaction of wind and rotor; consider fatigue; and examine the process of electricity generation and supply to the grid (wind farms).

Emerging Energy Technologies

There are a number of highly promising but, as yet, commercially unproven energy technologies which may play a very important role in our future energy systems over the longer term. We focus on emerging Carbon Capture and Storage (CCS), geothermal, solar, Generation III and proposed Generation IV nuclear power plants and hydrogen technologies.

Course Aims and Objectives

This course aims to:

- Provide an increased understanding of the global energy systems and the sustainability related issues likely to influence future energy development and management
- Identify those new energy technologies (and their limitations), which are likely to affect the course of future energy development and management
- Provide a detailed understanding of options and opportunities for these new energy technologies to help Australia and the world address major energy challenges

Learning Outcomes

At the successful completion of the course, the student will be able to:

- describe key issues and design choices in achieving more sustainable energy systems
- explain the key attributes of the sustainable energy technology options that have been presented over the course
- apply a range of relevant quantitative models for these technologies
- assess and appreciate the challenges of our transition towards greater sustainability

Graduate attributes are the skills, qualities, understandings and attitudes a university agrees its students will develop during their program of study. Some faculties including Engineering have contextualised agreed UNSW-wide Graduate Attributes according to their disciplines and professional areas. The course delivery methods and course content address a number of core UNSW graduate attributes; these include:

- The skills involved in scholarly enquiry, in particular, the appreciation of and ability to indulge in research.
- An in-depth engagement with the relevant disciplinary knowledge in its inter-disciplinary context
- Development of analytical and critical thinking.
- Ability to engage in independent learning.
- Information literacy - skills to appropriately locate, evaluate and use relevant information
- Development of effective communication skills
- The skills required for collaborative and multidisciplinary work

Refer to http://www.ltu.unsw.edu.au/content/userDocs/GradAttrEng.pdf for more information.

Teaching Method

Lectures will make extensive use of PowerPoint slides and white board work. PowerPoint printouts will be provided at the start of lectures by the lecturers. Additional information and reading materials will also be progressively made available, however they are no substitute for accurate notes, and active student participation through questions and informal exercises during the lectures.

Another key component of the teaching method is the field trips that will be taken over the course. Participation is obligatory.

Students are expected and will benefit from attendance at every lecture. The course will cover a diverse range of material with an approach that is not readily found in textbooks or the literature. Note that UNSW policy is that you are expected to be regular and punctual in attendance at all classes in the course. See https://my.unsw.edu.au/student/atoz/AttendanceAbsence.html for details. Class rolls may be taken.

Assessment

Major assignment (essay)	25%
Presentation	10%
Class assignments	20%
Final exam	45%

Students are required to attend all lectures and tutorials and to complete all assessment tasks. Failure to do so without legitimate reason will result in failure to graduate from the course.

Students will be assessed throughout the program. The assessment is in three parts:

(1) Most units of the program will have some form of assessable activity. Questions will be assigned from the readings and class work

(2) Essay and oral presentation. Students will be assigned in week 1 to small groups, to work on a project specifically in one of the topics covered by the course. Students will write a report to be completed by week 4 and also make a short verbal presentation on the project in the final week in Sydney.

(3) Final examination. A multiple-choice exam covering all course work will be given in the final week of the program in Cairns.

All marking will be in accordance with the UNSW scale:

Fail	<50%
Pass	50-64%
Credit	65-74%
Distinction	75-84%
High Distinction	>85%

Course Notes

Copies of PowerPoint slides and notes will be provided by each of the lecturers in the course.

UNSW Engineering: School and Units

The Faculty of Engineering consists of ten schools:

Biomedical Engineering

General Information - Website: http://www.gsbme.unsw.edu.au/

Chemical Sciences and Engineering

General Information - Website: http://www.chse.unsw.edu.au/

Civil & Environmental Engineering

General Information - Website: http://www.civeng.unsw.edu.au/

Computer Science and Engineering

General Information - Website: http://www.cse.unsw.edu.au/

Electrical Engineering and Telecommunications

General Information - Website: http://www.eet.unsw.edu.au/

Mechanical and Manufacturing Engineering

General Information - Website: http://www.mech.unsw.edu.au/

Mining Engineering

General Information - Website: http://www.mining.unsw.edu.au/

Petroleum Engineering

General Information - Website: http://www.petrol.unsw.edu.au/

Photovoltaic and Renewable Energy Engineering

General Information - Website: http://www.pv.unsw.edu.au

Surveying and Spatial Information Systems (formerly Geomatic Engineering)

