Alternative Energy Conversion
(Sustainable Energy Future)

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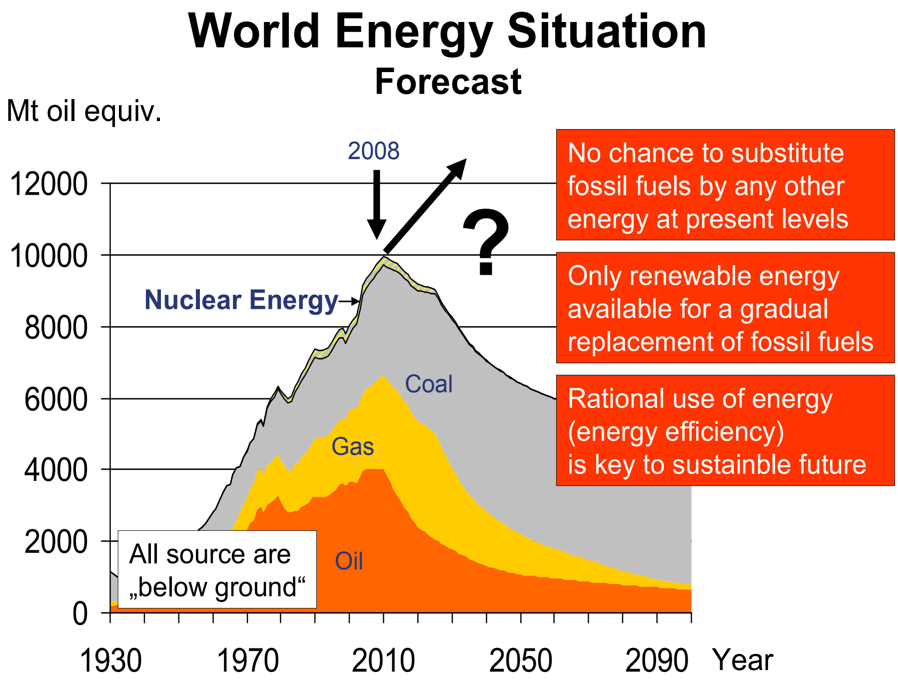
1. Summary

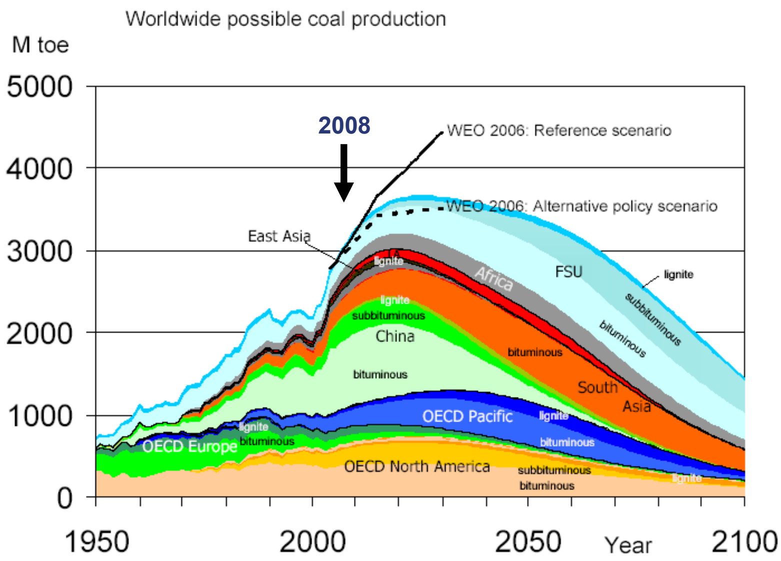
The establishment of a sustainable energy future is one of the most pressing tasks of mankind for the 21 st century. With the exhaustion of fossil fuel resources the energy economy has to change from a chemical to a physical base. This transition is one of physics, not one of market preference or energy policies. Fortunately, proven technology and existing engineering experience are available for this unavoidable transition process which will take many years to complete.

Unfortunately, politics seems to listen to the advice of visionaries, lobby groups and environmental activists, all presenting qualitative arguments for fascinating solutions many of which are not based on facts and physics. In particular, overall energy considerations are often missing. A secure sustainable energy future must be built on solid grounds of science and engineering. Here is the present situation:



