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Design for Sustainability

ecological dimension

Module 4
Appropriate Technology: Energy

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1. Introduction

The Section of Appropriate Technology module of the Ecological Design Dimension mainly focuses on technologies for the generation and use of energy. There is great interest in the sustainable design of carbon neutral energy systems because of climate change. We need a fundamental re-design of our energy systems at local, regional and global scale. The urgency of responding to climate change dictates a shift away from fossil fuel use and towards renewable energy sources. This is why we examine these energy technologies as part of a resilience strategy for sustainable communities and ecovillages.

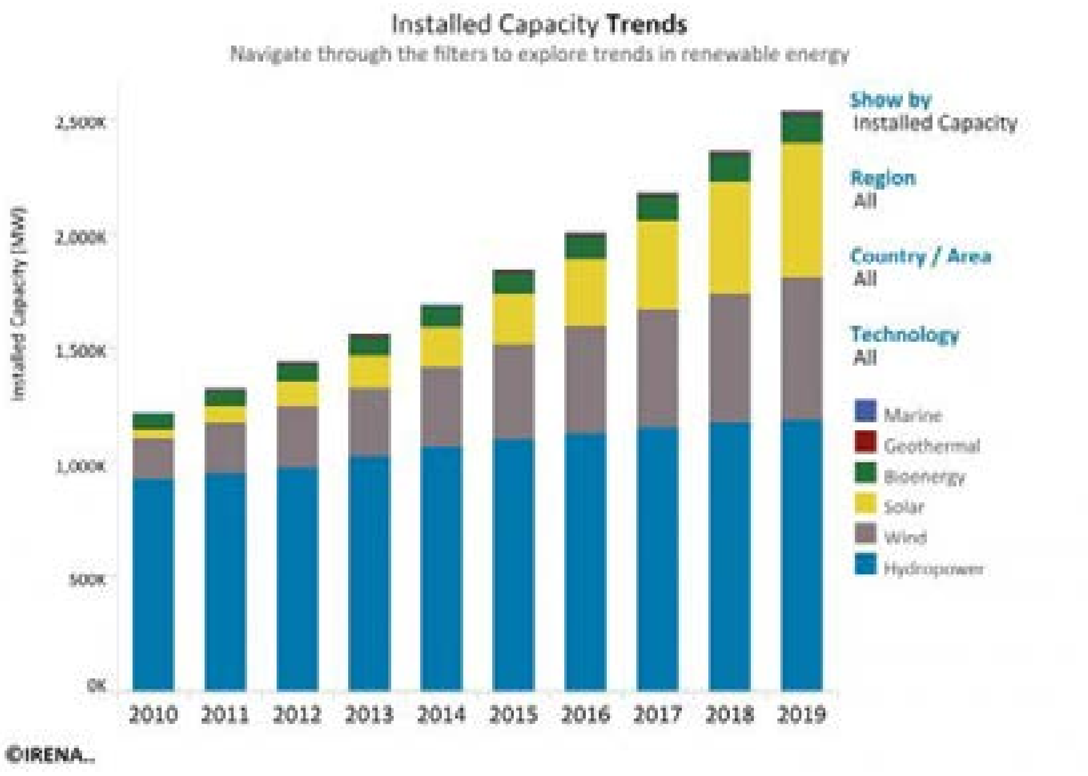
The Contents of this Module starts off by providing the broader Context of energy supply by highlighting the recent positive trend of investments in renewable energies, but this is juxtaposed against a backdrop wherein the world economy is still driven by fossil fuels, and hence the extreme urgency to facilitate much more renewable energies which are aligned with the SDGs and that mitigate climate change. This follows with a section on "The Rationale for a Paradigm Shift in Energy Thinking" in order to provide a wide lens of overarching energy issues to contemplate for the design of appropriate energy solutions. In turn, this provides the backdrop for exploring a "Whole Systems Thinking Approach for Energy Supply" from a policy / strategic level through to a bioregional, local and on-site level. Thereafter, a wide spectrum of "Energy Generating Technologies" are outlined before highlighting the potential of "Energy Efficient Technologies", and some "Sustainable Energy Alternatives". "Sustainable Transport Options" are then briefly explored before the final "Conclusion".

Context

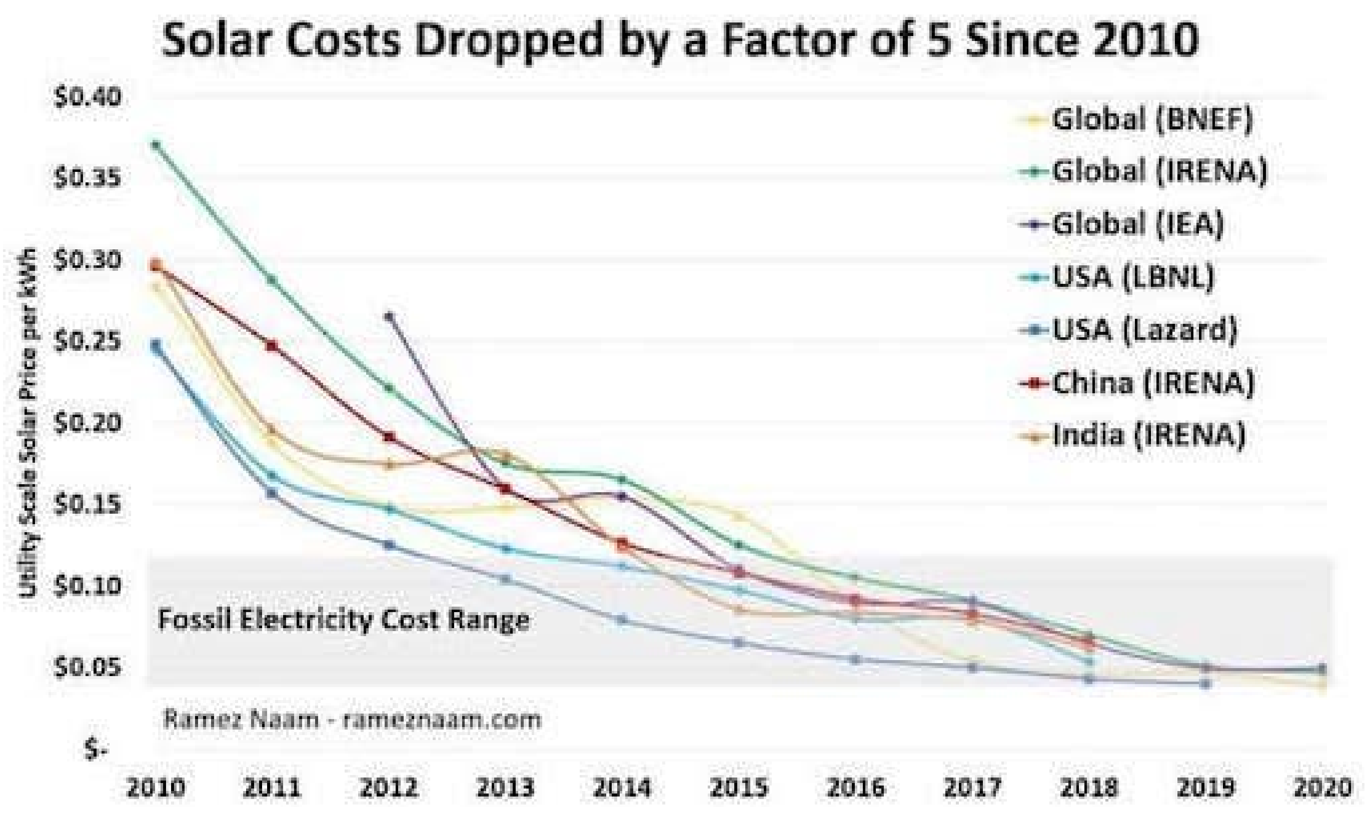
The many phases of the Industrial Revolution have until this last decade always been powered by abundant and relatively cheap fossil fuels, namely, coal and oil. National energy systems are optimised to extract efficiencies of scale by locating power stations as close as possible to coal mines in order to minimize transport and resource handling logistics. This has created a centralised energy system with concentrated pockets of energy generation, which have been linked with major high voltage electricity supply lines to strategic nodes, which in turn, reduce the voltage to supply sub-nodes, from where electricity is distributed via local networks to end users. In time, as coal reserves were depleted, major hydro-electric and nuclear generation was necessary to sustain electricity supply into this centralised energy grid. More recently, natural gas and gas from hydraulic fracking have augmented this energy generation, together with the necessary pipeline networks.

The development of most coal fired power stations, nuclear power plants and the centralised energy supply grid, have mostly been major public sector funded capital development projects, many of which have been fraught with delays, cost over-runs,graft and corruption, not to mention environmental degradation and deterioration of air quality. Furthermore, these centralised energy systems, although initially driven by grand economies of scale, have in hindsight, become prone to systemic risk as they start reaching the end of their economic lifetime and cannot simply be replaced with modern technology updates without incurring yet another major capital expansion plan. Moreover, these centralised energy systems are also vulnerable to Black Swan type disaster events, such as, the nuclear disasters at Chernobyl, Fukushima, Long Island, and many others which are covered up, just like the disposal of nuclear waste material. Then there is also the threat of terrorism attacks against these so-called "national strategic points".

The oil crisis in the early 70s did stimulate the advance of renewable energy systems, but this faded somewhat as new oil reserves were discovered. It's only in the last decade that renewable energy has become mainstream in response to mitigate greenhouse gas emissions, and, with economies of scale, the price of renewable energy has significantly reduced to become very competitive, and in some recent public energy tenders, has crossed the threshold to be cheaper than fossil fuels (source). In tandem, investors and finance institutions have become more ethical as they align their policies and strategies with the SDGs which simply do not favour funding for fossil fuel type projects, thus seeing a significant growth in renewable energy projects (source).



Source: Canadian Biomass Magazine



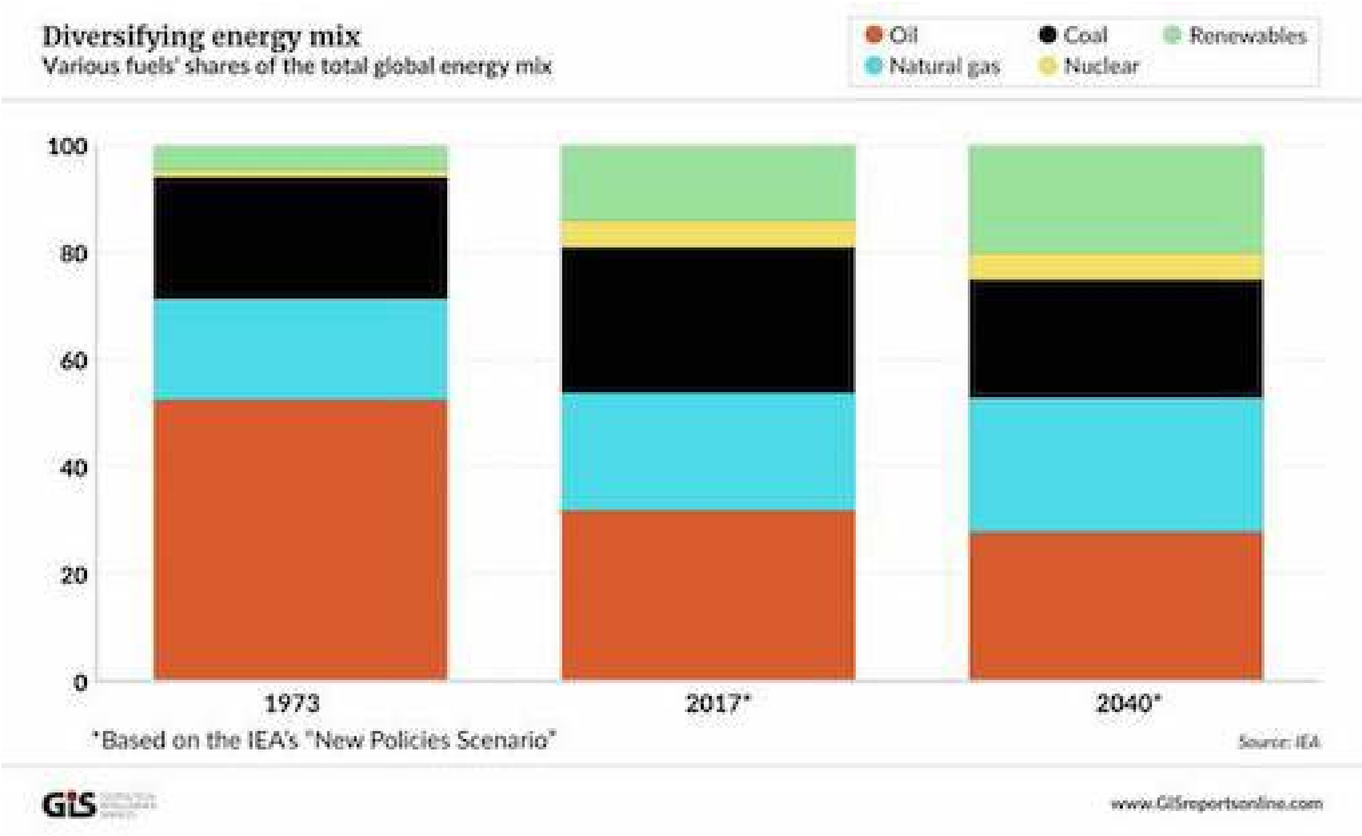
Source: Ramez Naam

You can check energy consumption by source here.

And the projected here.

Many countries have facilitated this rapid growth of renewable energy systems to their national grids. However, whilst this growth trend in renewable energy is very positive, the global energy mix is still very much dependent on fossil fuels (source) for at least the next 20 years and more. Unfortunately, the GHG emissions resulting from this prolonged reliance on fossil fuels, will negatively impact efforts towards climate change mitigation. For this reason, there has never been a greater sense of urgency to transition to a carbon neutral society than now, failing which, humanity will face ecocide through runaway climate change.

Given this sense of urgency, one should not be tempted to accept grandiose carbon sequestration schemes that require massive investments in large scale untested technologies as a quick fix solution. Instead, the Precautionary Principle should be applied, which is a strategy to cope with possible risks where scientific understanding is yet incomplete and where the potential impact is not fully justifiable. However, besides the sheer technical transition, society in general has to make a paradigm shift in values and consumption patterns in order to transition towards a carbon neutral society. This Module explores the technical frontiers towards this transition, but also touches upon some fundamental shifts that humanity ought to make.