General Information - Website: http://www.gmat.unsw.edu.au/

Plagiarism

Plagiarism is the presentation of the thoughts or work of another as one's own.* Examples include:

- direct duplication of the thoughts or work of another, including by copying work, or knowingly permitting it to be copied. This includes copying material, ideas or concepts from a book, article, report or other written document (whether published or unpublished), composition, artwork, design, drawing, circuitry, computer program or software, web site, Internet, other electronic resource, or another person's assignment without appropriate acknowledgement;
- paraphrasing another person's work with very minor changes keeping the meaning, form and/or progression of ideas of the original;
- piecing together sections of the work of others into a new whole;
- presenting an assessment item as independent work when it has been produced in whole or part in collusion with other people, for example, another student or a tutor; and,
- claiming credit for a proportion a work contributed to a group assessment item that is greater than that actually contributed.†

Submitting an assessment item that has already been submitted for academic credit elsewhere may also be considered plagiarism.

The inclusion of the thoughts or work of another with attribution appropriate to the academic discipline does *not* amount to plagiarism.

Students are reminded of their Rights and Responsibilities in respect of plagiarism, as set out in the University Undergraduate and Postgraduate Handbooks, and are encouraged to seek advice from academic staff whenever necessary to ensure they avoid plagiarism in all its forms.

The Learning Centre website is the central University online resource for staff and student information on plagiarism and academic honesty. It can be located at:

www.lc.unsw.edu.au/plagiarism

The Learning Centre also provides substantial educational written materials, workshops, and tutorials to aid students, for example, in:

- correct referencing practices;
- paraphrasing, summarising, essay writing, and time management;
- appropriate use of, and attribution for, a range of materials including text, images, formulae and concepts.

Individual assistance is available on request from The Learning Centre.

Students are also reminded that careful time management is an important part of study and one of the identified causes of plagiarism is poor time management. Students should allow sufficient time for research, drafting, and the proper referencing of sources in preparing all assessment items.

* Based on that proposed to the University of Newcastle by the St James Ethics Centre. Used with kind permission from the University of Newcastle

† Adapted with kind permission from the University of Melbourne.

STAFF

Course Conveners

Dr. Iain MacGill, BE MEngSc (Melb) PhD (UNSW) MIEEE

Associate Professor in Energy Systems
School of Electrical Engineering and Telecommunications
The University of New South Wales
Ph: 02 9385 4920
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Iain MacGill is Joint Director (Engineering) of the Centre for Energy and Environmental Markets (CEEM) and an Associate Professor in the School of Electrical Engineering and Telecommunications at UNSW. His main research interests are in the policy and technical frameworks required for integrating renewable energy technologies into power system planning and operation. Iain has a decade of experience in the energy sector and undertakes consulting work for a range of government and industry clients.
For more information on CEEM's work visit website: www.ceem.unsw.edu.au.

Dr. Peter L Rogers, BE (Adel) MBA (UNSW) DPhil DSc (Oxon) FIEAust

Emeritus Professor
School of Biotechnology and Biomolecular Sciences
The University of New South Wales
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Peter Rogers is an Emeritus Professor in the School of Biotechnology and Biomolecular Sciences, UNSW. He has a BE in Chemical and Metallurgical Engineering, an MBA and research Doctoral Degrees the latter from Oxford University. He carried out postdoctoral studies in bioprocess modelling at the Canadian National Research Council Laboratories in Ottawa, and has been held Visiting Professorships at MIT (Boston) and ETH (Zurich). He has an active involvement in renewable energy research and holds international patents and numerous scientific publications on high productivity processes for fuel ethanol production. He has been a consultant to an R&D program with the National Renewable Energy Laboratories (NREL), Golden, Co. and Dupont on conversion of agricultural/forestry resources (biomass) to ethanol. He has extensive experience in SE/NE Asia and has worked with the World Bank, UNESCO, UNDP and other United Nations programs. In 2004, he received the Exxon-Mobil award for 'Excellence in Innovation in Chemical Engineering'.