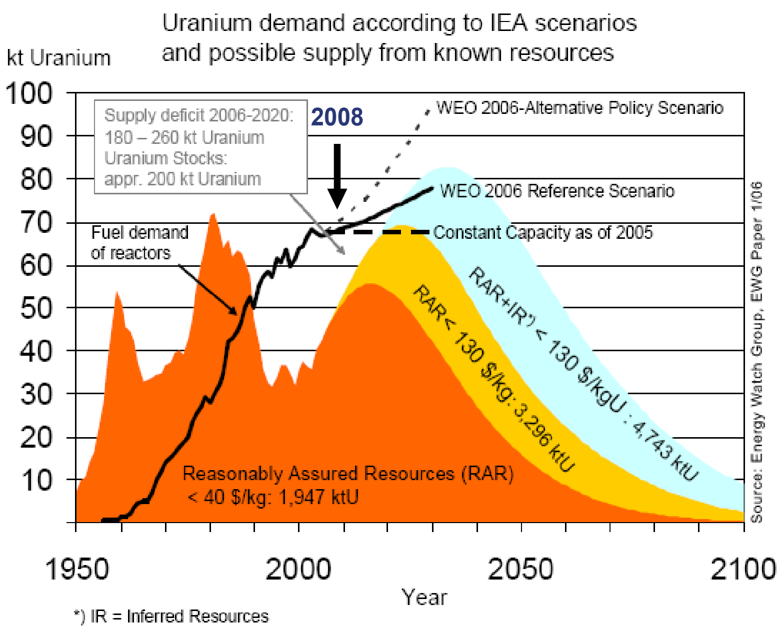
We are running out of energy. Oil supplies are rapidly depleted. Energy consumption is still growing. The contribution of nuclear energy to the World demand is 2.5% now and is not likely to satisfy future needs.

Coal Supply and Demand



We are also running out of coal. We will still coal in the ground many years from now, but cannot mined in quantities needed to solve the global energy problem.

Uranium Supply and Demand



We are also running out of Uranium. Uranium production is far below today's Uranium demand. Nuclear electricity is produced with Uranium stockpiled during the Cold War.

This article is in part a response to shaky ideas promoted within energy circles on both sides of the nuclear rift. Although most suggestions can be realized, many of them do not recognize that we have to solve an energy problem, not a problem of new energy carriers or conversion technologies. Before new hardware is developed, one has to question its sense or nonsense. Where does the energy come from to be converted and delivered to consumers by new energy carriers? How much precious energy is needed for energy mining and distribution? With how little energy can the energy needs of society be satisfied without loss of comfort? How much energy is gained compared to the energy invested for construction and maintenance of a new energy installation? Is the overall energy balance of a proposed new energy process positive?

In particular, one should always remember the fundamental law of physics:

1.) Energy cannot be created or destroyed….
…. neither by governments, political parties, energy companies ….

2.) Energy can only be converted from one form into another….
…. by power plants, engines, water turbines, wind generators ….

3.) Some energy is always lost when energy is converted.

Politics cannot solve the energy problem for the individual, but must pave the road for the unavoidable transition into a sustainable energy future. The availability of energy is not a fundamental human right, but consumers must adjust their energy consumption to their personal needs by energy conservation, energy efficiency and energy collection. Governments should stop promising bright and secure energy futures, but let the people know the truth.

Unfortunately, many of the suggested solutions to the energy dilemma, such as the use of synthetic hydrogen as energy carrier, the agricultural growth of biofuels, the sequestration of carbon dioxide, nuclear fusion, synthesis of Methane by recombination CO_2 and water, deep-well geothermal heat etc. do not properly consider the overall energy balance. Most of these schemes are technically feasible, but make no sense energetically. What is thought to be a new source of energy turns out in reality to be an energy sink. Because of subsidies and tax benefits or speculative market prices new energy installation or processes may be economically profitable even though their overall energy balance is negative [2]. We have to solve an energy supply problem, not one of technology or distribution.

2. The Sustainable Energy Future

Two postulates need to be satisfied to make the energy system sustainable. This means:

1.) All energy must come from sustainably managed renewable sources
2.) Energy must be distributed and used with highest efficiency.

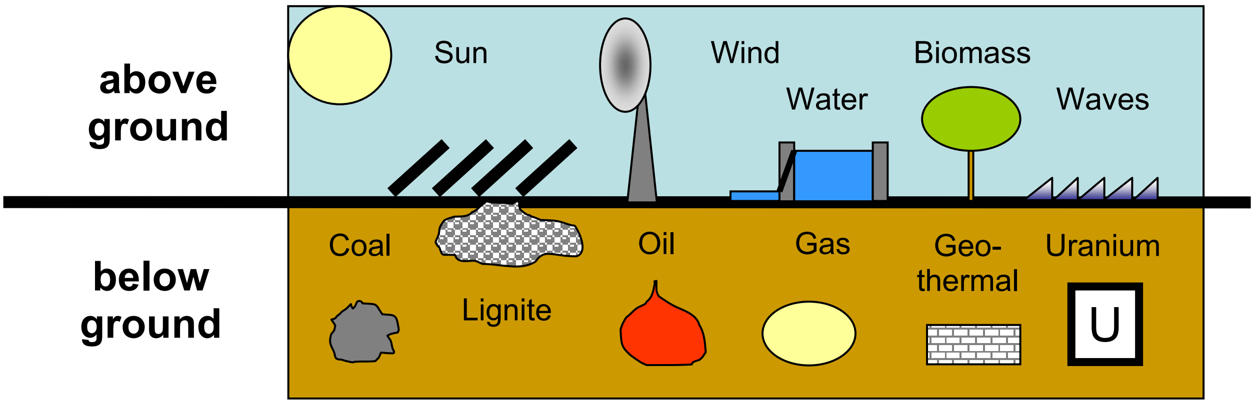
In this context "sustainable" is used in its original meaning. The concept of sustainability ("Nachhaltigkeit") was first postulated by the Director of Mining of Saxony in 1713. It simply suggests "never take more wood out of a forest than nature can replenish between two harvesting periods". This rule applies to all interactions between man and nature. In the energy area, it involved the harvest of energy from, as well as the release of reaction products into the environment. Nature's limited ability to deliver or absorb is restricting the use of energy from all "below ground" energy sources [3].