Source: *Geopolitical Intelligence services*

2.

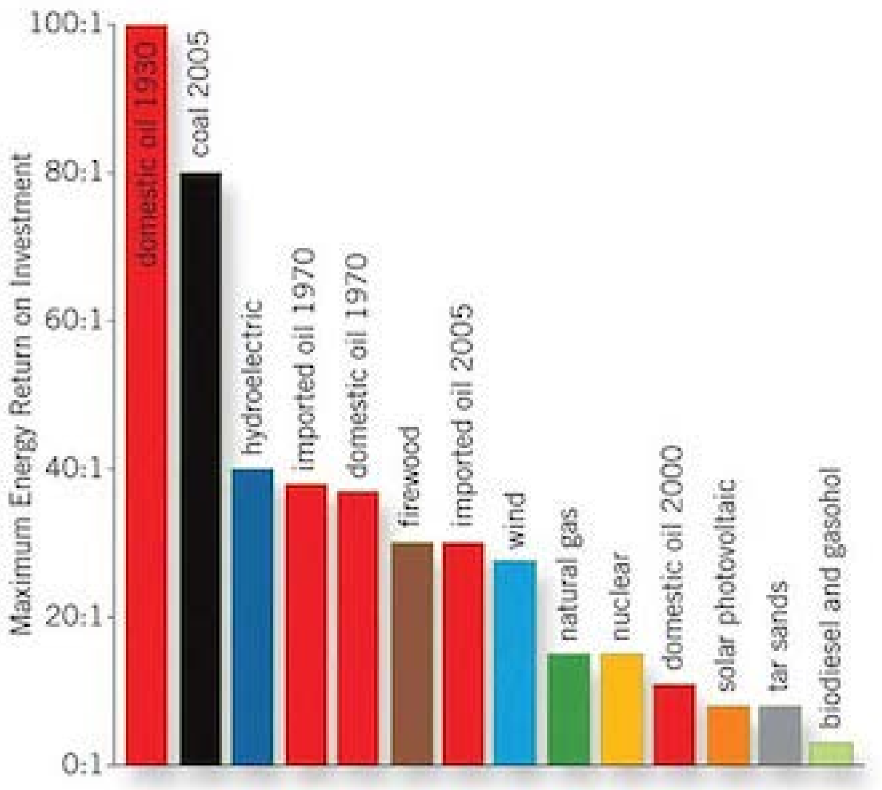
The Rationale for a paradigm shift in Energy Thinking

This section explores the rationale for the necessary paradigm shift in energy thinking by introducing the concept of Biophysical Economics in order to appreciate that to produce energy requires energy, together with the trending energy efficiencies over time. Thereafter, the ecological and carbon footprint of energy sources, as well as the embodied energy footprint of commonly used materials, further emphasises that our modern society is gripped by a voracious appetite for development, which needs to be seriously addressed in every facet. Finally, some innovative negative emissions technologies are discussed which have emanated from recent IPCC reports together with their implications. The purpose of this section, is to provide a wide lens of key energy issues so as to better understand the urgency that is required to address global energy issues in such a manner that;- is able to sustain our complex society with renewable energy sources; uses low embodied materials to reduce ecological and carbon footprints; and, is discerning in the use of appropriate negative emissions technologies.

Biophysical Economics

The basket of energy sources available to humanity to sustain itself needs to be understood in the context of biophysical or ecological economics.Herein, some pioneering scientists who understand the physical limits to growth have developed the concept of "Energy Return on Energy Invested (EROEI) ", also known as, "Net Energy Return (NER)". One of the pioneers who coined this concept is Charles A.S. Hall . His simple way to explain this concept is that, "A predator, such as a trout or cheetah, cannot expend more energy in chasing prey than it gets from that prey. And, it must also pay for its own repair, depreciation, replacement and R&D".

The formula in the previous page (Defitition of EROI) uses energy units to derive a ratio between the total energy delivered compared to the total energy required to deliver such energy. The latter includes the total energy equivalent costs, such as the direct costs of



Source: Charles A. S. Hall and John W. Day Jr./ American Scientist, Graph: Matthew T. Stallbaumer

energy production, and the indirect costs, such as the cost to the environment for waste disposal, rehabilitation, road infrastructure, water extraction, pollution, etc. The EROEI ratio for a wide range of energy sources from Dr Charles A.S. Hall is shown in the Figure below. It also shows how the energy return form oil extraction has drastically dropped since the 1930s.

The energy return on investment for firewood includes what you spend cutting and splitting it. However, after some rest and a good meal it's 100 percent renewable!

The interesting observation of this chart, is the diminishing ratio of oil extraction efficiency over time, and hence the reason why oil exploration is going deeper and wider than ever before. Put simply, the age of peak energy has arrived, and the era of abundant cheap energy is over, as the diminishing EROEI ratios indicate. The implications for economies and sustainability, is that more and more energy will be required to sustain energy hungry economies, thus leaving less and less discretionary income to generate the new capital to sustain aging infrastructure and/or develop new infrastructure for renewable resources.

Paying attention to EROEI ratios can guide decision-makers towards making the more sensible decisions when energy sources are compared. For example, the controversial fracking for gas industry will be found wanting if the true cost of water consumption, wastewater treatment and transport is fully costed, compared to alternatives such as wind and solar energy.

The Biophysical Economics Policy Centre, an international "think-tank", has been researching the theme of EROEI to help policy-makers understand the importance of energy, especially its biophysical limitations, with respect to economic development policy. This research has evolved around trying to understand the linkages between energy consumption and economic growth, and also, why is it that economic growth since the last global financial crash in 2008 has stagnated in relative terms. Whilst there may be many attempts to explain this phenomena in terms of interest rates, systemic risks, trade wars, etc., a simple explanation put forth by David J. Murphy and Charles A.S. Hall, is that declining EROEI ratios means that relatively more energy is required to create energy, which until before 2008 favoured economic recovery because of relatively cheap energy, whilst post 2008 energy has become relatively more expensive, hence the general sluggish economic recovery.

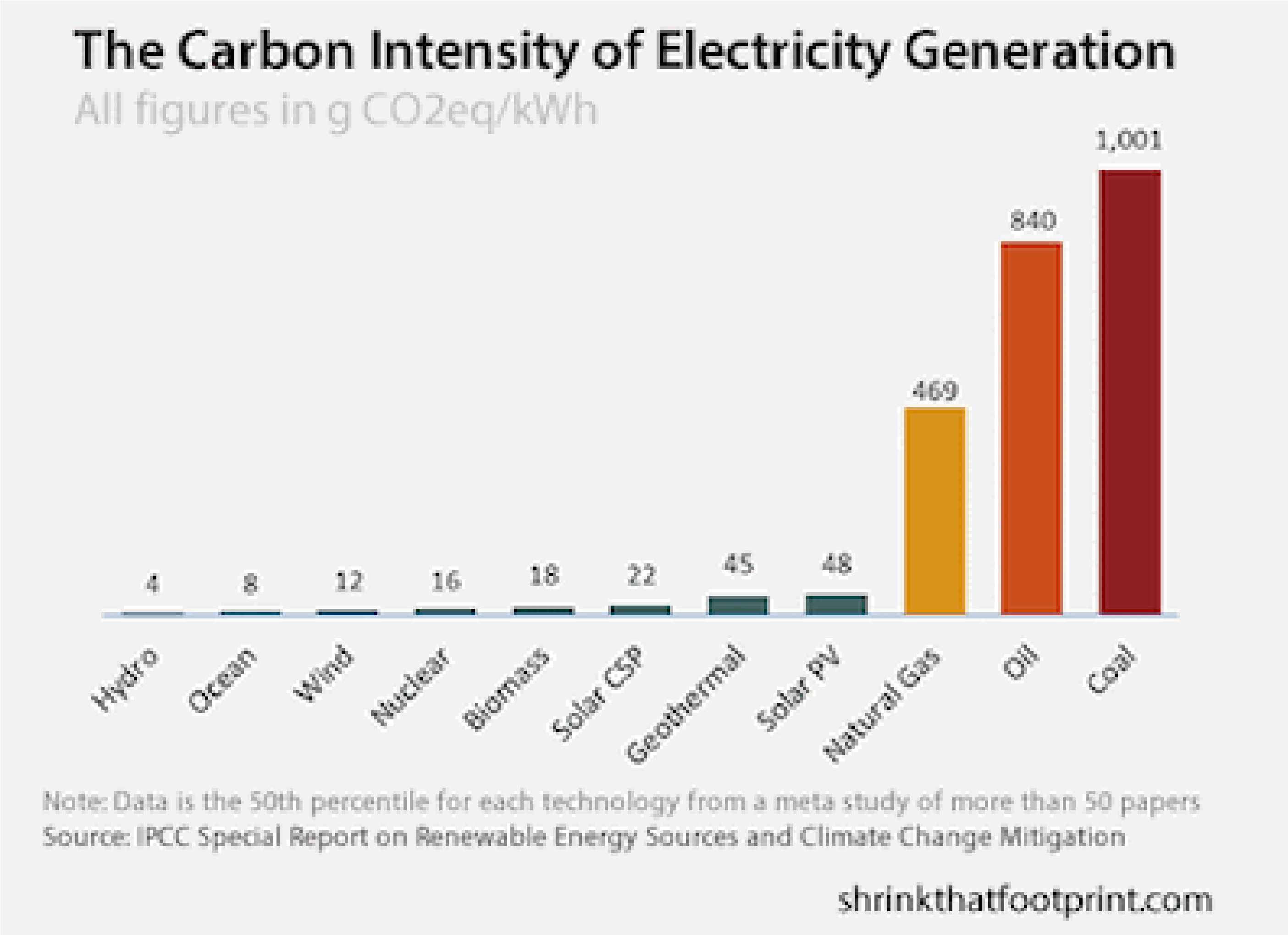
Another related and more daunting issue about EROEI, is that whilst it may be apparent that societies collapse because of environmental degradation, disease, invasions, extreme climatic events, etc., the underlying cause is economic due to diminishing returns on investments in social complexity, this in accordance to Joseph A. Tainter ,author of the book, “The Collapse of Complex Societies”. It has been estimated that complex societies, such as in the first world, require at least a general basket of EROEI ratio of 5:1 to merely sustain themselves, whilst a society with an EROEI ratio below 3:1 will simply collapse (source: Charles A. S. Hall). This is what seemingly happened with the fall of the Roman Empire when the EROEI in terms of its total calorific value from its grain harvest decreased as the terrain could no longer support the relatively higher yields it achieved during its growth and conquest phases, coupled with crippling taxes to support a crumbling empire. Similar parallels are explored in Jared Diamond’s book,“Collapse: How Societies Choose to Fail or Succeed”.

2. The Rationale for a paradigm shift in energy thinking

2.1. Ecological and Carbon footprint of Energy Sources

Different methods of generating energy have very different ecological and carbon footprints. Another related and more daunting issue about EROEI, is that whilst it may be apparent that societies collapse because of environmental degradation, disease, invasions, extreme climatic events, etc., the underlying cause is economic due to diminishing returns on investments in social complexity, this in accordance to Joseph A. Tainter ,author of the book, “The Collapse of Complex Societies”. It has been estimated that complex societies, such as in the first world, require at least a general basket of EROEI ratio of 5:1 to merely sustain themselves, whilst a society with an EROEI ratio below 3:1 will simply collapse (source: Charles A. S. Hall). This is what seemingly happened with the fall of the Roman Empire when the EROEI in terms of its total calorific value from its grain harvest decreased as the terrain could no longer support the relatively higher yields it achieved during its growth and conquest phases, coupled with crippling taxes to support a crumbling empire. Similar parallels are explored in Jared Diamond’s book,“Collapse: How Societies Choose to Fail or Succeed”.

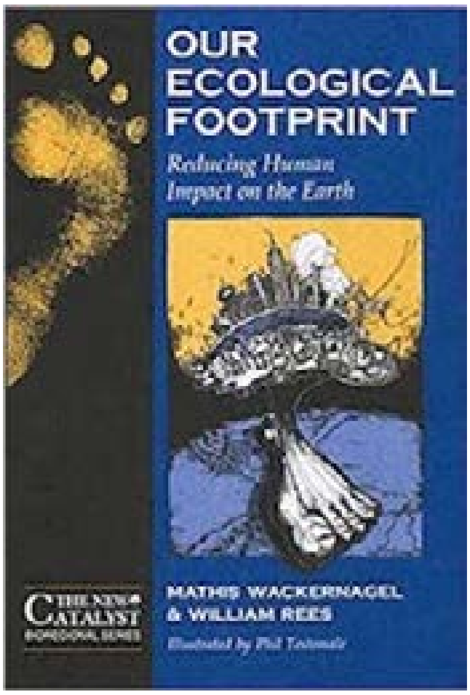
In the chart on the next page from “Our Ecological Footprint”, fossil fuel generated



For more information see [Shrink That Footprint]

electricity has ten times the the footprint of hydro and PVs and a hundred times that of wind. The carbon footprints of fuels and generating methods are given in the following energy conversion tables.

Industrial processes can be heavy energy consumers and can also emit carbon as part of the manufacturing process. An example is the cement industry, which emits up to 8% of the planet's CO_2 ([more info]).



