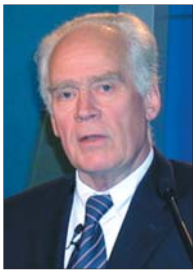
Energy in Germany

After Nuclear Has Gone

Germany's forthcoming energy system is de-cocooning. It compares well with a caterpillar still in its cocoon: so far it is not known yet whether a beautiful peacock butterfly or simply an ugly moth will emerge. Not much is for certain, but one thing certainly is cocksure: the next Fukushima is impending! Only when and where is open.



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To start with, a few facts about Germany: the country has 82 m. people; it is situated at latitudes between 47° and 58° north; altering from year to year, its south has up to 1,800 annual sunshine hours at most, its north including offshore a good wind regime of up to 8 to 10 m/sec; it is a green country, bio-technologically and – with some 20 % of election votes for the »Greens« – politically; the country has only meagre indigenous resources besides the scientific knowledge of its scientists and engineers and the skills of its craftsmen; it has to import more than 75 % of its primary energy raw material requirements, i.e., 60 % of its hard coal, 98 % oil, 84 % gas, 100 % uranium; it converts energy at a national energy efficiency rate of a very modest 30 % (for comparison, the world is at about 10 %!); it grew industrially to join today's top ranks worldwide, and – its Bundestag decided with a large majority on 30 June 2011 to reduce stepwise to zero by 2022, i.e. in a little more than ten years time, its entire nuclear power capacity, which for the time being meets some 22 % of the country's annual electricity needs.

Seven energy laws

In order to maintain and perpetuate the well-being of the nation, there are several approaches that have to be taken; they can be summarized as Germany's Seven Energy Laws:

- Double the national energy efficiency from today's 30 to 60 % with the technologies at hand and without excluding any link of the national energy conversion chain, from primary energy raw materials to primary energy, from there to secondary energies, to end energy, useful energy, and finally to the four energy services
  1. heating and cooling homes and buildings,
  2. energy support in transport and production,
  3. lighting rooms and city streets, and
  4. communication services.

Efficient energy services, the final link of national energy conversion chains, are the only indisputable reason for running through the chain; all the preceding links have no justification in themselves, they are simply means to an end. Here, where the nation's conversion chains end, lie dormant untouched huge amounts of decentral energy as well as potentials of technical work (exergy);

- utilize all sorts of indigenous renewable energies: of the basically eight renewable energies nature offers, namely solar, wind, biomass, hydro, ambient heat, geothermal, ocean energy and tides, the first seven are available in Germany, in absolutely unequal capacities, though;
- complete the still incomplete secondary energy scheme, incomplete even after more than two hundred years of modern anthropogenic energy, by introducing in parallel to electricity the second secondary energy carrier, hydrogen;
- exergize energy, in particular through hydrogen and fuel cells, thereby making more technical work available from energy, up to the physical maximum;
- clean up and electrify transport, and make it much more efficient by replacing hydrocarbons with hydrogen and combustion engines with fuel cells on board vehicles;
- import with the help of hydrogen otherwise nonstorable and nontransportable energy from abroad, e.g., wind from Patagonia, solar from Africa or Australia;
- as a result: further, cleanly and securely, the ongoing low-risk electrification of the nation's energy scheme and add to it a second secondary grid, the hydrogen energy grid. Besides the traditional scientific and engineering field of thermodynamics of heat engines, electrochemistry of electrolysers and fuel cells presently is and will become increasingly the next important field of activity for scientists and engineers.

Power plant Irsching: stationary gas turbines have gained 40 %, in combination with steam turbines in combined cycles they reach slightly more than 60 % – admirable, not only for the engineer Source: Siemens

Repair politics

Seen from a different, though deadly realistic perspective, Germany's forthcoming energy policy is simply repair politics:

- Reduce nuclear risks, finally nearing zero;
- stop anthropogenic climate change by reducing greenhouse gas emissions and environmental hazards;
- raise energy and in particular exergy efficiencies to the mandatory physical limits;
- introduce the so far »forgotten« renewable energies and the second secondary energy carrier hydrogen and their technologies;
- install high voltage transmission connections between the windy north of the country and its heavy energy demanding south; likewise, install hydrogen – gaseous or liquefied – transport between north and south in order to facilitate usage of northern wind-hydrogen and/or import-hydrogen disembarked from abroad;
- make buildings energy providers rather than energy consumers by installing »zero-energy buildings«, zero meaning almost entirely self-supplying, with no energy from the market; close the leaking thermal insulation envelope of homes and buildings;
- add fuel cells of various temperature grades from less than 100 °C up to almost 1,000 °C to the prevailing heat engines like reciprocating piston engines and gas or steam turbines – stationary or mobile – and, where applicable, finally replace them;
- optimize industry and appliances in home systems.

Swiss engineering colleagues are excellent engineers; they generally stand on firm ground, and introduced into their thinking the term »2 kW-society« aiming at technological means and behavioural attitudes of each citizen, including industry, transport, trade and administrations, to reduce energy demand to not more than 2 kWh per hour per person without quality-of-life loss. That is by no means unrealistic, if not a matter for the blink-of-an-eye.

Engineering approach

The ways to put Germany's energy laws into operation are exceptional. Many around the world smile or even gibe, only some try to understand. Here, an engineering approach is used to suggest technological, economic and ecological reasons why the way to go is not too grim and stony, why the procedure of changing from one paradigm technology to another is truly nothing really new, and why there is good reason for the conviction that the exemplary goal of an energy system free of nuclear can be reached in due time at tolerable cost. In more or less all the aforementioned seven ways, energy and exergy efficiencies, renewable energies and hydrogen are constitutional.