Three essential questions require answers:

> ***1.) Where dose the energy come from?***
> ***2.) In which form is the energy harvested?***
> ***3.) How much and in which form is energy needed?***

It should be clear that people do not need gasoline, heating oil or hydrogen. They need a comfortable room climate, motion for transport or machines, light, communication etc. The energy problem is not solved by substituting gasoline by some other chemical energy carrier, but by the transition from today's dwindling chemical energy resources to the infinite supply of energy derived by solar radiation. This is not a "green" vision, but a physical necessity. Society can only target the time frame for the transition to sustainability in 10, 50 or 200 years.

Where Does the Energy Come from?



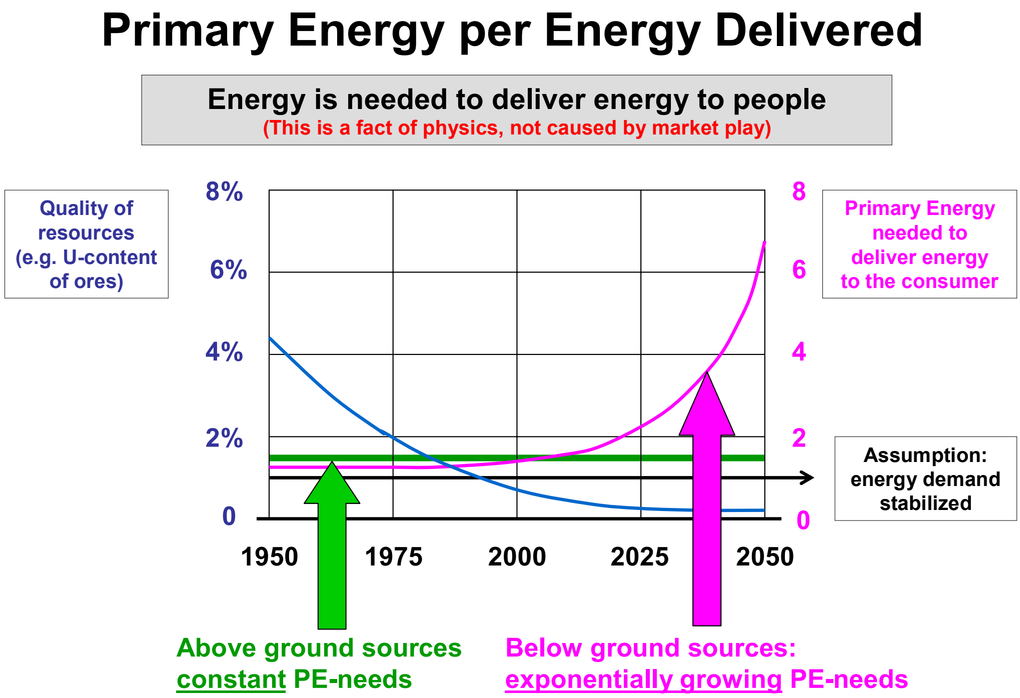
For reasons of physics, energy sources are classified as "below ground" (fossil fuels, uranium, geothermal heat) and "above ground" (solar energy, wind energy, hydropower, biomass, ocean waves and tides). While no energy is needed to make the sun shine or the wind blow, the energy needs for the recovery of energy resources from the ground will grow exponentially with the depletion of resources.

As a result, the primary energy required to satisfy specific energy needs is growing exponentially with time. To obtain oil one has to drill deeper, pump harder, transport over longer distances and use more energy to convert lower grade crude into standard high grade fuels. However, all oil wells are different. The exponential growth rate of the production energy differ from well to well and from source to source. The same exponentional law also applies to natural gas, coal, geothermal heat and Uranium

This trend is illustrated schematically in the following picture for a time span from 1975 and 2050. The energys end use is considered to remain unchanged over the years (horizontal black line). As the quality of the Uranium sources (Uranium concentration, accessibility, transport distances, mining conditions etc.) decreases, the primary energy needed to the constant demand must increase exponentially with time.

This exponential law does not apply to energy from above-ground sources. One does not have to invest energy to make the wind blow or the sund shine. Conseqeuntly, the cost of energys from renewable soruces will remain unchanged over the years.

This important difference between below-ground and above-ground energy has hardly ever been discussed. It is given by phsics and cannot be changed by research, investments or public debate. It is one of the strongest arguments in favor or a swift transition to a sustainable energy future.