Additional Course Teaching Staff

Robert Largent, AS (USA)

Technical Support Staff
School of Photovoltaic and Renewable Energy Engineering
The University of New South Wales
Ph: 02 9385 5457
Email: r.largent@unsw.edu.au

Robert Largent has been the manager of the Design Assistance Division (DAD) of the UNSW Key Centre for Photovoltaic Engineering for over a decade. The DAD provides photovoltaic engineering, renewable energy systems expertise and expert non-partisan services to companies and government bodies. In Australia, Robert has worked strongly with the National Parks and Wildlife Service providing the design, specification, and later commissioning of diesel-PV-battery hybrid systems at Montague Island National Park and Greencape National Park. Robert has worked closely with the Vanadium Research Group at UNSW designing equipment and offering system expertise for the installation of the Vanadium Battery-PV hybrid residential systems in Thailand. He has consulted for the Federal Ministry of Health, India through the World Health Organisation.

Dr. Veena Sahajwalla, PhD (U Michigan) FTSE, FIEAust CPEng
Scientia Professor
School Materials Science and Engineering
The University of New South Wales
Ph: 9385 4426
Email: veena@unsw.edu.au

Scientia Professor Veena Sahajwalla is the leader of research into Sustainable Materials as the Director of Sustainable Materials Research & Technology (SMaRT@UNSW) at the University of New South Wales. She holds an ARC Future Fellowship. Veena's research interests throughout her career have been in sustainability of materials and processes with an emphasis on environmental and community benefits. Through this interest, Veena has invented an environmentally friendly process of recycling plastics and rubber tyres in steelmaking. Veena is an international award winning scientist and engineer who has presented on her research and experiences throughout the world. She has collaborated with Australian companies and overseas companies/institutions. She has established excellent working relationships and a deep knowledge of industrial processes and issues/problems. She has published in excess of 190 papers in journals and conference proceedings. In 2005, she received the Eureka Prize for Scientific Research. She also received the 2006 Environmental Technology Award from Association of Iron & Steel Technology in the United States for her research into recycling waste plastics in steelmaking. She was elected as a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE) in 2007. Veena was born in India. She received BTech, Metallurgical Engineering, Indian Institute of Technology, Kanpur, India; MASc, Metals and Materials Engineering, University of British Columbia, Canada and PhD, Materials Science and Engineering, University of Michigan, USA. She is passionate about science and engineering. She encourages young people to consider science and engineering as a career path; and is very active in communicating her ideas to students. She is one of the judges on the ABC TV show, "The New Inventors".

Dr. Maria Skyllas-Kazacos, AM, BSc (Hons I), PhD (UNSW), FIEAust, FRACI.
Professor
School of Chemical Engineering
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Maria Skyllas-Kazacos is a Visiting Professorial Fellow in the School of Chemical Sciences and Engineering. After working for a year as a Postdoctoral Fellow at Bell Telephone Laboratories in Murray Hill New Jersey in 1979 she was awarded a 2-year Queen Elizabeth II Postdoctoral Fellowship at UNSW where she continued her research in liquid junction solar cells. In 1982, she was appointed as Lecturer in Chemical Engineering and Industrial Chemistry, reaching the level of Professor in 1993. In 1985 she led the team that invented the All-Vanadium Redox Battery (VRB) that is now being commercialised by a number of companies around the world, including Sumitomo Electric Industries Japan. Her pioneering work on the VRB led to more than 30 international patents, over 100 publications in international journals and a number of prestigious awards. Since 1994, more than 20 VRB systems have been installed in a range of applications in Japan, USA, Australia and Europe. These range from wind energy storage systems on the Japanese island of Hokkaido and on Australia's King Island, to PV, load-levelling, peak shaving and emergency back-up power applications. Between 200 and 2006, Maria was Director of the UNSW Centre for Electrochemical and Minerals Processing that also conducted teaching and research programmes in Aluminium Smelting Technology. Her research interests continue to cover energy storage and aluminium smelting, where her focus has been on energy efficiency and greenhouse gas reduction.