[Our Ecological Footprint by Mathis Wackernagel and William Rees]

Energy	Units	kWh	KgCO2/kWh
LPG (bottled)	kg	15,28	0,214
LPG (metered)	litre	7,64	0,214
LPG (tank)	litre	7,64	0,214
Kerosene	litre	10,78	0,25
Gas Oil	litre	10,86	0,25
Wood Pellets	kg	4,70	0,00

Transport	kgCO2/km
Train	0,11
Bus	0,09
Underground	0,09
Ferry	0,47

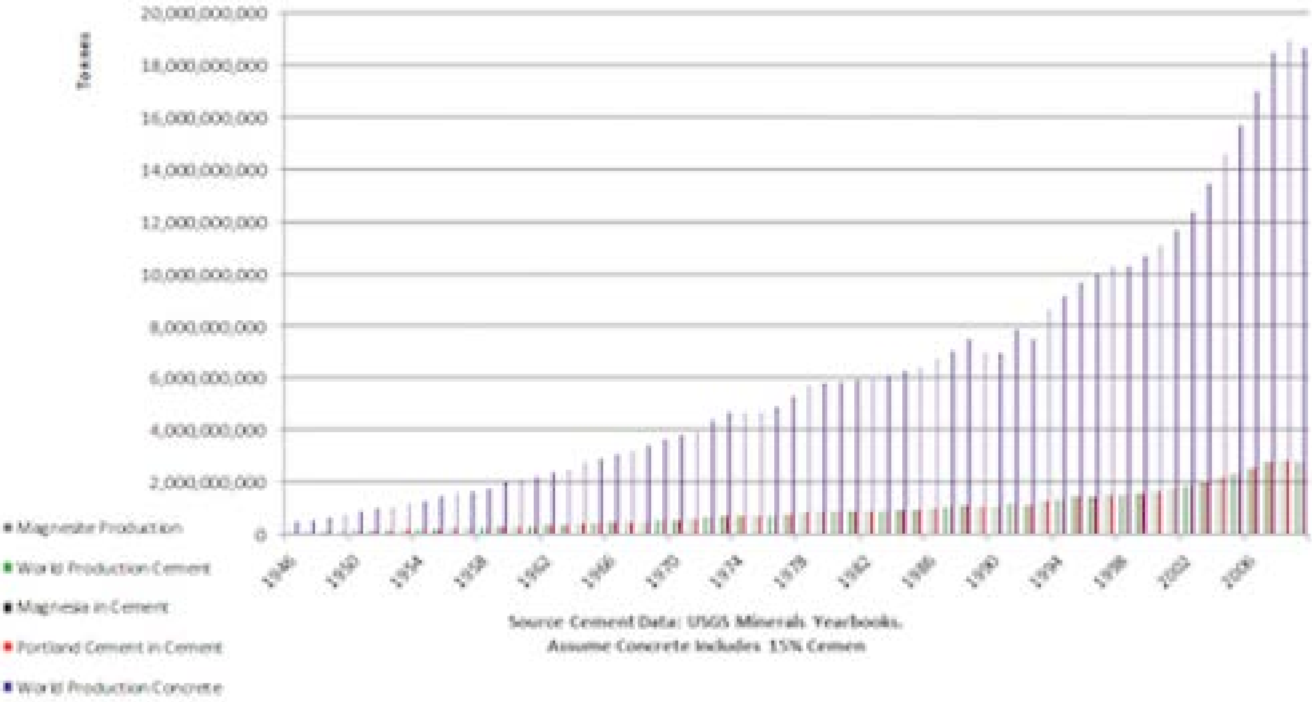
Fuel Source	kgC/kWh	kgCO2/kWh
natural gas	0,0518	0,19
oil	0,068	0,25
solid	0,0817	0,30
renewable	-	-

Diesel oil conversions	
1.187	litres/tonne
12.668	kWh/tonne
0,25	kgCO2/kWh
10,7	kWh/litre

Rape Oilseed		
Number	Unit	Comments
6,257	kWh/l	Analysis of Rape Oilseed
6,876	kWh/Kg	Analysis of Rape Oilseed
1	ton/ha	SAC Report
1.099	l/ha	Analysis of Rape Oilseed
250	£/ton	UK Cost
0,83	£/litre	'Home' price

Materials	Emobodied Energy And Carbon Data	
UNITS	EE-MJ/Kg	EC-kgCO2/kg
ALUMINIUM(Gen)	155	8.24
AGGREGATE(Gen)	0.1	0.005
BRICKS	3	0.22
CEMENT(PORTLAND)	4.6	0.73
CEMENT WITH 25% FLYASH	3.52	0.62
CEMENT WITH 50% FLYASH	2.43	0.42
CEMENT MORTAR(1:4)	1.21	0.177
CONCRETE (PLAIN)	0.95	0.13
CONCRETE(REINFORCED)	1.21	0.148
CONCRETE BLOCKS(8MPa)	0.6	0.061
CONCRETE PRECAST	2	0.215
GLASS(GEN)	15	0.85
STEEL(GEN)	24.4	1.77
STONE	1	0.056
TIMBER	8.5	0.46
PLYWOOD	15	0.81
MARBLE TILES	3.3	0.187

Embodied Energy And Carbon Coefficients. Table extracted from: Research Gate



Global CO2 emissions from cement in billions of tones -1 tonne of cement releases ~0.93 tCO2

The IPCC and Approariate Technology

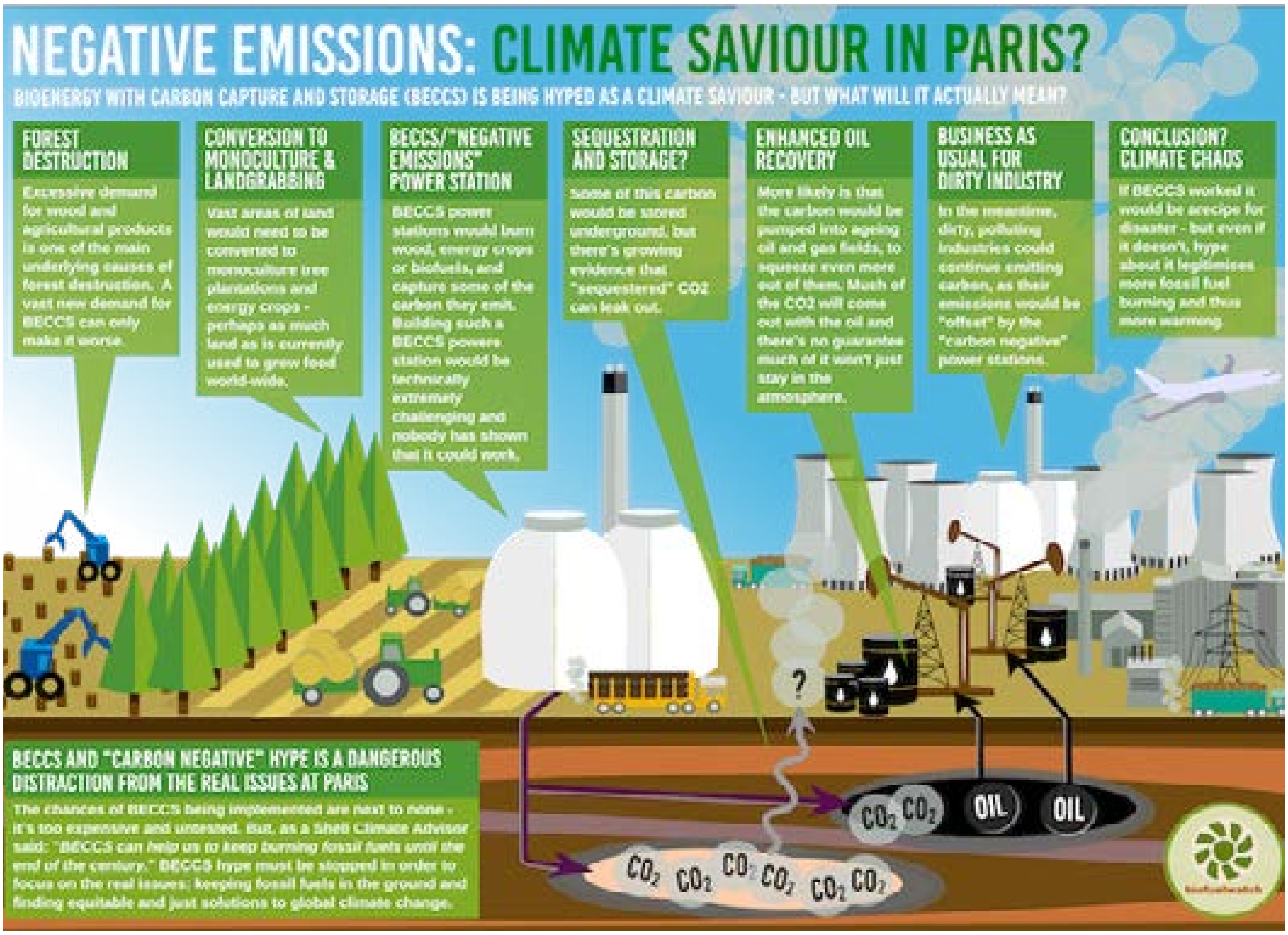
Before we look at the forms of appropriate technology we can chose to provide for our needs without compromising biosphere integrity, it's worth considering the recent IPCC reports and their Negative Emissions Technology. As we have seen, in order to achieve carbon neutrality the IPCC has proposed certain pathways to 'net zero emissions' and these are being adopted by governments and advocated by mainstream media. According to the Paris Agreements, these pathways will be turned into firm regulatory commitments at the COP26 in 2020.

The term 'Net Zero Emissions' is not the same as zero emissions, but entails balancing emissions with drawdown using 'negative emissions technologies'. It also entails the use of biofuels, which will be discussed below, carbon capture and storage technology as well as certain 'geoengineering' projects that including whitening clouds to reflect sunlight (the Albedo effect),

fertilising the oceans to sequester more carbon in them, as well as spraying aerosols to create rain. All geoengineering proposals entail considerable risks to biosphere integrity and cannot be tested in the laboratory prior to implementation.

Here we will look at the negative emissions technologies that are already being widely adopted, such as tree planting, and those attracting research funding, such as CCS (Carbon Capture and Storage) and DACS (Direct Air Capture and Storage).

This diagram from the NGO Biofuelwatch explains the options and sums up some of the dangers inherent in adopting these proposals.



- **CCS will allow the fossil fuel industry to continue to convert fossil fuels to electricity in power plants but the CO2 emissions will be captured in machines that filter out the gas through a process using amines known as 'scrubbing'.** When the filter is full, the CO2 is carried through pipes to be stored in old oil wells. As it is pumped in, the residues of oil rise so that it can be accessed. This is referred to as Enhanced Oil Recovery. CCS has been proposed for industrial production processes driven by coal or oil too. Effectively, it would mean business as usual for a very dirty industry with the impacts of drilling and mining on the environment continuing unabated.

- **CCS technology is still in its infancy and at present cannot be up-scaled to accommodate the amount of CO2 and it could also turn out to be very expensive.** Who will pay for it given that it will also raise the price of energy and consumer goods? Is this feasible given the imperative for economic growth? Will the expense be distributed equally or fall as a burden on the poor and on developing nations. All of these questions need to be raised and answered.

- **DACS uses the same amine scrubbing technology but captures the gas directly from the air.** It is being tested on a small scale in various places and the CO2 is not stored underground but re-used either by pumping it into greenhouses to stimulate plant growth or to put the bubbles in bottled water. The main problem with enhanced plant growth through forcing with CO2 is that while the plants grow more rapidly the nutrient content decreases.

- **Trees are referred to as negative emissions technologies and already the mania for tree planting to draw down and sequester carbon has started. Given the scale of the deforestation we have witnessed over several millennia, and especially over the last two centuries, reforestation seems like a highly beneficial activity.** But there are caveats. The Bonn Challenge is the 'forest land restoration approach' to climate change and environmental degradation. The aim is to restore 150 million hectares of degraded and deforested lands in biomes around the world. We must be careful, however, to ensure that the reforestation projects genuinely restore woodland ecosystems rather than using the land for monoculture plantations of fast-growing trees for biofuel energy or other timber industries. Under the Bonn Challenge, 40% of plantations will be allowed, but without independent monitoring the percentage could be much higher. Plantations are highly lucrative for investors as they attract subsidies for carbon sequestration, and for biofuels, and the crop can be sold in 10-20 years. Monoculture plantations have many drawbacks besides the loss of habitat for a diversity of wildlife, including the increased risk of wildfires. Rapidly growing, genetically modified pine and eucalyptus have been developed for plantations which dry out landscapes and ignite easily during droughts. And we must also make sure that indigenous peoples are not moved off their lands in order to plant trees so that effectively reforestation projects turn into land grabs.

- **BECCS is extremely popular with Western governments.** It entails burning biomass from trees in power stations to generate electricity with amine scrubbing technology for capture and storage. Already, biomass is being regarded as a clean and renewable form of energy for electricity generation, and is subsidized by the European Union and individual governments. However, scandals around the illicit logging of old-growth forests are emerging already and, moreover, studies have shown that burning biomass is not emission-free either.

The IPCC report published in August 2019 entitled "Climate Change and Land" estimates also that carbon can be sequestered in soil through changes to farming methods. Regenerative agriculture also becomes a 'negative emissions technology'.

There is a great deal of potential here, as we have seen, for agriculture as ecosystem restoration and so we should consider the potential for regenerative agriculture on many functional levels, its potentially beneficial impact on the entire systemic biosphere crisis, restoring habitat to combat biodiversity loss, it's potential for cooling and combating desertification through rehydrating landscapes, and not merely as a 'technology' to sequester carbon with the danger of land grabs and inappropriate land-use change.

Regenerative agriculture and reforestation as ecosystem restoration also have a range of beneficial impacts on local communities, revitalizing rural economies and promoting the SDGs.

As we have seen in previous modules, functioning ecosystems are essential for biosphere systems and even for climate regulation. Any technologies proposed as appropriate should be tested against their impact on fully functioning ecosystems.

3. Whole Systems thinking approach for Energy Supply

To apply a Whole Systems Thinking Approach for Energy Supply, one needs to think from the macro policy and strategic level right down to a bioregional, local and on-site level. This hierarchical thinking is necessary since from the outset the strategic direction should be to find solutions within the available national and bioregional biocapacity, or carrying capacity. This section explores this thinking at the following levels with some examples:

- **Policy and strategic level –** Approaches that support energy policies and strategies away from the "business-as-usual model" (BAU) towards more sustainable models within the national and bioregional carrying capacity.
- **National and bioregional level –** The shift from centralised to decentralised energy systems.
- **Built environment level –** Passive design and Integrated Renewable Energy Systems.

Policy and strategic level

The roadmap on this page outlines bioregional paths to an effective renewable energy strategy that integrates the generation, distribution, and use of renewable energy at the household, community and regional scale. Amory Lovins' excellent book Reinventing Fire describes a national roadmap for the United Sates to shift to a renewable energy system and near zero carbon emissions.

Watch this video about the new fossil fuel free energy economy.

Likewise, the Centre for Alternative Technology in Wales has created a feasibility proof and strategy for Zero Carbon Britain .

Watch the video about this research. The shift towards a renewables based zero-carbon energy system is a scale-linking design issue that will have to be implemented through local, regional, national and international collaboration (see the European Supergrid example of large infrastructures).