Clearly, fossil fuels and nuclear (fusion and fission) energy do not satisfy the sustainability criteria on both ends of the energy chain. Resources are finite and the released geo-carbon dioxide or radioactive waste cannot be absorbed by nature. Biomass is not sustainable per se, but its growth and harvest must be managed in a sustainable way. Also, the sustainability of some hydro power projects could be questioned. Silt is gradually filling the lake formed by the Assuan Dam thereby reducing the geneneration of hydropower. Furthermore, the damage caused by flooding fertile valleys may be in conflict with the sustainability mandate.

However, renewable energy is harvest in a sustainable way with most hydropower stations, solar energy, wind power, ocean energy or geothermal installations. Add energy obtained from sustainably managed biomass and organic waste to complete the list of renewables. After depletion of fossil and uranium deposits energy must come from the following sources:

Solar energy	photovoltaic	DC **electricity**
	collectors	heating
	concentrators	AC **electricity**
Wind energy		AC **electricity**
Hydropower		AC **electricity**
Ocean energy	waves	AC **electricity**
	tides	AC **electricity**
Geothermal	low temp. heat	heating
	high temp. heat	AC **electricity**
Biomass		synthetic fuels
	low temp. heat	heating
	high temp. heat	AC **electricity**
Organic waste		synthetic fuels
	high temp. heat	AC **electricity**

There is no other source of energy that could possibly contribute to the energy needs of mankind in a sustainable way.

With the exception of biomass, renewable energy is harvested as physical energy, some as heat, but the vast bulk as electricity. Converting physical energy (also from nuclear reactors) into a commercial chemical energy (e.g. transportable fuels) is not trivial, a wasteful process and poses significant technical challenge. It will take years to switch from today's fossil-based primary energy system to a new platform built on physical energy harvested from nature in a sustainable way.

Onset and speed of this transition to sustainability depends on:

1. **Climatic conditions for harvesting solar, wind and biomass**
2. **Topology along shorelines for harvesting ocean energy**
3. **Availability of land and sites for renewable energy installations**
4. **Establishment of high energy efficiency standards for energy use**
5. **Political leadership with deep understanding of "sustainability".**

The transition may also be retarded sometimes by local dominance of fossil resources, existence of conventional power installations or strong business interests. Countries without fossil resources like Switzerland and Denmark are already moving towards sustainability. Countries with rich fossil deposits like Saudi Arabia, USA or Russia slowly begin to recognize the threat. There is no global road map to sustainability, but regional solutions are needed to reflect local situations. International agreements may slow the process in lead countries as established energy economies may discourage changes.

3. Renewable Energy and Energy Demand

For a planned transition from today's to a sustainable energy base one needs to consider the properties of renewable energy supplied by nature. Without any question, the energy demand of mankind can be satisfied from renewable sources. The sun supplies many thousand times more energy globally than required to satisfy the world energy demand. It takes the Sun only 30 minutes to deliver the annual World energy requirements. However, meteorological fluctuations, variations by climate zones, availability of sites etc. need to be considered and specific regional solutions must be found. Energy from renewable sources is already competitive in some areas. The number of attractive sites is rapidly increasing with exploding oil prices and further development of "green" energy technologies. Wind energy has become economically attractive on windy sites of all continents. There is no global distribution problem for energy from renewable sources. Renewable energy is available where people live: wind in the Chicago area ("Windy City"), sun in Arizona, forest biomass many areas.

With the exception of biomass, renewable energy is harvested as physical energy, some as heat, but the vast bulk as electricity. This must leads to a fundamental change of our energy system.

Today, about 80% of the energy is derived from chemical and only 20% from physical sources, the future will see just the opposite. About 80% will be harvested as electricity or low-temperature heat, while perhaps 20% will be available from chemical organic sources.

On first sight the significantly different distribution of the primary energy spectrum, in particular the lack of chemical carriers appears frightening. A closer look, however, reveals that the future energy supply is much better matched to the energy demand of consumers. People need chemical energy only for food. All other energy services are in the form of physical energy: motion of cars, heat or cold for indoor climate and cooking, artificial lighting, communication, etc. Today, chemical energy is converted to physical to satisfy these needs. In future, electricity could be used directly to assure comfort and living standards. Fortunately, consumer needs of energy services are better matched in a sustainable energy future than in today's chemical energy world.

The change from chemical energy to electricity is certainly much less difficult than a change in the other direction would be. We have to part from well-established chemical energy traditions and switch to equally well established electrical energy. The future will be an "Electron Economy". It is certainly easier to gradually extend the use of electricity than to create chemical energy from electricity to continue with the heritage of James Watt and Sadi Carnot. Certainly, the energy needs have to be reduced by conservation and efficiency. Also, end use technologies and consumer habits need to be adapted to electricity, the base energy of a sustainable future.

We should also accept that this transition is unavoidable and predetermined by the laws of nature. Underground deposits are not renewable. The establishment of a sustainable energy future is not a dream of environmentalists. Also, being unavoidable, it cannot be a goal of "green" politics. Governments and people can only set the time scale for this transition, e.g. "50/50" for a 50% transition by 2050.