Ted Spooner, BE, ME (UNSW)
Former Senior Lecturer, Visiting Fellow
School of Electrical Engineering and Telecommunications
The University of New South Wales
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Ted Spooner received his BE and ME degrees from the University of New South Wales in 1970 and 1973 and has been a Senior Lecturer at The University of New South Wales in the School of Electrical Engineering and Telecommunications since 2002. His research interests are in renewable energy applications and power electronics. He was project leader for Australia's renewable energy systems testing laboratory now known as RESLab. He is currently a chair of Australian Standards Committee responsible for renewable energy systems. He is also the Australian representative on the International Electrotechnical Commission's (IEC) technical committee TC82 for Photovoltaics and leader of the IEC TC82 systems working group developing international standards for photovoltaics.

Dr. Alistair Sproul, BSc (Hons I) (Syd) PhD (UNSW)
Associate Professor
School of Photovoltaic and Renewable Energy Engineering
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Alistair Sproul is an Associate Professor and Postgraduate Coordinator within the School of Photovoltaic and Renewable Energy Engineering at UNSW. His current research interests are in the area of PV/energy systems for low energy buildings and highly efficient water pumping systems. Alistair has worked in the area of photovoltaic research and R&D since 1985 in a range of positions with various companies (BP Solar, Pacific Solar) and research institutions (UNSW, Fraunhofer Institute for Solar Energy Systems). Since 2001 he has been strongly involved in developing and delivering the undergraduate program within the School of Photovoltaic and Renewable Energy Engineering at UNSW. http://www.pv.unsw.edu.au/Staff/alistairsproul.asp

Study Abroad Conveners

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Contacting Students

At any time during the program students can be reached by mail at the following address:

Student's Name
c/o UNSW Study Abroad Summer School
UNSW Study Abroad Office
Level 16, Mathews Building
The University of New South Wales
Sydney, NSW 2052
Australia

Messages can also be left for students using the contact details above for Clare or Tom.

Hotel/hostel contact details appear in the Course Itinerary section of this pack. They are however, subject to change.

ACCOMMODATION

Darwin

Melaleuca on Mitchell
52 Mitchell St
Darwin, NT 0800
Phone: +61 8 8941 7800
Fax: +61 8 8941 7900
15 June - 24 June

Melbourne

Nomads Melbourne Backpacker Hostel
198 A'Beckett St
Melbourne, VIC 3000
Phone: +61 3 9328 4383
Fax: +61 3 9328 4863
24 June - 27 June

Sydney

New College
330 Anzac Parade
University of New South Wales
Sydney, NSW 2052
Phone: +61 2 9381-1999
Fax: +61 2 8344 4550
27 June - 12 July

Cairns

Rydges Esplanade Resort
Corner The Esplanade and Kerwin Street
Cairns, Queensland 4870
Phone: +61 7 4044 9000
Fax: +61 7 4044 9001
12 July - 19 July

CLASSROOM ALLOCATIONS

Darwin

Week 1:

16 - 18 June	Bul Bul Room, Travelodge Mirambeena Resort
22 June	Bul Bul Room, Travelodge Mirambeena Resort
23 June	Nemarluk Room, Travelodge Mirambeena Resort

Sydney (UNSW)

Week 2:

28 June	Room 418, Electrical Engineering and Telecommunications (map ref G17)*
29 June-	Room 418, Electrical Engineering and Telecommunications (map ref G17)

Week 3:

2 July	Room G11, Materials Science (Map ref E8)
3 July	Field Trip: Energy Efficiency Centre (Silverwater)
4-6 July	Room 418, Electrical Engineering and Telecommunications (map ref G17)

Week 4:

9 July	Room 418, Electrical Engineering and Telecommunications (map ref G17)
10 July	Room G17, Biological Sciences (map ref D26)
11 July	Room G17, Biological Sciences (map ref D26)

Cairns

Week 5:

14 July	Field Trip: Sugar Producing Areas (Mossman, Port Douglas)
15 July	Crystal Twig Room, Level 1, Rydges Esplanade Resort
16 July	Crystal Twig Room, Level 1, Rydges Esplanade Resort