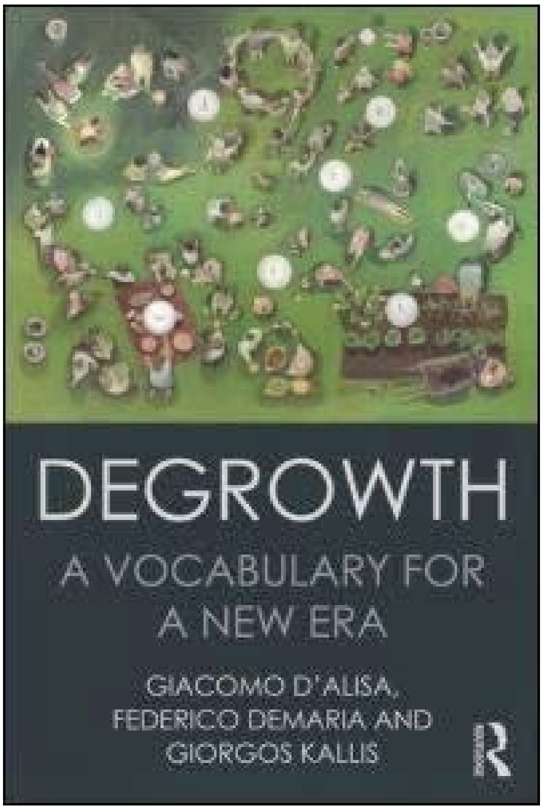
The Transition Network is a growing worldwide movement that has mobilized community support and action groups that purposefully work from a bottom-up approach towards practical sustainable solutions that mitigate climate change, promotes the local circular economy and establishes resilience. One of the key achievements of a Transition initiative, be it a town, a city, a district or a region, is the adoption by the local council, or political representatives, of an "Energy Descent Action Plan (EDAP)" which sets out a long-term timeframe (20-years) of how that entity will descend gracefully in tandem with declining energy availability and consumption whilst sustaining a reasonable standard of living. Transition Totnes in the UK was among the first councils that adopted an EDAP (see book), which has been described as: "The EDAP is a comprehensive, lively and colourful community-based guide to reducing local dependence on fossil fuels and reducing the community's carbon footprint over the next 20 years, a period during which the changes associated with declining oil supplies and the impacts of climate change are anticipated to become more apparent (Source: Transition Network). An EDAP is more aligned to recovering ecological overshoot and sustaining within its biocapacity than a BAU plan, which is based on endless and unrealistic economic growth. In any event, even though only a few EDAPs have been adopted, this new thinking may well be influencing conventional planners towards practical solutions for adopting the new SDGs.For an inspiring documentary about "Transition in action, check out".

Watch the documentary (1h 7mins).

Degrowth movement also well understands the limits to growth, since "by 'degrowth', we understand a form of society and economy which aims at the well-being of all and sustains the natural basis of life. To achieve degrowth, we need a fundamental transformation of our lives and an extensive cultural change. The current economic and social paradigm is "faster, higher, further". It is built on and stimulates competition between all humans. This causes acceleration, stress and exclusion" (Source: Degrowth). Essential for degrowth is:

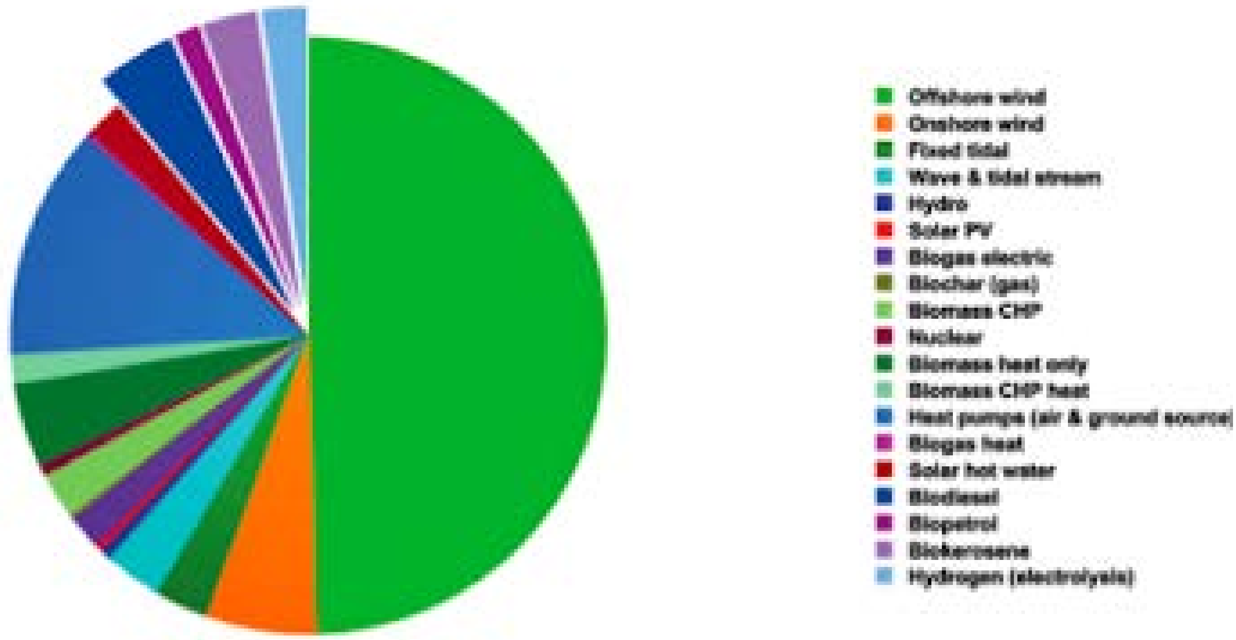
- **Striving** for the good life for all. This includes deceleration, time welfare and conviviality.
- **A reduction of** production and consumption in the global North and liberation from the one-sided Western paradigm of development. This could allow for a self-determined path of social organization in the global South.
- **An extension of democratic** decision-making to allow for real political participation.

Transition Network.org



Degrowth: A vocabulary for a new Era

Fig 8.13b



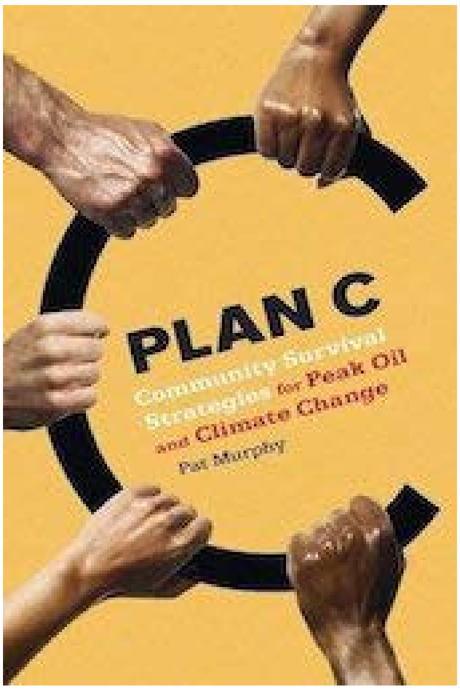
Delivered energy provision, by source in ZCB2030, for a) electricity and heat sectors, and b) electricity, heat and transport fuel sectors.

Proposed energy portfolio for Zero Carbon Britain

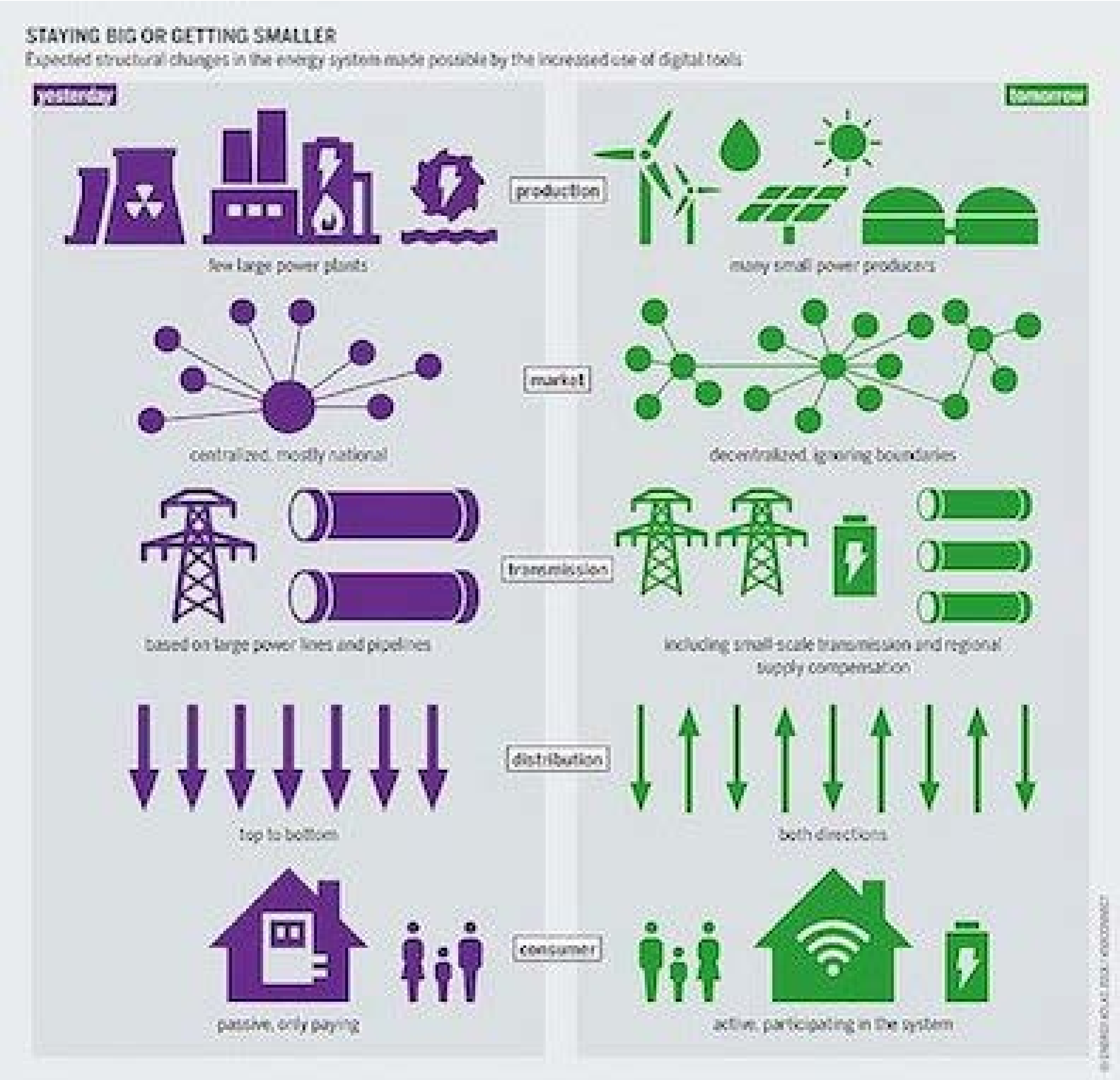
- **Social changes** and an orientation towards sufficiency instead of purely technological changes and improvements in efficiency in order to solve ecological problems. We believe that is has historically been proven that decoupling economic growth from resource use is not possible.

- **The creation** of open, connected and localized economies.

"Plan C" is put forward by Pat Murphy from Community Solutions , who drew inspiration from one of their earlier documentaries, "The Power of Community – How Cuba Survived Peak Oil". Plan C: Community Survival Strategies for Peak Oil and Climate Change, is based on Curtailment, Community and Co-operation, as strategies for surviving the energy descent future. By the way, "Plan A" is the business-as-usual economic growth model; "Plan B" is Lester Brown's Earth Policies Institute; "Plan C" is Curtailment, Community and Co-operation; whilst "Plan D" is die-off or survival islands, and not an ideal option.



Plan C: Community survival strategies for peak oil and climate change



[*Staying Big or getting smaller*]

Centralised versus Decentralised National Energy Systems

As introduced in the context of this Module, the transition to renewable energy systems also entails a shift from a centralised capital intensive mega-project energy system, to a decentralised small scale multi-project energy [smart-grid system]. In a decentralised system, there are many small renewable energy producers that are connected via a decentralised network grid to end-users. These end-users can both buy energy and also produce energy and sell it to the grid or a local micro-grid, in other words, these end-users are "prosumers".

The comparative risks between a Centralised and Decentralised Energy System are outlined in the table below in order to advocate for the less risky Decentralised Energy System which is also more robust, resilient and sustainable, besides addressing SDGs in a more meaningful manner.

Comparative Risks: Centralised versus Decentralised Energy Systems

Centralised Energy System: Techno State

Fossil fuel based centralised energy systems are propped up by large capital projects through State investments and loans, leading to higher energy prices and slow economic growth, with non-alignment to SDGs and risk exposure to overall declining EROEI to sustain complex societies. Aging and outdated centralised energy infrastructure is often not maintained and replaced by the State, resulting in rolling blackouts with crippling socio-economic consequences.

Centralised Energy Systems are prone to becoming Techno States, reliant on State intervention due to the central ownership of the system, and overall, are prone to the vagaries of politics, and therefore unreliable or costly in the long-term.

Decentralised Energy System: Resilient State

Renewable energy based small-scale projects in decentralised systems promotes SDGs and stabilizes EROEI to sustain and grow a complex economy.

Public-private sector partnerships can take on smaller scale projects attracting less risk, and can bankroll a State's energy transition.

Decentralised Energy Systems have greater network connectivity among participants, thereby strengthening connections and better supporting network gaps, whilst enjoying public-private ownership, thus making for more resilient energy systems over the long-term.

Passive Design and Integrated Renewable Energy Systems

The most effective way to design a more sustainable energy system is to start by paying attention to "nega-watts". This concept is to save energy from needing to be generated from any source, simply by creating designs that use very little energy in the first place. The highest reduction in the impact of energy systems on the environment will be achieved by reducing the amount of energy we need in the first place and by using the energy we have at our disposal as efficiently and effectively as possible.

The first priority is energy conservation, which involves ecological architecture (bioclimatic building, thermal mass, super-insulation, etc.); efficient and appropriately sized energy equipment and occupant attitudes.