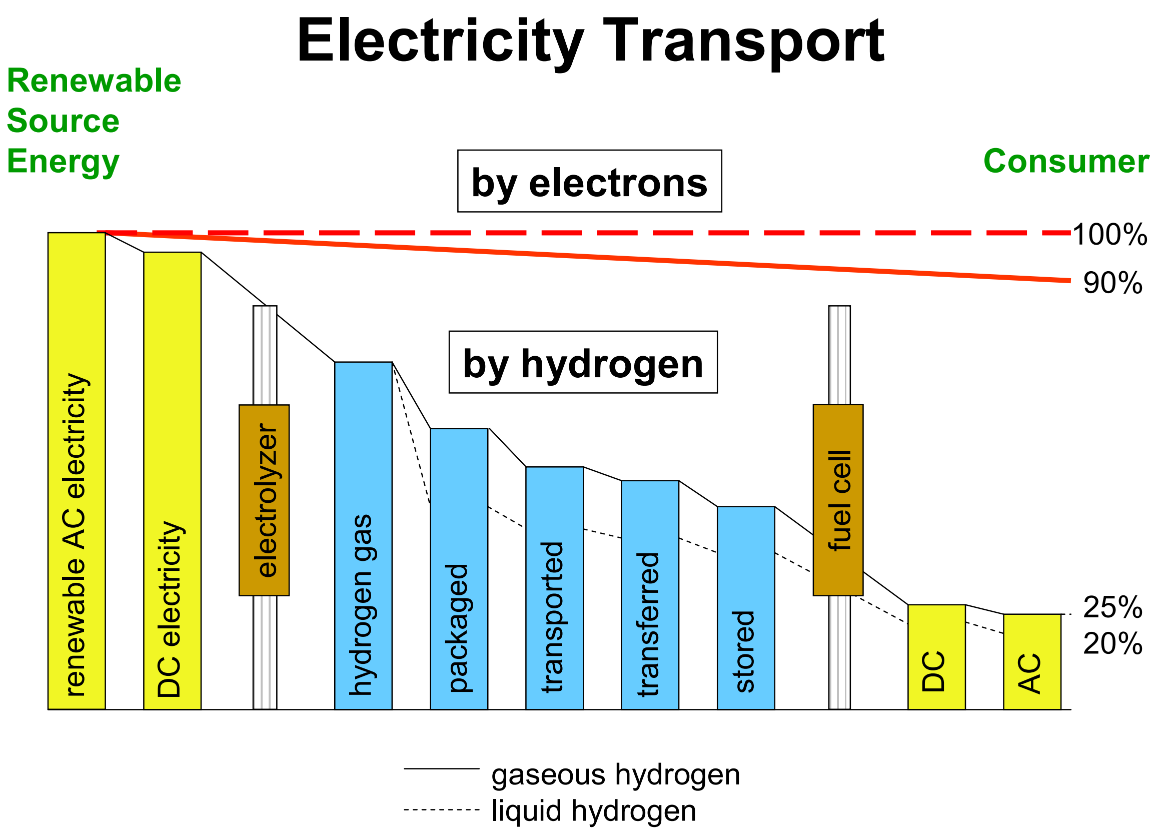
4. Inversion of the Energy System

We can predict that due to the obvious physical advantages of electrical energy and the relatively weak position of chemical energy concerning sustainability, CO_2 problematic, limited resources in future,. etc., the entire energy supply chain will undergo significant changes to become compatible with the requirements of sustainability.

Today's energy system is dominated by chemical carriers like coal, oil and gas. Electricity and transportation energy are derived from chemical energy by thermal power plants, heat engines, or fuel cells. During the last two centuries scientists and engineers have developed fascinating thermal energy conversion machines and a profound body of intellectual wealth. From oil wells to driving on highways, much of today's economy is directly related to the conversion of chemical energy of fossil origin to energy services of physical nature, however at the cost of heavy losses during the different energy conversion steps.

With the decline of fossil reserves also the era of chemical energy conversion will fade out. This development is predictable and irreversible. It can only be retarded by energy conservation, politics, energy wars, or the introduction of synthetic energy carriers like hydrogen. We have to face the future and prepare for it.

How does the future look like? The future will be dominated by electrical energy from renewable sources. This energy will be transmitted directly to the user via existing and new electrical power lines. Chemical energy must be derived from electricity, e.g. by electrolysis of water. However, due to the large conversion losses, electricity-derived hydrogen is unlikely to be converted back to electricity by thermal power plants or fuel cells. Renewable electricity will gradually replace fossil fuels. Electric cars will appear in large numbers. Electricity will become the base of our energy system. It does not make sense to convert good electricity into hydrogen to extend the era of heat engines. While 90% of source electricity (from any source) can be put to use, only 25% is available if energy is transported by hydrogen. By laws of physics, a *Hydrogen Economy* on a large scale will never make sense.