***Campus Map included in Student Handbook**

TEACHING PROGRAM

Darwin and Kakadu

Date	Time	Activity
Friday 15 June	12.00pm	Arrive Darwin Met at Darwin International Airport by UNSW Summer School staff and taken to accommodation Staying at: Melaleuca on Mitchell Backpacker 52 Mitchell St Darwin, NT 0801 Ph: +61 8 8941 7800 Fax: + 61 8 8941 7900 http://www.momdarwin.com/
	3.00pm - 4.00pm	Collect course material from Melaleuca on Mitchell deck area
	4.15pm	*Assemble in Melaleuca car park and walk to the Mirambeena Resort*
	4.30pm - 6.00pm	*Travelodge Mirambeena Resort* Orientation and introduction of academic staff
	6.00pm - 7.30pm	Welcome Reception
Saturday 16 June	1.00pm - 5.00pm	*Bul Bul Room, Travelodge Mirambeena Resort* Class: Course Introduction (Iain MacGill)
Sunday 17 June	9.00am - 1.00pm	*Bul Bul Room, Travelodge Mirambeena Resort* Class: Energy and Sustainable Development I (Iain MacGill)
	3.00pm - 4.00pm	Excursion: NT Museum and Art Gallery
	Evening activity	**Mindil Beach Markets**
Monday 18 June	9.00am - 1.00pm	*Bul Bul Room, Travelodge Mirambeena Resort* Class: Energy and Sustainable Development II (Iain MacGill)
Tuesday 19 June - Thursday 21 June	7.00am	*Bus departs to Kakadu* **3-Day Field Trip: Kakadu National Park**
Friday 22 June	1.00pm - 5.00pm	*Bul Bul Room, Travelodge Mirambeena Resort* Class: Photovoltaic Devices and Systems I(Ted Spooner)
Saturday 23 June	9.00am - 1.00pm	*Bul Bul Room, Travelodge Mirambeena Resort* Class: Photovoltaic Devices and Systems II (Ted Spooner)
Sunday 24 June	*10.45am*	*Assemble in Melaleuca foyer for departure*
	1.30pm	Depart Darwin on QF839 to Melbourne

Melbourne

Date	Time	Activity
Sunday 24 June	6.05pm	Arrive Melbourne and transfer to accommodation: Nomads Melbourne Backpacker Hostel 198 A'Beckett St Melbourne, VIC 3000 Ph: +61 3 9328 4383 Fax: +61 3 9328 4863
Monday 25 June	*10.00am*	*Assemble in lobby for departure for field trip*
	11.00am - 12.00pm	**Field trip: Centre for Education and Research in Environmental Strategies (CERES) (Guided Tour)**
	PM	Free time
Tuesday 26th June	*7.00am*	*Assemble in lobby for departure for field trip*
	11.00am	**Field trip: Codrington Wind Farm – Port Fairy (Guided Tour)**
	2.00pm - 7.00pm	Return to Melbourne via Great Ocean Road
Wednesday 27 June	*10.30am*	*Depart accommodation for airport*
	1.00pm	Depart Melbourne on QF434 for Sydney

Sydney

Wednesday 27 June	2.25pm	Arrive Sydney Domestic Airport. Bus transfer and settle into New College UNSW New College Anzac Parade, Kensington NSW 2052 Ph: +61 2 9381 1999 Fax: +61 2 8344 4500
Thursday 28 June	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Energy Storage I (Maria Skyllas-Kazacos)
	PM	Campus Tour and student ID's
Friday 29 June	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Energy Storage II (Rob Largent)
Saturday 30 June - Sunday 1 July		Free Days
Monday 2 July	9.00am - 1.00pm	*Room G11, Materials Science* Class: Energy and the Process Industries (Veena Sahajwalla)
Tuesday 3 July	9.00am - 1.00pm	**Field Trip: Ausgrid Energy Efficiency Centre, Silverwater** (Iain MacGill) NOTE: Closed shoes need to be worn during this field trip for safety reasons
Wednesday 4 July	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Energy Efficiency I (Alistair Sproul)
Thursday 5 July	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Energy Efficiency II (Alistair Sproul)
Friday 6 July	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Wind Energy (Iain MacGill)
Saturday 7 July - Sunday 8 July		Free Days