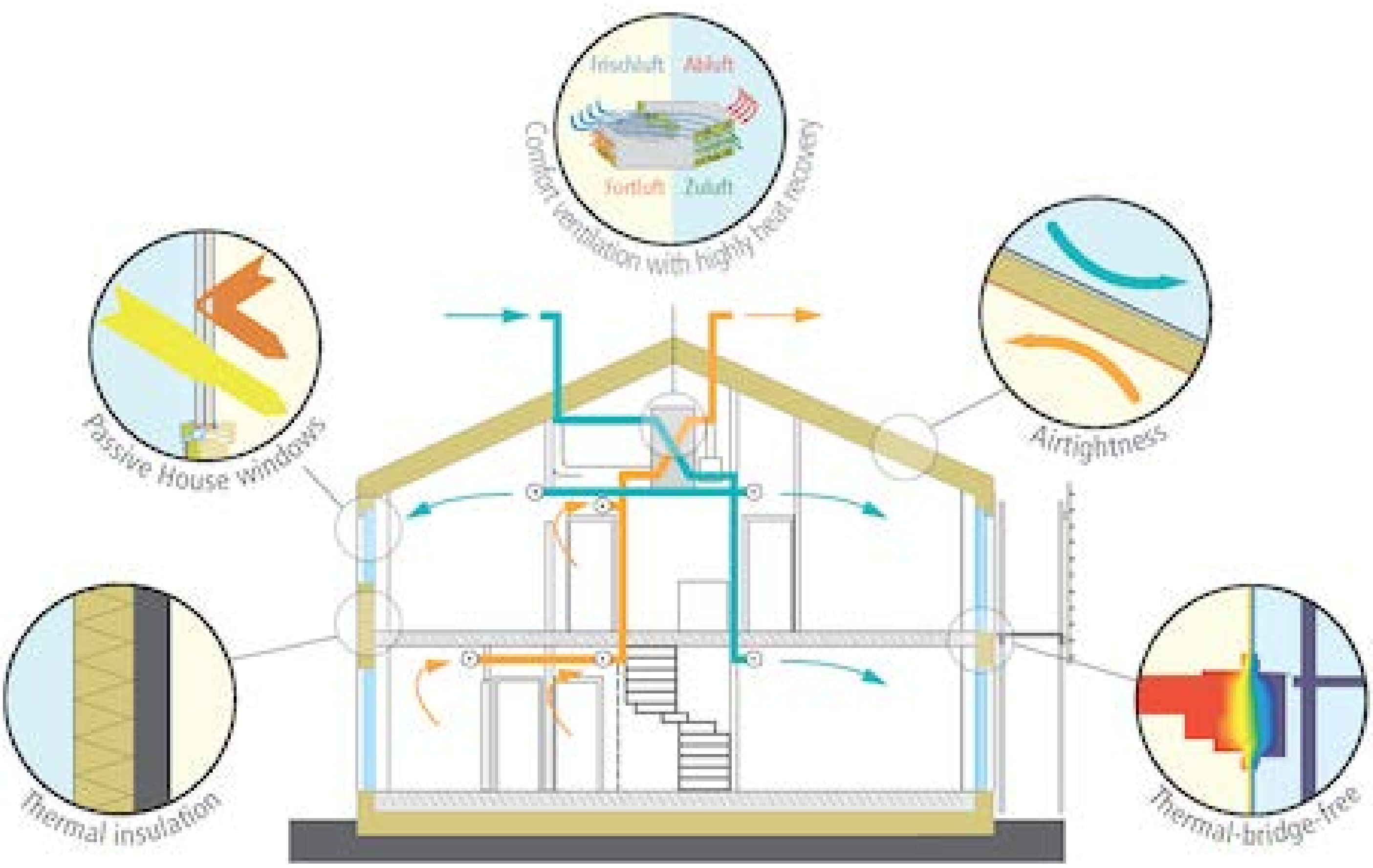
IRENA aims at becoming the main driving force in promoting a rapid transition towards the widespread and sustainable use of renewable energy on a global scale

PREPARATORY COMMISSION FOR INTERNATIONAL RENEWABLE ENERGY AGENCY IRENA

[INFORSE](#) is a worldwide network consisting of 140 Non Governmental Organisations working in about 60 countries to promote sustainable energy and social development.

Passive Design in the built environment, such as Passivhaus, AECB Gold Standard, LEED Platinum, or a low and zero carbon standard, reduces the energy footprint substantially from "BAU". Many European countries have brought in advanced low carbon standards for all new buildings. Alternative energy policies typically allow for grants and subsidies of appropriate technologies. Not all standards set their aim equally high. Some specify only reductions in energy use and carbon emissions, others aim for houses that generate their own energy and reach zero emissions, while the Living Building Challenge and Living Communities Challenge require a net-positive impact of the project through the application of biomimetic and regenerative design.

Integrated Renewable Energy Systems further reduces a building footprint towards carbon-neutral, be it for a new-build or a retro-fit



The basic principles of passive House Construction

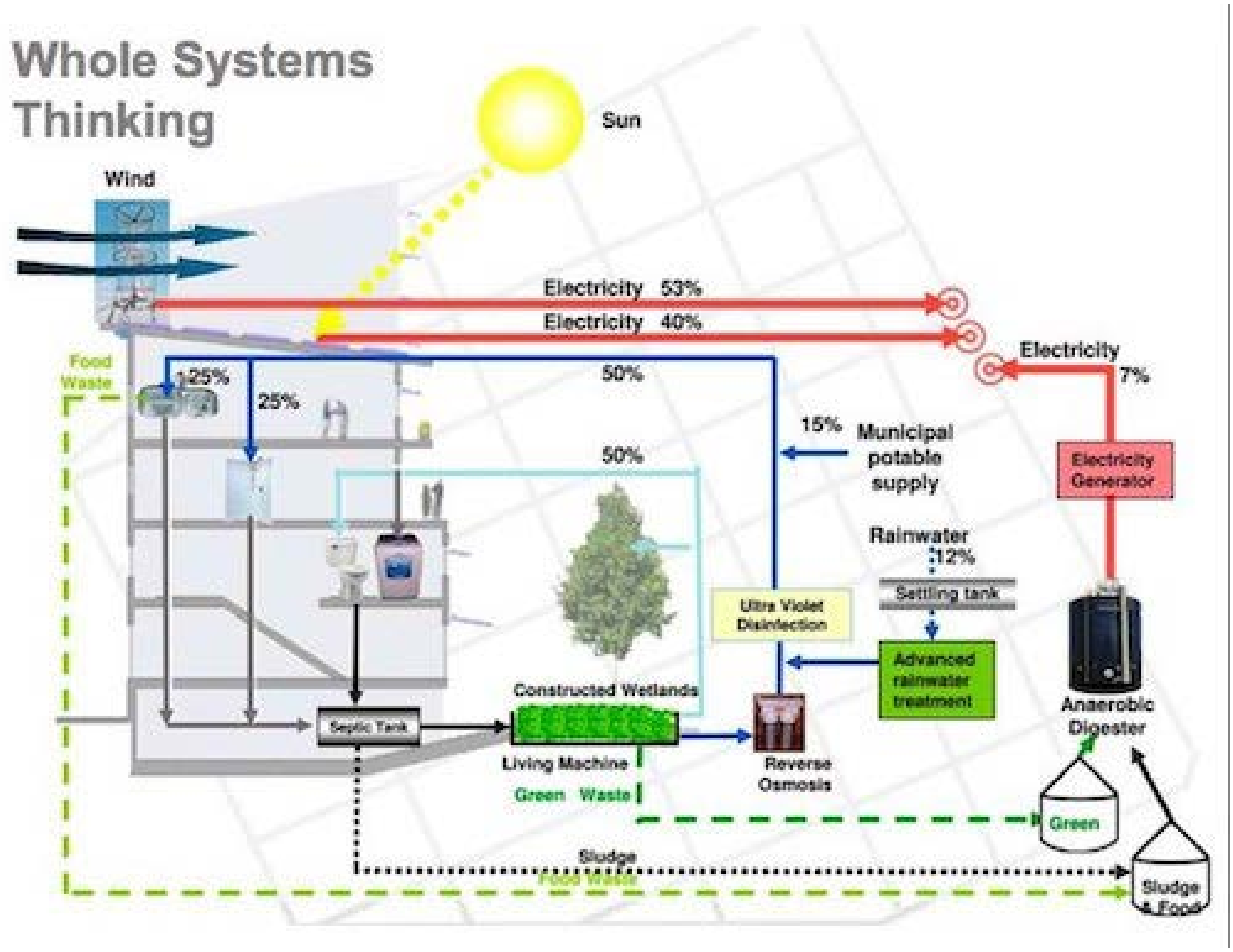


Image from [China Green Building]

project. Ideally, it will be easier to design new-build, but there is much potential to simply retro-fit the existing building stock for energy conservation. All renewable energy systems should be explored and integrated with on-site generation, storage and distribution, with a grid, or mini-grid connection to buy excess demand or sell surplus supply. The on-site systems that should be explored in conjunction with other related building services, includes renewable energy generation from wind, solar thermal, photovoltaic, biomass, biogas and compost heating. In turn, these solutions will reduce the negative waste impact and also the operational cost of utilities, such as, water, sewage, electricity and solid waste removal.

4.

Energy generating technologies

The design of energy systems is best considered as part of an integrated infrastructure design. Conservation, energy, water, food-growing, building design and transport can be integrated to deliver cost effective, ultra-low energy systems. In Module1 on the Whole Systems Approach to Ecological Design we have reviewed a number of approaches to integrated whole systems design. The applications of the principles of industrial ecology to the integration of community infrastructures can help us close loops in energy, waste, and water systems, while reducing energy requirements and increasing the overall efficiency of the system.

The urgency of climate change makes the shift to 100% renewable energy and zero carbon energy systems a survival imperative for our species. We will therefore focus on these technologies. All the generating technologies mentioned do not use any fossil fuels in operations, except perhaps in the transportation of biomass or biofuels. Some may have high-embedded energy in their materials and construction, such as is often the case for hydroelectric projects (especially large scale dams).

Throughout this section, indicative costs per unit of energy generated are shown, but these should be validated for specific projects since they will vary considerably per region, whilst some technologies have improved their relative efficiencies as well as their costs.

By installing over-capacity, offsetting is possible by exporting green power. Thus a windy island can install wind turbines for their own power and export surplus energy to offset unavoidable uses of fossil fuels (eg Samso Island).

American Energy Wind Association

The Danish Wind Energy Association

The generating technologies generally fall into two categories:

1. Technologies which harness natural forces of weather and tide - with wind, solar and marine as examples;
2. Technologies which employ biological processes, such as biomass, biofuels and anaerobic digestion.

A growing trend is the generation of several types of energy from an integrated process, such as a fuel cell delivering heat, electricity and hydrogen from a single system.

Wind Power

Wind power is currently the major generator of alternative energy in many countries. Some nations have an abundance of hydroelectric systems, for example Brazil.

Although wind varies over the day, week and year, by measuring the average wind velocity in m/s, the output of wind generators can be assessed. Typically a capacity factor is applied to the nominal rating of the turbines. Thus a 1 MW wind turbine with a 25% capacity factor will generate an average of 250 kW for 24 hours and 365 days a year, giving an output of 2,190 MW per annum. Because of the variability of wind, the issue is load management of the use of the power and the potential of storage of electricity.

The location and tower height of turbines is critical to get good performance. Locating turbines on high ground with a substantial tower and well away from trees and other obstructions to the wind will result in optimised performance (high capacity factor).

There is considerable interest in offshore wind turbines , because of the strong winds and aesthetic issues. For turbines installed on the seabed, the depth of water ideally needs to be less than 15 metres. However large wind farms can be installed in deep water on platforms similar to oil and gas rigs (more).

Wind Turbines being erected at the Findhorn Ecovillage, where the Wind Park generates 30% more power than used by the Ecovillage over a year

Hydrogen generating project in Norway

Small-scale wind - 2-10 KW - residential

- 3-4 times the energy production as PV per € for build
- ~€7 to €10/watt build (after capacity factor)
- ~€0.08/kWh generated (financed)

Mid-Scale Wind Parks - up to 1 MW

- Manageable - good size for dedicated user
- Can use reconditioned equipment
- ~€5 to €7/watt build
- ~€0.04 to €0.06/kWh generated (50% financed)

Large Wind Farms - over 1 MW

- Most economic – scale matters
- ~€2 to €3/Watt build
- ~€0.02 to €0.03/kWh generated (50% financed)
- Large offshore potential

One of the issues with wind generation is storing the electricity when the wind is blowing for use when there is little wind. This can be achieved by generating hydrogen by electrolysis and burning it when required in a fuel cell. This is illustrated by an island project in Norway. The current issue is the high cost of the equipment. Here is a short video explaining how hydrogen based storage can help to overcome the intermittency issue of windpower and other renewable energy sources.

If you are interested in alternative storage options for decentralised or remote renewable energy systems where grid connection is not an option, here is a link to a summary of island based case studies that lists different battery storage options and compares them.

Photovoltaic and Solar-Thermal Energy

There are two main ways solar energy can be delivered and captured:

- Photovoltaic panels, which generate electricity by the conversion of the sun's energy falling on the panel. This energy can be used as a "stand alone" system, which will require battery storage for the hours of darkness, or as a supplement to a public or private grid supply.
- Solar thermal panels, which collect the sun's energy in a "plate" through which water flows, or through the use of mirrors focussed on tubes filled with water. This system supplies hot water to the building, both for preheating water for a space heating system or for supplying domestic hot water for showers and washing. Like the PV panel, the system can be "stand alone" or can supplement the supply from a different heat source.

Energy Saving Trust is a non-profit organisation that provides free impartial advice to help you save money and fight climate change by reducing carbon dioxide emissions from your home. Both designs of panel have no moving parts for the collection of solar energy. They are robust, long lasting and require little or no maintenance. The solar thermal panels are, of course, connected to a plumbing system, which will have pumps and valves.

Solar Electric (PV - Photovoltaic)

- Reliable proven systems - expected to last for 50 - 100 years
- Practically zero maintenance
- €10 to €15/Watt build = expensive
- €0.18 to €0.25/kWh generated
- Typical payback 25 years

Solar Thermal

Solar thermal panels to heat domestic hot water is now a common application. 3 m2 of solar thermal provides ~2,000 kWh/annum in northern Europe and ~3,000 kWh/annum in Southern Europe. Typically, the operating cost of the panel is solely the cost of financing the extra cost of the solar portion of the installation, i.e. excluding the plumbing in the building. At present, financing runs around €0.08/kWh in Northern Europe, when the panel is paid off over 20 years.