The conversion of the energy system will affect our entire energy world. Many chemical energy conversion technologies may become obsolete. Coal, oil or gas fired power plants and internal combustion engines will "run out of fuel" while electric heat pumps will become real energy multipliers. Without Carnot losses, the overall efficiency of the energy system may rise over 50%. Efficient electrical transmission and appliances will replace inefficient chemical energy conversion and distribution technologies. Combined with efficient energy distribution and use, "green" electricity will become the base of a sustainable energy world. Because of the improved overall efficiency, even a growing demand of energy services can be satisfied from renewable sources. In a sustainable future it will take much less primary energy to provide the same energy services and the same standard of living to the user. We will live better with less energy.

The transition from a chemical to an electrical energy base is too complex to be analyzed in detail. We have to face the need for change and go to work without fruitless debates about economic consequences. The future cost of renewable electricity should not be compared to the present cost of electricity from amortized coal-fired power plants. In a few years from now amortized wind power plants will generate electricity at negligible cost far below the generating costs of any thermal power station including nuclear plants. As a result of higher efficiency the monthly energy bills may even be lower than today. Therefore, future options should be compared with other future options, but not with today's energy solutions. Renewable energy itself is a free gift of nature, while oil and gas prices will gradually climb with demand and depletion. Investments in lasting renewable energy equipment should soon become extremely profitable. If society wants to have inexpensive energy in future, it has to invest in solar and wind power plants now.

5. Energy Return on Energy Investment

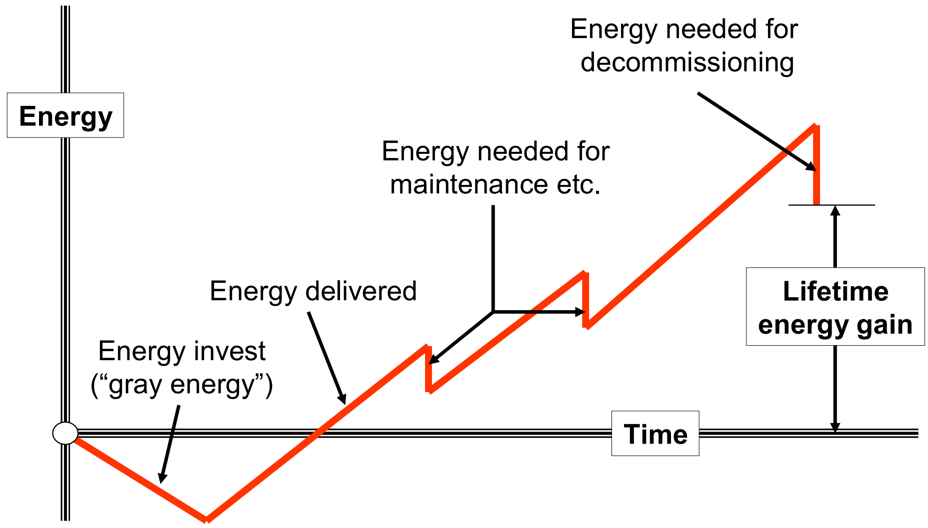
The ongoing energy debate is highly focused on monetary analyses like the cost per kilowatt installed or the price of a kilowatt-hour delivered. This has reduced the solution of energy problems to a commercial exercise. Established technology is compared to unproven energy conversion schemes. Today's energy prices form the base for highly speculative comparisons of power plants scheduled to go online ten years from now and to be operated with profit for one half of a century. Also, installations are planned despite the highly uncertain future of energy supplies. Nuclear power plants are designed to last for 60 years. Energetically affordable Uranium supplies may be depleted long before these plants are scheduled for shutdown. Eventually, more energy will be needed to produce the nuclear fuel from low grade sources than can ever be recovered in nuclear power plants. By laws of physics, for all vanishing "below ground" energy sources, the energy needed to make energy available to the consumer will grow exponentially with falling quality of the deposits. One has to drill deeper, pump harder, transport over longer distances, spend more energy for refining. Time has come to leave these vicious cycles. Fortunately, none of the "above ground" energy sources follows this exponential dependence, because one does not have to invest energy to make the wind blow or the sun shine.

Today, energy prices are linked to the price of a barrel of oil at the New York Stock Exchange. Because of the shortage of supplies, speculation has pushed up prices well above what supply and demand would justify in a free market. Consequently, energy prices are out of control. It is unlikely that they will ever return to commercial conditions. We have to accept instable and increasing energy prices for all "below-ground" energy resources.

Not so for energy from renewable sources. As nature does not charge for sunshine and wind, the cost of electricity from wind power or solar installations is set by the capital costs and amortization times. The cost of energy from renewable sources will remain high as long as banks demand high interest on loans or investors expect good profits. Not the globally active energy companies, but the local finance institutions dictate the cost of green energy. Renewable energy is expensive only for new installations and expensive bank loans. The availability of inexpensive capital would certainly accelerate the implementation of sustainable energy solutions.

"Return-on-Investment" (ROI) is a well-established parameter in economics. A similar concept should be applied to energy investments, because the "Energy-Return-on-Energy-Investment" (EROEI) is a true measure of the effectiveness of sustainable energy solutions.