Monday 9 July	9.00am - 1.00pm	*Room 418, Electrical Engineering and Telecommunications* Class: Emerging Technologies (Iain MacGill)
Tuesday 10 July	9.00am - 1.00pm	*Room G17, Biological Sciences* Class: Introduction to Bioenergy (Peter Rogers)
Wednesday 11 July	9.00am - 1.00pm	*Room G17, Biological Sciences* Class: Student Presentations (Iain MacGill/Peter Rogers)
Thursday 12 July	*7.00am*	*Assemble at New College for departure by bus to the airport*
	9.15pm	Depart Sydney on QF924 to Cairns

Cairns

Thursday 12 July	12.25pm	Arrive Cairns and settle into accommodation Rydges Esplanade Resort Cnr The Esplanade and Kerwin Street, Cairns, Queensland 4870 Ph: +61 7 4044 9000
Friday 13 July		Free Day
Saturday 14 July	9.00am - 4.00pm	**Field Trip: Sugar growing regions at Mossman and Port Douglas** (Peter Rogers)
	6.30pm - 8.30pm	Activities information and sign up – Joseph Banks Ballroom
Sunday 15 July	9.00am - 1.00pm	*Crystal Twig Room, Rydges Esplanade Resort* Class: Bioenergy (Peter Rogers)
Monday 16 July	9.00am - 11.00am	*Crystal Twig Room, Rydges Esplanade Resort* **Final Exam**
	7.00pm - 9.00pm	**Final Program Dinner**
Tuesday 17 July - Wednesday 18 July		**End of academic program** Relax in Cairns Optional trips to Great Barrier Reef diving/ snorkelling, white water rafting, bungy jumping and skydiving
Thursday 19 July	*3.30am*	*Assemble in foyer for departure to airport*
	5.30am	Depart Cairns on QF799 to Brisbane (ETA 7.30am)
	10.55am	Depart Brisbane on QF15 to Los Angeles (ETA 7.00am, 19 July)

ASSIGNMENT DETAILS

As part of the assessment for this course you have to submit a group report on one of the following topics. The assignment will be worth 25% of the final assessment. Your group will also have to give a short presentation on the essay topic, which will be worth 10% of the final assessment.

Method of allocating groups and topics will be determined when we first meet and the allocation made before the end of week 1. Every effort will be made to give you your preferred choice of topic.

You should contact the report supervisor at least twice. Given that you will be in Darwin for the first 2 weeks of the course, where you will have access to the Internet but not personal access to your supervisor (except for Iain MacGill and Ted Spooner), the first contact should be as soon as possible by e-mail. A good time for the second contact is a few days before the presentation is due. The supervisor will be the marker of the report.

ASSIGNMENTS ARE TO BE HANDED IN AT THE TIME OF GIVING THE PRESENTATION IN SYDNEY ON WEDNESDAY OF WEEK 4.

Assignments should be structured as:

- One page Executive Summary
- Introduction;
- Objectives;
- Body of Report;
- Conclusions;
- References.

You can find advice on technical report writing at the UNSW Learning Centre website – www.lc.unsw.edu.au. Expected length is about 3000 words (not including references).

PRESENTATIONS will be of 10 minutes duration, with a further 5 minutes available for questions. Data projection facilities will be available for PowerPoint presentations.

All the professors will be invited to attend but please note that not all will be available. Your presentations will be held in a recess period at UNSW and many other Universities. Many conferences and other such events, both international and local, are therefore held at this time and some of your lecturers may be away attending one of these.

Topics

Energy and Sustainable Development 1

Discuss the prospects for renewable energy resources over the next decade in the context of growing global environmental concerns. What (global) policies could enhance the rate of uptake of renewable energy technologies?

Energy and Sustainable Development 2

Describe the concept of peak oil and present the various arguments for and against the likelihood that we have already, or are close, to reaching an oil production plateau.

Energy and Sustainable Development 3

From the perspective of the US economy, outline what you think will be the key energy issues through to the year 2025 and describe their implications.

Contact for all Energy and Sustainable Development projects: A/Professor Iain MacGill, School of Electrical Engineering. E-mail i.macgill@unsw.edu.au

Energy Efficiency 1

Describe the concept of energy services with respect to the design of energy efficient technologies and systems. Provide examples of how this approach can work. Outline some key energy efficient equipment and appliances options for the residential sector and estimate the potential energy consumption reductions that can be achieved.