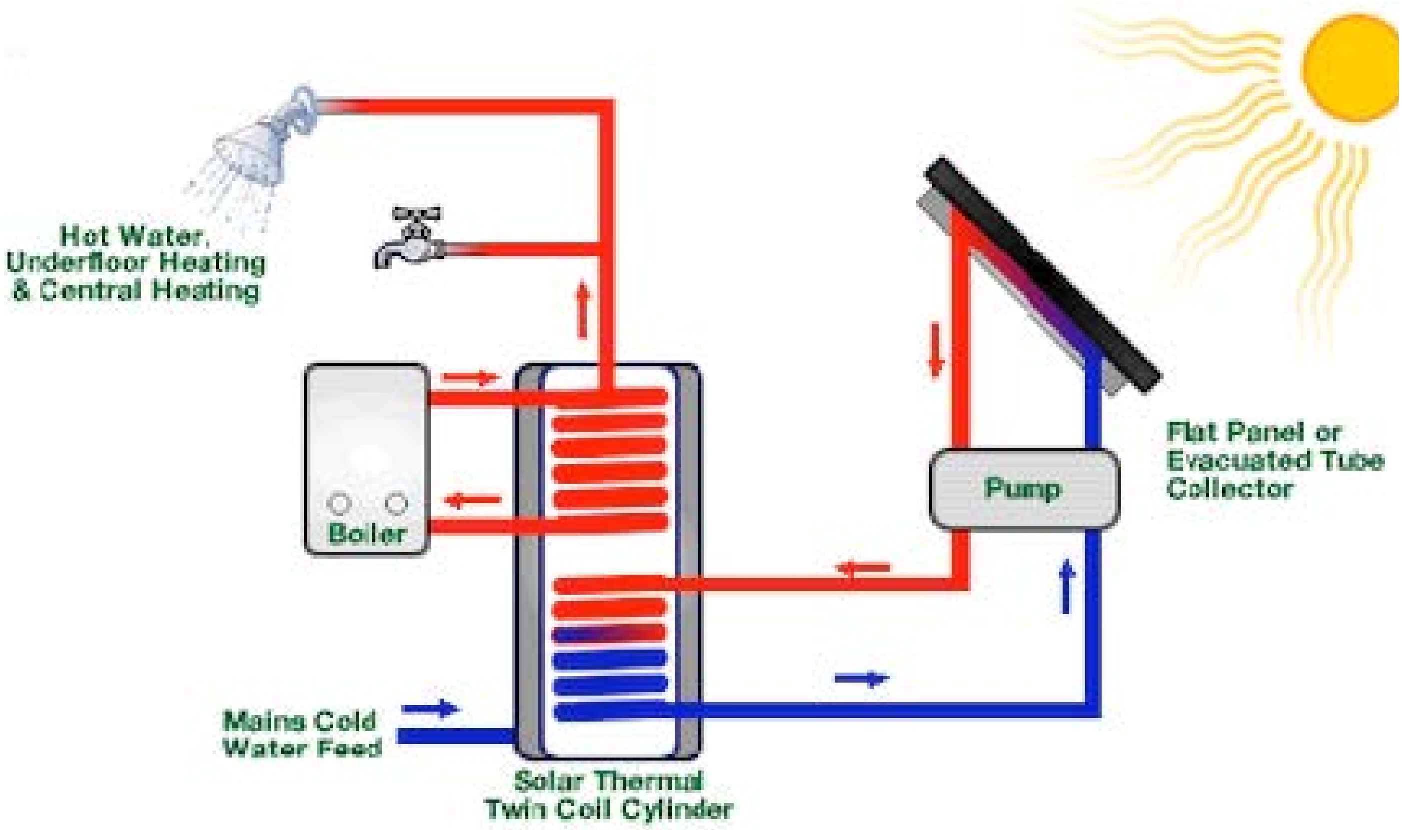


Image from [Solar Utilies]

There are also large scale installations based on solar-thermal power. Many of these systems use mirrors to heat water to generate steam, which then drives a large turbine. These installations are called solar-thermal power stations and are predominantly in dry or desert regions in Spain or the USA.

Biomass Heating

The word biomass means wood and/or other biological materials that can be burned to generate heat. The reason biomass heating is carbon neutral is that the trees and/or plants have sequestered the same amount of CO_2 during their growth as emitted when burned. Wood is the main source for biomass heating and is generally used in two forms, namely:

1. Logs or wood chips, with the trees grown in a continuous cropping and sustainable way. Typically, a fast-growing tree is chosen and harvested in a process called SRC or Short Rotation Cropping. This means harvesting after around eight years of growth. The area required is then eight times the area of trees to be harvested each year. In Northern Europe the area of forest required for sustainable wood production is ~0.7 hectares per house. If willows are the crop of choice, the trees are smaller and harvesting happens every three years. Usually the wood is chipped and dried after cropping.

2. Wood pellets, made from wood and other waste agricultural products, such as the remains of rapeseed after pressing for oil. The advantage of wood pellets is that they are drier than wood chips and have a higher energy output per tonne. They are also easier and less bulky than chips. For

Image from Alternative Energy Primer

example, pellets can be blown into storage hoppers from trucks and act like oil for stoking.

The Biomass Energy Centre, in UK, gives information about the various biomass fuel types that are commercially available or being researched.

Wood chips need to have a moisture content of 25% or less for efficient burning. Wood chip boilers require more operations than the same size of pellet installation, because of the large bulk and handling of the irregularly shaped chips. Boilers and chip storage is more expensive as a capital cost than for the same heating capacity of a wood pellet installation. In Northern Europe, the current bulk price of chips is ~€80/tonne and the current bulk price of pellets is ~€165/tonne.

Many installations now are multi-fuel biomass boilers, i.e. the boiler can handle chips and/or pellets or pellets and/or logs. The storage of chips, pellets and logs is, of course, The Biomass Energy Centre , in UK, gives information about the various biomass fuel types that are commercially available or being researched. different. All boilers are automatic

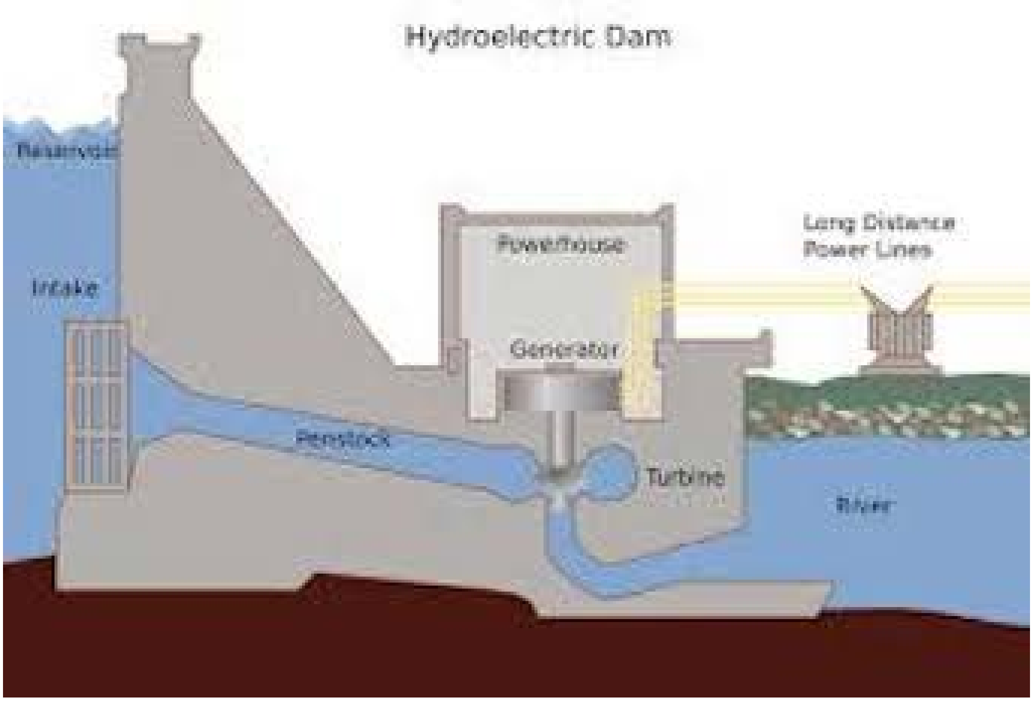
Wood chip boiler and wood chips feeding to boiler/ Comparison Of Wood Chip And Wood Pellet Installations

in operation and flame control. They all have to be de-ashed regularly.

All of the processes described above are microbial. In order for the necessary microbes to thrive, appropriate habitats must be created within the treatment systems. Plants and artificial media (gravel and sand) are used in natural treatment systems to create the media necessary to support rich microbial communities.

Why Consider Wood Fuel?

- A renewable fuel and CO_2 neutral;
- Heat is one third of UK energy equation; Security of supply and perhaps local;
- Price stability;
- A mature and highly efficient technology suitable from 5kW to 50MW;
- Space heating and process steam.



The RETScreen Clean Energy Project Analysis Software is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software, provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology and climate databases, a detailed online user manual, and a case study based college university-level training course, including an engineering e-textbook.

Wood stoves and wood boiler systems are also available with automatic refuelling systems, remote control, mobile activation, and highly efficient programmes to optimize combustion and increase efficiencies. Among the advantages of these systems are:

- Fully automatic feed
- Automatic ignition

Siphon intake systems have advantages to reduce initial civil construction cost

- Capacity control
- Remote system control and monitoring
- Typical efficiency 90% +
- Very low ash remains – c.0.5-1.5%

Hydroelectric Generation

Power is drawn from hydroelectric projects in relation to the hydraulic head (the height of the water above the generator) and volume of water available at a particular site to run through a generator. If a site has a good source of water, such as a dam, and a fall to a point

Hydroelectric Design Table to produce a 100 kW supply						
Head	Flow	KW	Turbine	KW	MWH/	Pipe Dia.
(m)	(l/sec)	Theor.	Efficiency	Output	Yr	(mm)
50	379	156	63%	98	861	610
100	189	156	63%	98	861	457
150	126	156	63%	98	861	381
200	98	161	63%	102	889	305
250	79	162	63%	102	897	305
300	63	156	63%	98	861	254

where the generator can sit, a pipe or pipes can carry the water from the dam to the generator. The volume of water released from the pipe can control the power.

Image from DW

The table above illustrates different design solutions for generating a 100 kW supply. If the head is low at 50 metres, the flow has to be high at 379 litres per second and the pipe to carry the water will be big at 610 mm diameter. However, if the head is 300 metres, the flow is only 63 litres per second and the pipe diameter 244 mm. The turbine efficiency is like the capacity factor of a wind generator, taking into account the energy losses in the pipe and the turbine.

Often rainfall is seasonal and the water level in the dam can run low. In this case, the output will be less as the flow is cut from the design optimum.

Rivers can now be harvested with floating turbine assemblies as illustrated. Often these can be quite small systems. If you have two dams or lakes with a small head between them, a siphon system can generate some useful power.

Source: Knoydart Hydrowater

Nano & Micro Hydro

- New Low-Impact Technology opens up more sites
- Economics good down to small creeks feeding individual buildings
- Connection to local utility simple & important
- Siphon Intakes - No breaching of dams, draw water over banks
- Low Head systems down to 1 m @ 200 l/sec for 1 KW
- High Head Systems down to 50 m @ 3 l/sec for 1 KW
- Costs ~€3 to €15/Watt = payback of 3-20 years

Source: Inhabitat

Microhydro equipment can often be sourced from local industries

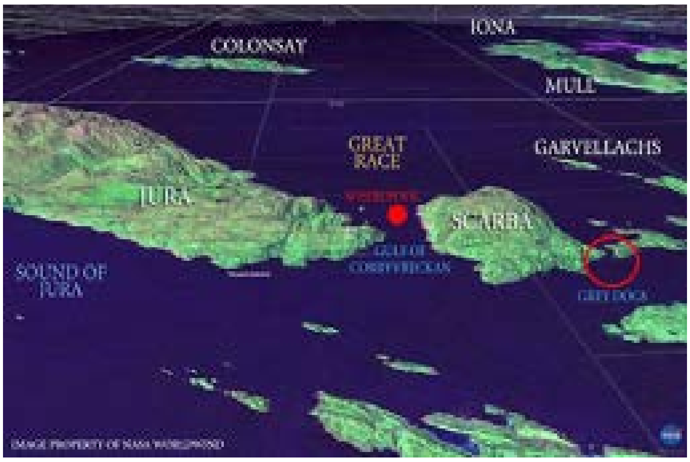
- Can use existing off-the-shelf motors for generators
- Low weight/kW = easily transported
- Robust - not easily damaged
- Low maintenance = low call-backs

Source: Inhabitat

Typical moderate sized installation

- Gilkes and Gordon Pelton wheel
- Head of 274.3m
- Turbine output – 350kva, delivering 280kw
- Auxiliary back up diesel generator

The village of Knoydart is in a remote part of the West of Scotland, where the hydroelectric system is their only source of electric power (more). However, with the greatly increased cost of electrical energy, small hydro projects are becoming increasingly viable.



NASA image from the Gulf of Corryvreckan. Tidal power stations can range in size from 20 to 250MW of generation capacity (more)

If a settlement has access to the requirements for hydro at a reasonable cost, this is likely to be the best option for carbon neutral electrical power. Many remote mountainous regions have micro-hydro systems in remote villages.

Marine Energy

Marine power from wave and tide is still in relatively early stages of development with many competing innovations being tested worldwide (example) ; however, there is great energy in the oceans and the potential will show in the next decades.

Tidal Turbine Farms are often a series of seabed-mounted turbines in a tidal flow. These flows are often strong in narrow openings between islands or in estuaries and tidal ocean bays. Where there is a narrow gap between islands and the seabed rises from deep water, the tidal flow is forced to quicken as a large volume of water is forced through a narrow channel, such as in the Gulf of Corryvreckan on the West Coast of Scotland. The Pelamis Wave Energy Converter is a large floating articulated tube, which converts the energy of the waves to hydraulic energy, which in turn drives electrical turbines

Biofuels

Biofuels are produced from various crops and have their origin in agriculture or aquaculture. They are used as an alternative to fossil fuels for powering cars or machinery. As a result, the basic materials have fixed current carbon, which is then released when burned or used in a vehicle. Carbon is used as part of the biofuel production process for fertilizer, farm machinery, transportation and also for distillation in ethanol from sugar cane. As a result there are different ratios for biofuels of energy in and energy out. The type of biofuel and location of its production greatly impacts the environmental impact that it causes. For example palm oil plantations are one of the major causes of rainforest destruction.

The two most common current biofuels are bioethanol, which can be blended into petrol, and biodiesel , which can be blended into diesel. Blended in small quantities (currently up to 5%) these biofuels can be used safely in today's road vehicles. It is also possible to use higher blends of biofuel (100% biodiesel and 85% ethanol) but this may require modifications to engines.