Energy Invested and Energy Gained

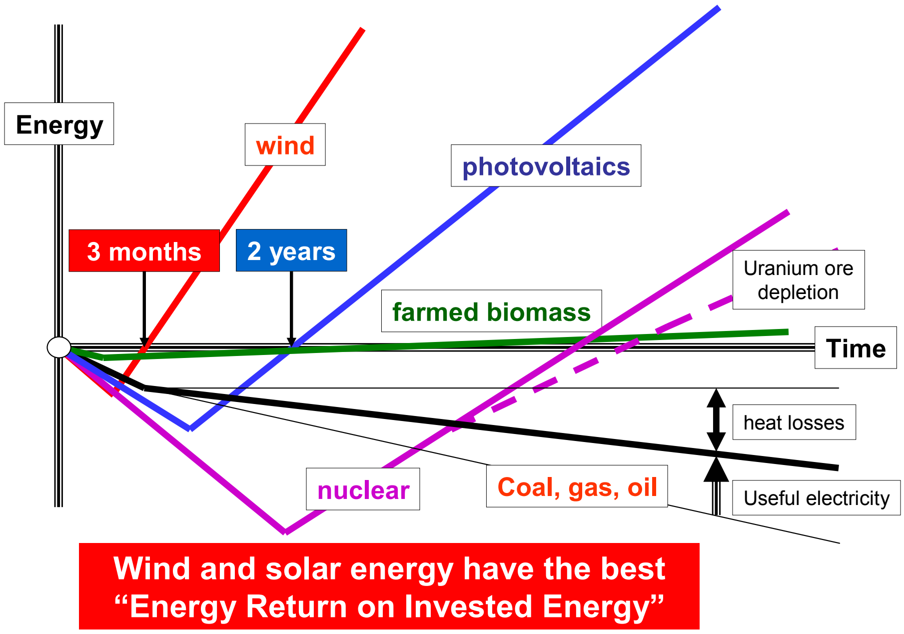


Energy problem must be solved with technologies with positive lifecycle energy balances.

Energy is needed for building energy installation like wind generators, nuclear power plants or photovoltaic arrays. Then these plants begin to deliver energy. The invested energy is gradually recovered. From time to time energy is needed for maintenance. Ultimately, at the end of the life of a plant is energy is needed for decommissioning. The enrgy problem can oly bde solved with technologies whose lifelong energy delivery exceeds the overall energy investment.

For a swift transition from today's energy economy to a sustainble solution technologies with a short EROEI should be preferred. The following figure shows typical lifecycle energy curves for selected energy technologies. .

Typical Net Energy Gains



For well-placed wind energy plants the "gray energy" needed for materials, fabrication and construction is recovered after the first three months of operation. Photovoltaic systems from advanced production lines will return the invested energy in about two years. Nuclear power plants need much longer, in particular, as more and more energy is needed for Uranium mining from low-grade ore. As long as fossil energy is available at modest prices, it should be used to produce wind and solar energy power plants which, in turn, will generate electricity to build more of the same.

6. Energy Return from Land Use

Renewable energy is harvested above ground. Surfaces are needed to convert wind or solar radiation into electricity or heat, land is used to grow biomass and countryside is needed for artificial lakes and hydropower. There is an unavoidable visual impact, because renewable energy installations cannot be sheltered or built underground. People have to accept the appearance of wind and solar power installations as much as they have accepted other essential changes of landscape by railroad tracks, freeways, factories, airports, noise from a variety of sources and air pollution many sources.

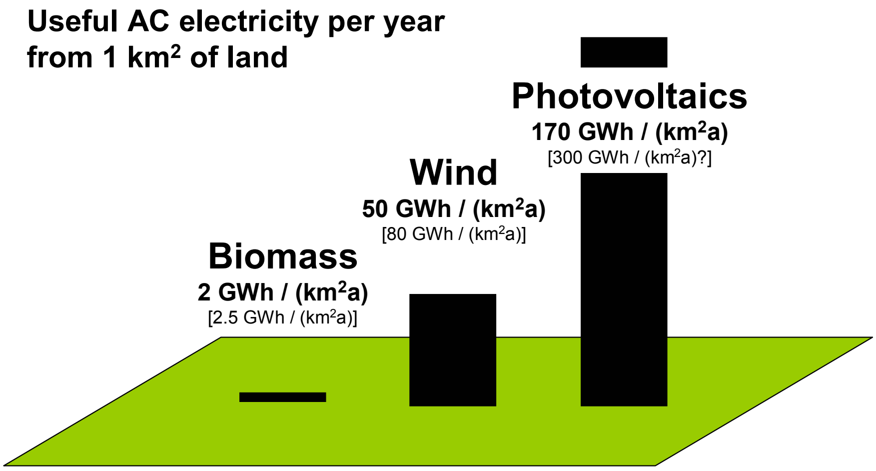
However, land is not abundantly available in areas where people live and demand energy. Energy transport over long distances is difficulty for any kind of physical carrier. Therefore, one of the challenges of the transition to sustainability is the energy-efficient use of land.