Energy Efficiency 2

Outline some key energy efficient equipment and appliances options for the commercial sector, estimate the potential energy consumption reductions that can be achieved and describe key policy options and efforts to date in the United States to achieve these.

Contact for all Energy Efficiency projects: A/Professor Alistair Sproul, School of PV and Renewable Energy Engineering. E-mail a.sproul@unsw.edu.au

Wind Energy 1

Objectives:

- To apply your skills for research and information gathering to a wind turbine design task;
- To explore design factors that are relevant to wind turbine durability and efficiency;
- To use the results of your research to design a state-of-the-art wind turbine;
- To discuss, analyse and collate the research results and summarise these in the form of a report.

Task:

You are a member of a wind turbine design-engineering group. The team has been given a brief to develop the next generation of utility-scale wind turbines for operation in all climates and extreme wind conditions. Summarise the main design features, which should be incorporated. The project is not limited by cost at this stage – the objective is to explore the cutting edge of technology developments. As a starting point, it is suggested that you assess the advances in turbine design over recent years, considering all major components (rotor, generator, power electronics, tower etc.).

In your report you should consider such aspects as:

Materials (including materials used for individual components); Design (including the geometry and size of components); Quality control aspects.

Wind Energy 2

Objectives:

- To apply your skills for research and information gathering to a wind farm design task;
- To explore design, construction and operational factors relevant to commercial wind farm projects.
- To use the results of your research to prepare an example project proposal for a US utility that has put out a tender for additional generating plant.

Task:

A large mid-west US electricity utility has put out a tender requesting proposals for new power projects to help it meet growing electricity demand. You are the leader of a team developing a proposal that offers to build this utility a large wind-farm. You need to develop a strong case for why this utility should consider wind power rather than gas, nuclear or coal fired generation. You need to design a wind farm for the utility clearly highlighting the engineering choices available and the financial and operational impacts of these choices.

Your report should take the form of an 'example' proposal along the lines of

- why the utility should consider wind power
- a range of possible wind farm designs that highlight the choices available, and decisions required in terms of wind turbine design and wind farm locations, size, grid connection, operating impacts on the utility grid, estimated power production and capacity factors, estimated capital and operational costs, community issues etc.

Useful references for all the wind projects include:

- Danish Wind Energy Association. This has an excellent on-line tutorial on all aspects of wind power. www.windpower.dk
- American Wind Energy Association. Excellent information on the US wind resource including wind maps, recent US projects, estimated costs etc. www.awea.org
- The European Wind Energy Association. This site has some useful publications including one on best practice guidelines for wind farm developments. www.ewea.org
- US NREL wind technology centre. The home of US government research into wind technologies. http://www.nrel.gov/wind/

Contact for all wind energy projects; A/Professor Iain MacGill, School of Electrical Engineering and Telecommunications. E-mail i.macgill@unsw.edu.au

Energy and the Process Industries 1

Electric Arc Furnace (EAF) Steelmaking is the process of recycling scrap metal to make new steel. The furnace can be charged with up to 100% scrap. This method is lower cost than traditional BOF steelmaking when scrap steel is readily available. It conserves raw materials like iron ore and coke. Steel is 100% recyclable.

Power is supplied by electrodes to the furnace. The power applied creates an arc between the electrodes and the scrap steel. The energy from the electric arc melts the scrap and raises the bath temperature to 1600°C. The EAF Steelmaking process usually takes from 35 minutes up to 180 minutes.

In USA, EAF steelmaking accounts for approximately 50% of the steel production. Analyse the energy consumption in EAF steelmaking process for a range of steel producers in USA (at least 3 different steel plants). Explain the variation in energy efficiency for the range of producers considered. What recommendations could be made to improve energy efficiency of EAF steelmaking process.

Energy and the Process Industries 2

Ironmaking is the first step in the steelmaking process. It is a continuous process that runs 24 hours a day, 7 days a week. Burden are the materials charged into the blast furnace. The burden consists of coke (source of carbon for reduction), iron ore, and flux. These raw materials are charged at the top of the blast furnace.