Biofuels are not land efficient. In many cases biofuel replaces crops that were grown for food. There is an estimate that if the EU were to use 5% biofuel for powering its vehicles it would require a quarter of Europe's agricultural land. For the US to grow enough biofuel to power all of its cars it would take four times the country's arable land (more on the impact of inappropriate use or production of biofuels).

[The Renewable Energy Centre](#) *offers in its web site good information about all types of renewable energy sources, including tidal and wave energy*

[Rape seed](#): There are substantial crops of rape seed (canola) grown in Scotland and Northern Europe. With bright yellow flowers the fields are hard to miss when they are in bloom. Rapeseed can be used to produce biodiesel. The land efficiency is moderate and the advantage is that it can replace the use of fossil fuels.

In the jatropha plant the seed are 37% oil. The jatropha plant is grown in Africa, South America and Asia. It is a good source of biodiesel and the leaves can be used to grow silk worm. Image from [Gardening KnowHow](#)

[These photographs](#) *show the pressing of canola oil (rape seed oil) at two different scales. The smaller machine is suitable for many ecovillage applications*

[Cellulosic ethanol](#) has great promise. It comes from grass, trees or the non-edible parts of plants. It is five times better in terms of its net energy balance than corn-based ethanol. It can be produced with fast-growing grasses such as switchgrass that absorb carbon dioxide as they grow. Another advantage is that cellulosic ethanol plants will be able to run their energy-intensive boilers on the plant waste from their own processes (corn ethanol plants use natural gas). Emissions are 91% less than fossil fuels. The main current problem is production cost. Further research and development is taking place.

[Sugarcane ethanol](#) is quite efficient in the use of land. However the waste from the sugar cane plants is burned in the distillation process for cane ethanol. Current practice also leads to land degradation or the deforestation of the rainforest. This is particularly true of sugarcane in Brasil; the fires, the degradation of the land, the detraction of land that could be used for growing food and the miserable and toxic conditions for the workers outweigh many of the benefits.

Palm Oil biodiesel like sugarcane is often grown on land that was cleared of tropical forests. This causes an enormous release greenhouse gas pollution which outweighs any benefit. The palm oil industry is causing environmental devastation, social breakdown, health problems, and massive habitat and species loss in Malaysia, Indonesia and Papua New Guinea and other parts of the world. The fires emit large amounts of CO2 into the atmosphere and destroy the incredible biodiversity that rainforests support. Orangutans which are some of the World's most endangered species are killed daily in palm oil plantations.

Corn ethanol is poor in land efficiency. It is the most wasteful of the biofuel crops. It only saves 22% of emissions compared with fossil fuel and energy balance is low at 1.3:1. The corn is also often produced using lots of fossil fuel rich fertilizers and most crops in the USA are genetically modified and therefore come with the associated risks.

Algae are tiny biological factories that use photosynthesis to transform carbon dioxide and sunlight into energy so efficiently that they can double their weight several times a day. Using algae to produce biofuel is still in the research stage but it shows excellent promise.Algae can grow in salt water, freshwater or even contaminated water, at sea or in ponds, and on land not suitable for food production. It can even be fed carbon dioxide to make it grow faster.

Recycled oil: Cars and trucks with diesel engines can run on frying oil that was used by restaurants like fish and chip shops. The car exhaust smells like chips. While there is far from being enough of this type of recycled oil for wide use, it can be a solution for some people who like to be super green and to save money at the same time.

Pause and bring it to life!

Take some time to investigate where the energy you use everyday comes from: at home, work and school; for heating, cooking, cooking, general power, etc.

Some guiding questions:

1. If you live in the city or suburbs, where does your energy come from?

2. How regenerative and sustainable are those sources? How resilient?

3. Do you and other people in your community have access to alternative sources of energy?

4. If you live in a rural area, what are your sources of energy? Are they resilient and regenerative or sustainable?

5. Energy efficient technologies

Often the greatest gains in the design of energy systems come from energy conservation methods. This can mean the super-insulation of buildings, reducing the weight of vehicles and efficiency in the use of energy and so on. Many energy-consuming appliances have an energy rating, which leads to intelligent choices (eg: European Union Energy Label).

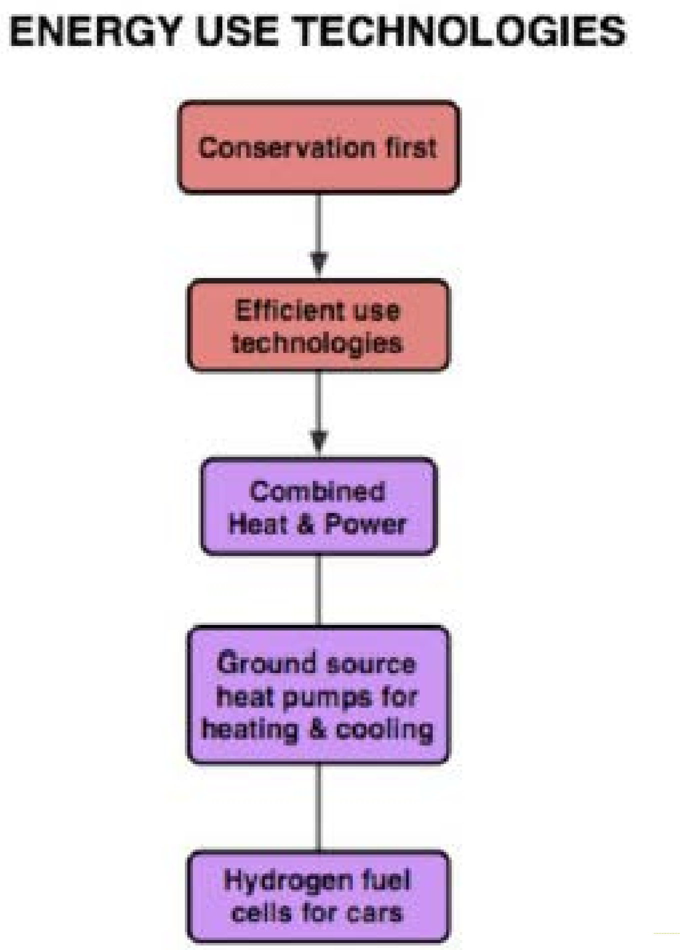


Image from Gaia Education

More and more industries concentrate on the security of their energy supply, which often means a private grid with some in-house generating capacity, along with connection to the national grid. For example, in 2015 Apple announced their plan to build a massive 130MW solar farm in California (more). Industries also work at achieving ongoing system efficiencies. This involves looking at industrial processes from first principles to reduce energy and waste. It also means smaller actions, such as replacing electric motors with more efficient models and smarter controls.

Combined Heat and Power (CHP)

CHP is the cogeneration of electricity and heat from the same system. It is particularly suitable for municipalities, where district heating is energised from the heat generated as a "byproduct" of producing electricity. Industrial processes also frequently need both heat and electrical power on the same site. Most large systems use conventional fuels; however, there is a growing use of methane from landfills powering gas engines and distributing heat where practical.

Non-fossil fuels for CHP can be methane from an anaerobic biodigestor or biomass from a local forest. Above about ~1 MW the wood fuel can be gasified (more on gasification). Smaller systems generate steam, which is used in a steam turbine. This reduces electrical generating efficiency to about 25%. Heat is often distributed through a district heating system.

"Decentralising a quarter of London's energy supply could help the capital reduce carbon emissions by 3.5m tonnes according to a study published by London First. The report, Cutting the Capital's Carbon Footprint - Delivering Decentralised Energy, calls for collaboration between the central Government, the Mayor and his agencies, energy companies, developers and boroughs to decentralise a quarter of London's energy. Linking large heat users such as housing estates, leisure centres and hospitals to locally-placed electricity plants can deliver massive efficiency gains, instead of centralised generation with its huge waste heat losses and losses from many miles of high voltage cables. Some local energy centres may produce power from renewable sources such as unrecyclable waste."

– UK CHP Association, 2008 (now Association of Decentralized Energy)

Micro CHP

There are now micro-CHP plants available, powered by natural gas or diesel.

The principle is that a gas or oil-fueled engine drives a generator that produces electricity. The heat from the engine block, oil cooler and exhaust, which would normally be wasted, is absorbed by coolant water through a high efficiency heat exchanger. This energy, stored as hot water, is then used directly for central heating, domestic hot water, or indirectly for

Combined heat and power plant. Image from Energuide

air conditioning. In general, the production of 1 kilowatt of power creates 2 kilowatts of usable heat energy. These co-generation units are powered by natural gas or diesel and have a heat storage system and advanced computer management (example). A wood pellet micro-CHP model based on the stirling engine has been created by an Austrian company called OkoFen.

Ground Source Heat Pump

Ground source heat pump technology can be used in large buildings, clusters of buildings or in a house. Generally, the larger systems have lower costs per kWh delivered.

A ground-source coupled (or geothermal) heat pump works like a refrigerator. If heat is required, a large amount of ground is cooled slightly and heat delivered in a "concentrated" or high temperature form to provide the central heating in a building.

In the cooling cycle, the system works in reverse – heating the ground and cooling the house. In the summer, the air conditioning is energised by the heat pump and in the winter the heated earth is cooled. In some regions, both heating and cooling (or dehumidification) are required, which is ideal for this technology.

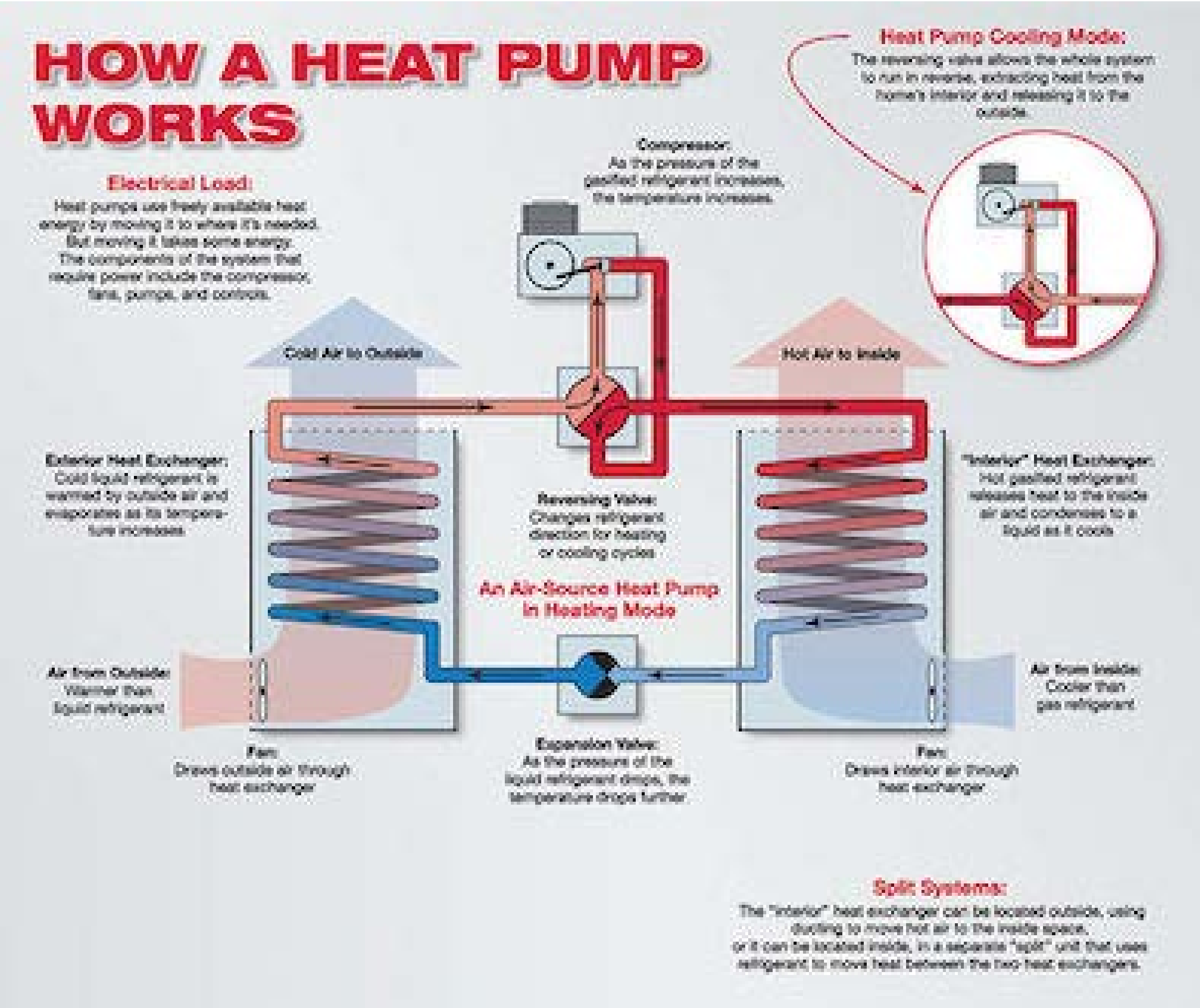


Image from [Home Power Magazine]

For the heating cycle, the energy taken from the ground during the winter to heat a residence is replaced by solar energy, which falls on the ground throughout the year. The energy moved, or "pumped", from the ground is natural "renewable" energy. This ground, or "earth" energy is tapped by circulating water from the well or coil in the ground.

The cooling of the circulating water by the heat pump causes heat energy to flow from the warmer earth surrounding the well or coil to the circulating water. The heat pump then transfers this heat energy into the building's heating system, which in turn warms the house. What makes this process of recycling stored solar energy from the ground so economical is that little electricity in the heat pump compressor is used to transfer considerable heat energy from the ground to the house. Heat pumps can deliver up to four times the energy used by the compressor.

Geothermal Energy

There are two different types of geothermal heat pumps, identified as:

1. Water–to-air heat pump, which takes heat from water in a heat exchanger and transfers it to air in another heat exchanger to distribute heat by air ducts in the house.

2. Water-to-water heat pump, which takes heat from water in one heat exchanger and transfers it to water in a second heat exchanger. These water-to-water units then distribute heat to the house, typically by radiant floor heating.

The US EPA has carried out in-depth research on heat pumps

The Heat Pump Association (HPA) is the UK's leading authority on the use and benefits of heat pump technology.

Steps Required In the Geothermal System Decision Process:

1. Selection of the heating or cooling distribution system is the most important first step, because it determines the type of heat pump required (water-to-water, or water-to-air) and impacts the efficiency of heating or cooling distribution, in a tightly constructed building.