Three questions need to be considered.

1. Which technology is best suited for energy harvest in a certain region. How much commercial energy can be harvested from a given piece of land? Should one invest in wind power, PV panels, biomass plantations or else?

2. Should the considered land be used for food production? Is it justified to plant solar arrays on arable land of high quality?
3. Is it possible to use the same land for agriculture and energy production? Crops can grow under windmills and sheep can graze under PV arrays. Cows don't mind spinning windmills overhead.

Biomass, Wind or Photovoltaics?



Photovoltaics and wind, not farmed biomass!

To answer these questions one should consider the amount of useful energy harvested from a given piece of land in given time. The energy is accounted on the base of what people really need: electricity. With the exception of firewood, biomass as such is a useless energy carrier. It has to be converted with external energy at a loss of energy into what people need: mechanical or electrical energy. When based on electricity, the comparison of the three main options of renewable energy harvest reveals a clear picture. From the same piece of land about 50 times more energy is harvested with wind mills and 100 times more with photovoltaic arrays than with farmed biomass.

The poor performance of energy farming is caused by the low efficiency of photosynthesis. Only a tiny fraction of the incoming sunlight is used to combine carbon dioxide and water to biomass. Depending on plants life, season, site and soil conditions only 0.5% to 1% of the received solar energy is stored in the dry biomass. This natural process cannot be improved significantly by plant selection or more advanced farming methods.

Consequently, farming of energy crops is not a good option for a sustainable energy future. Counting all energy inputs for fertilizers, insecticides, irrigation, seed production etc. the overall energy balances of biodiesel or ethanol may even be negative.

7. From Now to Sustainability

The energy sector will change rapidly even without political shocks, wars or OPEC decisions. Trends that were already apparent a few years ago have now emerged in full strength. Limited supplies at rising demands, emergence of powerful economies (e.g. China and India), depletion of resources, air quality issues, or speculations in a tighter market place contribute to rising energy prices and unpredictable market trends with the following noticeable effects:

In the stationary sector, the demand of heating fuels is declining as a result of

- improved thermal insulation of buildings,
- more efficient HVAC appliances,
- use of wood, wood chips and pellets,
- use of electricity for direct heating and heat pumps.

In the mobile sector the total fuel consumption is still growing as a result of an increasing number and more powerful cars on the road. However, the fuel consumption per passenger mile is declining as a result of

- improved efficiency of IC engines,
- introduction of hybrid electric vehicles,
- substitution of fossil fuels by natural gas and biofuels,
- use of small battery-electric cars and scooters for commuting.

The overall efficiency of our energy system is increased by

- higher conversion efficiency of power plants and IC engines,
- higher efficiency of the electrical energy distribution system,
- rising energy awareness and change in consumer behavior,
- growing supply of electricity from renewable sources,
- energy conservation on all levels.

The transition to electricity is already in progress. Electricity is winning market shares from fossil fuels. Electricity is gaining acceptance. A "hydrogen economy" may never come, but the gradual transition to an "Electron Economy" is already evident.

11. Conclusions

For the establishment of a sustainable energy future the present energy system has to undergo significant changes, not just minor adaptations or modifications. The key point is the transition from a chemical energy base built on fossil fuels to a physical energy base built mainly on electricity from renewable sources. This transition is predetermined by the laws of physics. It cannot be avoided or significantly delayed by politics or lobby groups. However, the transition will proceed more smoothly, if all players agree to move into the same direction at the same time. A swift introduction of sustainable solutions offers many economic benefits for the willing.

Physics is eternal and cannot be changed by man. Therefore, the transition to sustainability leads to an "Electron Economy". Fortunately, proven technologies (wind power, solar power, solar collectors, biomass converters, hydropower technology etc.) are available. No additional research is needed for this transition, but material resources should be used for the implementation of a sustainable energy future.

12. References

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Born 1936 in Germany, studied Mechanical Engineering in Darmstadt (Germany) and at the Swiss Federal Institute of Technology in Zurich with Diploma Degree (thermodynamics, fluid mechanics, nuclear engineering) in 1961. Short work period at Brown Boveri & Cie, then continued education at the University of California at Berkeley with a Ph.D. degree in Engineering in 1968 for experimental research in the area of rarefied gas dynamics. Two years Assistant Professor at Syracuse University, return to Germany, head of the free molecular flow research group at the DLR in Göttingen. Left field for solar energy in 1976, founder and first president of the German Solar Energy Society, started his own R&D consulting firm for renewable energy technologies and energy efficiency in 1979. In 1986 he was asked by Brown Boveri & Cie to join their New Technology Group in Switzerland. Since 1987 involved in fuel cells, 1989 manager of ABB's fuel cell development efforts worldwide. Left ABB in 1990 to become a freelance fuel cell consultant, with clients in Europe, Japan and the US. Many patents and publications related to fuel cells. He has created, and is still in charge of the annual fuel cell conference series of the European Fuel Cell Forum in Lucerne.