Reduction occurs and produces iron during the ironmaking process. The molten iron is drained into torpedo cars which transport the iron to steelmaking. The torpedo cars are on rails and are lined with refractory bricks to keep the iron hot and to protect the car itself. Iron contains approximately 4% carbon in addition to other impurities (Si, Mn, P, S). Energy for blast furnace (BF) ironmaking process is provided in the form of carbon which also serves as a reductant.

Analyse the energy consumption in BF ironmaking process for a range of iron/steel producers in USA (at least 3 different steel plants). Explain the variation in energy efficiency for the range of producers considered. What are the current limitations of the BF technology with respect to its reliance on the specific carbon requirements for the process.

For the two topics on Energy and the Process Industries, you could use the following: www.steel.org

Contact for Energy and the Process Industries topics: Professor Veena Sahajwalla, School of Materials Science and Engineering. Email: veena@unsw.edu.au

Energy Storage 1

Discuss the Current Status of Battery Development for Electric Vehicle Applications.

Energy Storage 2

"Review the recent progress on photoelectrolysis of water and discuss the potential cost and energy saving benefits over coupled photovoltaic-electrolysis systems for hydrogen production."

Contact for energy storage topics: Rob Largent, Manager, Design Assistance Division, Photovoltaics Special Research Centre. Email r.largent@unsw.edu.au

Photovoltaic Devices and Systems 1

Topic "Development of the Photovoltaics Industry"

The photovoltaic industry has developed rapidly over the past 2 to 3 decades. Investigate the significant developments, challenges and the role of external organizations in growing the industry. Investigate what the significant challenges the industry faces moving forward.

Photovoltaic Devices and Systems 2

The cost of photovoltaic (PV) systems has now reduced to the extent that they can be competitive with electrical grid extension in certain situations. In this topic, you will investigate the factors that affect a decision to install a PV system.

For each of the following similarly sized small homesteads, discuss whether (i) a stand alone PV system with battery storage, (ii) a grid connected PV system, or (iii) grid extension without a PV installation would be the best option based on economical (rather than environmental) considerations:

(a) Southern Alaska, 100km from the grid;

(b) Northern Montana, 15km from the grid;

(c) South eastern California, 3km from the grid.

In your report, discuss such factors as relative energy consumption likely in each location, insolation (sunshine) levels, effects of temperature, cost vs efficiency of different cell/module types and the necessity of including battery storage in stand alone systems. Assume that grid extension (approx. $15,000/km), and balance of system (batteries, inverter, cabling and installation) costs are similar at each location.

Finally, suggest alternative system configurations, (such as those which incorporate more than one renewable energy technology) which may optimise the cost effectiveness of the system.

Bibliography: (For all PV topics)

General info: http://www.iea-pvps.org/

Lots of interesting survey information on aspects of PV implementation and growth figures.

http://en.wikipediaa.org/wiki/photovoltaics

Solar data for selected sites: http://www.nrel.gov/rredc/solar data.html

NASA Surface Meteorology and Solar Energy:

http://eosweb.larc.nasa.gov/cgi-bin/sse/register.cgi

Equipment supplier site: http://www.pvpower.com/

Texts:

S.R. Wenham, M.A. Green, M.E. Watt & R. Corkish, *Applied Photovoltaics* UNSW 2nd Edition (2006) ISBN 0-7334-2175-X

Contact for all photovoltaic topics: Ted Spooner, School of Electrical Engineering and Telecommunications. Email: t.spooner@unsw.edu.au

Biomass 1

Analyse the impact of the current global biofuel production programs (eg in Brazil, the US, Europe etc) on reduction of Greenhouse Gas (GHG) emissions. Discuss also the evidence for the impact of increasing GHGs on climate change.

Biomass 2

Biofuels involving ethanol and biodiesel blends from renewable agricultural/ forestry resources are playing an increasing role in liquid fuel production.

Discuss the key factors likely to influence the future production costs of both carbohydrate-based and hydrocarbon-based fuels over the next 5 -10 years.

Key reference for both assignments:

US Roadmap for bioenergy and biobased products:

www1.eere.energy.gov/biomass/pdfs/obp_roadmapv2_web.pdf

Contact for both biomass projects: Professor Peter Rogers, Biotechnology, Samuels Building. Email: p.rogers@unsw.edu.au

N.B. All UNSW staff can be contacted by email or phone. Check the UNSW directory or see details provided in the 'Staff' section above