2. The second step is to specify the required heating & cooling levels to give the best long-term investment for the space-conditioning infrastructure in the building.

Where there is room around the building and the ground is suitable, a horizontal loop is normally the most economical. Where there is an aquifer, or a close pond, a horizontal loop is normally the most economical. Where there is an aquifer, the borehole method should be investigated. Water to water is the most efficient system. There are also air source heat pumps (which are not geothermal).

The technology is reliable, and although the capital investment is higher than conventional alternatives, the running cost is typically 30-50% less. The following are useful YouTube videos:

The Inconvenient Truth
My Geothermal water furnace
Geothermal heating
Inside a heating pump
Geothermal house design

6. Sustainable Energy Alternatives

This section takes a look at some good examples wherein communities are establishing energy independence or part thereof from a national centralised system. One of the important principles in this approach is an Integrated Energy System (IES) which has diversified its energy sources instead of being dependent solely on one source, thereby reducing risk of energy shortages and simultaneously establishing a more resilient energy system. Nevertheless, even one renewable energy source can provide some resilience against an erratic central supply. Some community-based examples are explored below.

Eigg Electric

Eigg Electric is an island-based, community owned, managed and maintained company which provides electricity for all island residents from the renewable sources of water, sun, and wind, as shown in this video (6 mins). The system consists of three hydroelectric generators, a group of four small wind generators and an array of solar electric panels sited at different locations around the island as determined by optimum availability of resources. The hydroelectric capacity is approximately 110kW, the maximum output of the wind farm is 24kW and the solar electric panels can produce up to 50kW. The total generating capacity of the whole system is approximately 184kW. Although the capacity of the scheme is around 184kW, not all renewable resources produce their maximum output all the time or at the same time. However, by having a balanced scheme of all three, one can maximise the available renewable resources and ensure there's enough to provide all or most of the island's electricity needs. Renewable sources have provided around 95% of our electricity since the scheme was first switched on in 2008. The remaining 5% is generated by two

Four small 6kW wind turbines below An Sgùrr. Image from European Commission

80kW diesel generators to provide back up when renewable resources are low or during maintenance. (Source: Eigg Electric).

Cloughjordan Ecovillage

The system effective technology. It is a sustainable model for developers and town councils to follow. See the video (3 mins).

Each house in the village has a hot water storage tank that distributes heat throughout the day. See the video (8mins).

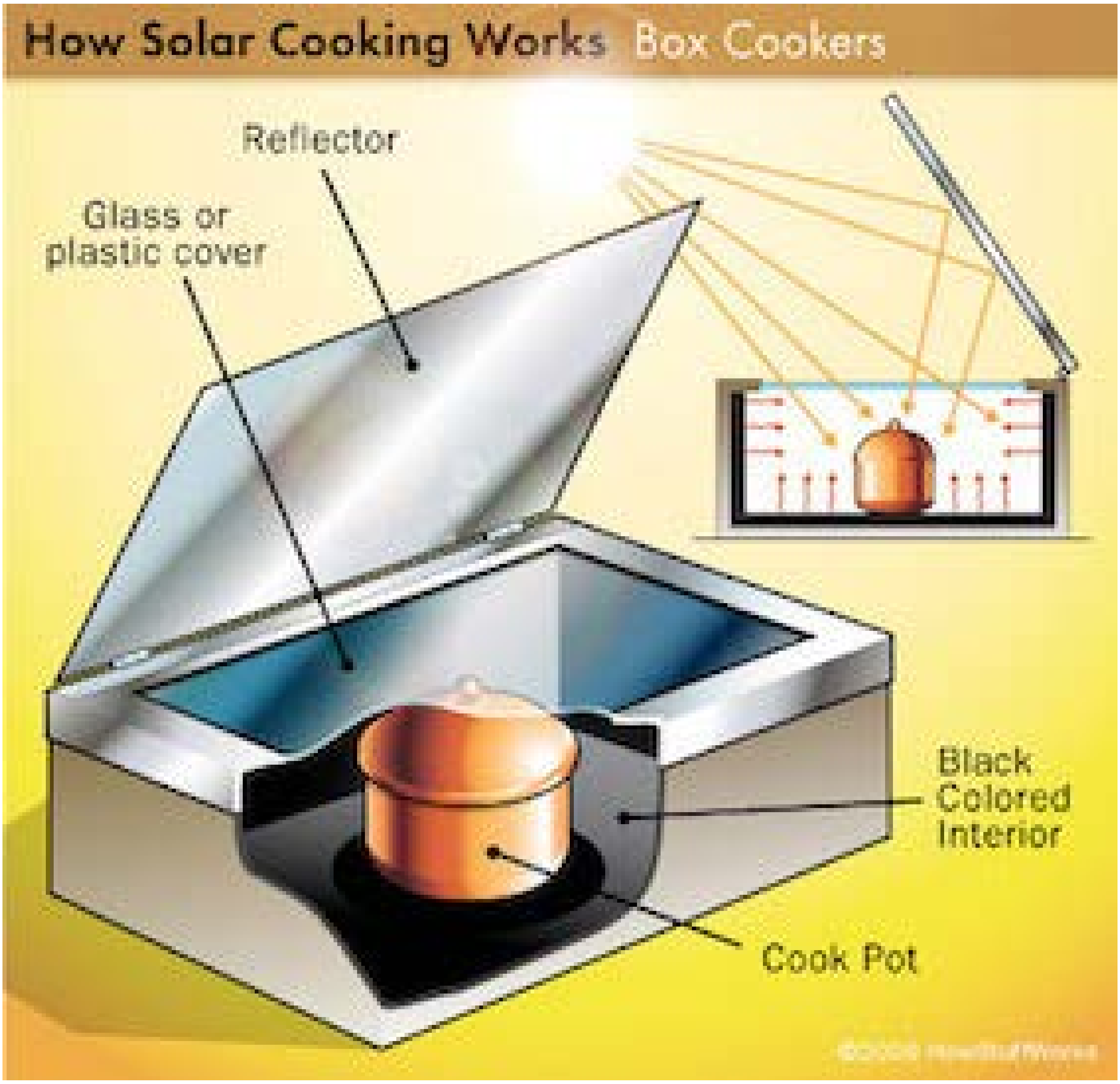
Parabolic solar cookers

In November 2003, the Barefoot College created the Society of Women Barefoot Solar Cooker Engineers in Tilonia, Rajasthan. It is the first association of illiterate and semi-literate women who fabricate, install and maintain parabolic solar cookers in their homes. The parabolic solar cooker is constructed from 300 mirrors that reflect the sun's rays onto the bottom of a cooking pot to cook food quickly and sustainably. Women who once spent long hours searching for firewood can spend their time on other productive activities. Communities with solar cookers can expand their livelihood opportunities and limit the negative effects of deforestation and pollution. See the video (7mins).

50kW Photovoltaic. Image from Solmatix Renewables

Image from UNESCO

Cloughjordan Ecovillage. Image from Green News



4,020 grams of harmful carbon emissions avoided by replacing kerosene with solar as a source of clean energy for light, heat and cooking. Image from [How Stuff Works]

Energy Autonomy for Tamera Ecovillage

The Tamera Ecovillage in Portugal is thriving at the cutting edge of innovative models of sustainability. One such aspect is its energy autonomy which harvests the abundant solar energy in the south of Portugal.

The SunPulse Water is a solar water pump with a low-temperature Stirling Engine, running on sunlight, using air as its working fluid. It uses zero fossil fuel and creates zero emissions, and is a "stand-alone" system. With an output hydraulic power of 300W it's ideal for decentralised water provisioning without any additional infrastructure. See the video (7mins).

Compost Heater

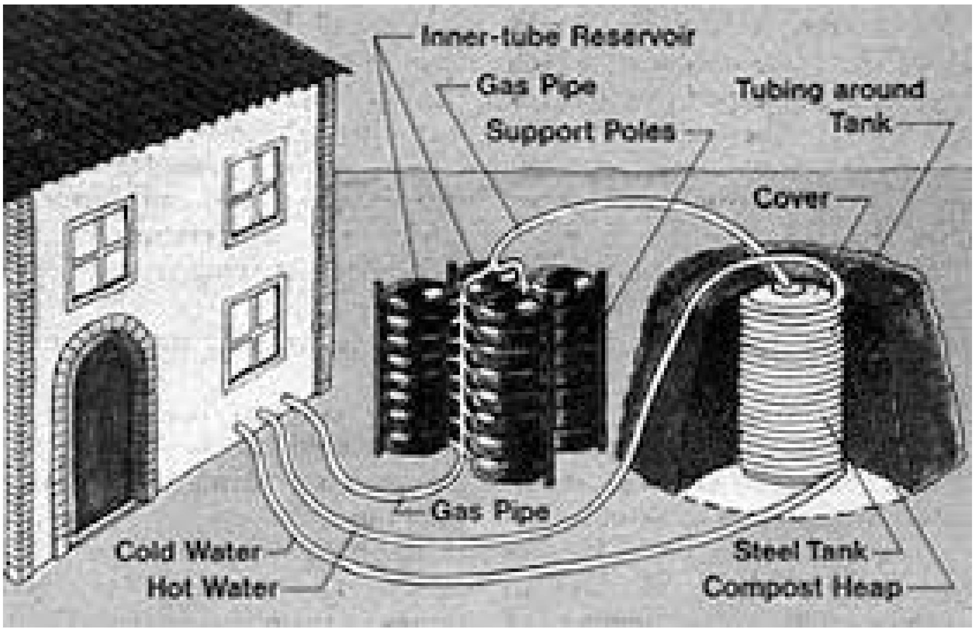


Image from Journey to Forever

Jean Pain was a pioneer of the Compost Heater, or Biomeiler as he called it, which harvests the heat generated from a composting process to warm a house and to provide hot water, as well as, to warm a greenhouse during winter. This system requires a relatively large compost heap that is intertwined with a spiral water hose, which acts as a heat-exchanger as it transfers the heat from the decomposing compost to the water pipes, thereby heating the water - see the video (2 mins). This system is aerobic because the cross-section of the compost heap is not more than 1,5m2 in cross-section at any point, otherwise any larger size attracts an undesirably odious anaerobic process as areas in the compost heap are starved of oxygen. However, the Jean Pain method has pushed the envelope size of this compost heap by using woodchips which do allow aerobic composting to relatively larger size compost heaps as seen in this video (3 mins). Although this basic system has become fairly well known, Jean Pain also had a more complex version which also generated biogas from the methane gas emitted from relatively larger compost heaps that gave rise to anaerobic composting processes.

Image from One Green Planet

Image from Journey to Forever

7.

Sustainable Transport Options

Transport is one the most difficult areas in which to lower the carbon footprint. We are so used to the effectiveness of fossil fuels to provide our mobile energy. We have created a globalized economic system that externalizes the environmental, social and health damage caused by our wasteful transport systems, while being directly supported by subsidies to the fossil fuel industries and cheap transport fuels. In the economic design dimension of this course we will take a closer look at these externalities and subsidies. At this point we should simply remember that many of the goods we are using do not need to come from quite so far away, and if transport would not be subsidised and all the costs and damages created by this system would be included in the final price of imported products – in short if we actually had a free and fair market – we would rely on regional production for regional consumption much more than we do today. In short, just like we should start with energy conservation ("nega-watts") when we try to reduce the impact of our energy systems, we should start with transport avoidance and more localized and regionalised supply chains if we want to create a more sustainable transport system.

For a designer focussed on the scale of sustainable community or ecovillage design, some basic guidelines apply:

- Minimise the need for transport within the ecovillage and the bioregion, which means localisation of activities and strengthening internal links.
- Encourage bicycles – perhaps electric bicycles for longer journeys.
- If biofuel crops are local, consider pressing suitable oils, and ensure that the production of bio-fuels does not deplete soils or compete with the regional capacity to provide a lot of its own food.
- If possible work with others in your community to create a community car pool (car sharing system) and explore whether enough people share certain transport routes enough to create public transport services or community buses to service that need.
- Adopt new technologies, as they become viable: the transport systems of the future are likely to evolve from today's experiments with electric, compressed air and hydrogen fuel cells, and sustainable biofuel technologies.

The wide and important topic of sustainable transport options cannot be given justice within the constraints of this course. Breakthrough technologies are being developed in the areas of hydrogen fuel cells as well as in battery improvements and electric vehicle design. The debate whether future transport systems should be based on hydrogen or electric vehicles is still polarised between advocates of both systems, who each have convincing arguments in their favour. What is clear is that a shift towards improved public transport systems (like the rapid urban transport systems of South America for example) and technologies that allow us to share mobility with other users (like MIT's mobility on demand) will all be part of the redesign of our transport systems.

Driverless cars, new types of collaborative use of transport infrastructures like car-sharing, Uber, or driverless cars are all likely candidates for being important elements of the sustainable transport infrastructures of the future.

Image from Gouri

8.

Conclusion

In this Module on sustainable energy systems we have explored a range of already approved and tested technologies that can help us re-design our energy systems away from their dependence on fossil fuels. The energy return on energy invested (EROEI) of fossil fuels is becoming less and less, and global commitments to reduce greenhouse gas emissions rapidly and permanently all indicate that we are living through the transition from the fossil fuel era to the era of renewable energy systems.

Renewable energy systems of the future are likely to be decentralized yet networked into regional, national and international grids in order to allow for maximum flexibility and resilience in the system. Each local and regional energy system will be designed in response to the ideal renewable energy sources available in that particular local. Solar photovoltaic, solar thermal, hydro-electric, wind, geo-thermal and marine energy will be harvested locally and distributed primarily locally and regionally. These systems will also be linked into the sustainable transport systems of the future which will no longer be dependent on fossil fuels and use hydrogen fuel cell or electric battery technologies to store the energy needed for transport.

With all of these technologies the most important design consideration is what renewable energy source to harvest and at what scale. All of the technologies mentioned in this section have the potential to be used as sustainable and regenerative energy option, yet applied in the wrong place and at the inappropriate scale they also can all contribute to unsustainable scenarios. In the energy and transport systems of the future there are no one-size-fits-all silver bullet solutions. We will have to create elegant solutions predicated by the uniqueness of place.

Pause and bring it to life!

List all the things you do on a regular day, how many times do you use energy?

What are the sources for that energy? How can you improve the use of this energy by 1) conservation and 2) improving the quality and source where it is generated?

What other things can you change in your life to reduce and improve the use of energy?