Never in the history of technologies did industry stick for eternity with one technology, the same is true for energy technologies: it took only some 200 years for the early renewables of the first solar civilization to be replaced by coal, coal by oil and gas, later by nuclear, heterogeneity grew; now hydrogen-energy-supported elevated efficiencies, the renewables of the second solar civilization and hydrogen energy are on the verge of taking over. Clearly, the trend leaves behind the dominance of energy raw materials and turns to the dominance of energy technologies: efficient technologies deliver energy gains, they »are« energy, you get more energy services from less (imported) primary energy. This is particularly true for energy-raw-materials-poor, but technologically-rich nations. Time and again, »creative destruction« (*Joseph Alois Schumpeter*, 1883 – 1950) opens ways to novel technologies, in this case to a novel energy system: centralized nuclear (and emission-heavy fossil) technologies lose, decentralized, hydrogen-supported clean and renewable technologies free of polluting and climate changing operational primary energy raw materials win; adding so-far-lacking hydrogen energy, constitutional to the second solar civilization, is imperative. Hydrogen exergizes energy, it harmonizes the discontinuous offerings of wind and solar (and other renewables) with continuous electricity demand, and it helps bringing exergetically efficient and clean fuel cells to market.

It's the innovations which carry forward the nation's well-being. In energy physics, electrochemistry complements the so far prevailing thermodynamics: heat engines, *James Watt*'s, *Rudolf Diesel*'s or *Nikolaus August Otto*'s (among others) heritage, get powerful competitors in *William Nicholson*'s or *Anthony Carlisle*'s electrolysers and *William Grove*'s and *Christian Friedrich Schönbein*'s exergetically efficient fuel cells. There is no need to first convert energy to heat and in a next step into electricity, as practised worldwide today: in essence the operational energy system emerged in a heat system. Fuel cells do it directly without a detour. Big turns into small: The unit capacity of fuel cells ranges from watts to a few megawatts, that of wind converters from kilowatts to tens of megawatts, of photovoltaic generators from watts to megawatts. In order to end up with significant macroeconomic capacities the units are combined into IT-controlled bundles. That way it's easy to get electricity capacities which compare well with the thousands of fossil and nuclear megawatts online today.

After some four to five decades of modern renewable and hydrogen technology research and development, Fukushima seemed to have been needed – rather bitter to say – to give them a big push to market entrance, to social acceptance, to environmental and climatic responsibility. However, to avoid fooling ourselves and pulling wool over our eyes: more decades are needed to achieve irrevocability for the paradigm change, a true *peripeteia*. After 2022, energy in Germany will be doable; however, time is needed: no excuses; energy needs time and – conviction! Usually, market approaches of novelties are S-shaped. To date, the paradigm's novel energies are still at the bottom of the S, with the upwards boost still impending.

Efficiency, energy productivity

Germany's national energy efficiency is a little more than 30 % (and it is dramatic to reiterate that the world's is only 10 %, perhaps marginally higher!). The Enquête Commission of the German Bundestag »Protection of the Earth's Atmosphere« already in the 1990s decided unanimously with the votes from both sides of the aisle to recommend to the Bundestag to double the national efficiency to 60 %. The commission stated that the necessary technologies are or will soon be available. The implementation has begun: hard coal fired power stations with heretofore unknown electrical efficiencies of around 50 % are in construction; stationary gas turbines have gained 40 %, in combination with steam turbines in combined cycles they reach slightly more than 60 % – admirable, not only for the engineer. The national electrical transmission system has an overall loss of only 4 %. The nation's primary energy consumption went down from 14,600 PJ (1999) to 14,250 PJ (2008); the energy related CO_2-emissions shrank in twenty years from 948 m. t/a (1990) to 690 m. t/a (2009). The energy intensity of Germany's industry as the quotient of primary energy demand over gross national product went down to approx. 70 % (2009; 1990: 100 %), an annual reduction of 1 to 2 % is regular; the future downward gradient is expected to continue, since energy-intensive industrial production continuously loses importance, and the emerging energy extensive services of all kinds gain (in more or less all industrialized countries).

Exergizing energy

Of utmost importance is putting the national energy system into balance: essentially, it so happened that the system developed prevailingly into a heat system which generates quasi en passant a few exergy services, too. The national exergy efficiency of Germany is only 15 % – shameful for us engineers! The system which came down to us produces heat with temperatures at places where it is of no one's use. Two examples only: the gas or light oil fired boilers of central heating systems in the basements of Germany's homes generate flame temperatures of around 1,000 °C, whereas the room radiators require only 60 to 70 °C. Consequently, the exergy efficiency is miserable. But a low-temperature fuel cell replacing the boiler delivers with an efficiency of 35 to 40 % firsthand electricity, i.e. pure exergy, and the remaining heat at a temperature fairly similar to that of the radiators' needs still suffices over most of the year to heat the home. And the other example: we admired above the modern hard-coal fired power stations with their electrical efficiency of 50 %. Excellent! But how about the other 50 %? Again, these plants are producing in the process high temperature heat of use to no one. If we, however, stop burning the coal, gasify it instead getting CO and H_2, shift the CO into CO_2, thereby getting more H_2, sequester the CO_2 and utilize the H_2 as a fuel in clean transportation or in a highly efficient triple high temperature fuel cell–gas turbine–steam turbine combined cycle – then the efficiency is raised well beyond 50 %. That, for example, is what is meant by exergizing energy.

The era of light

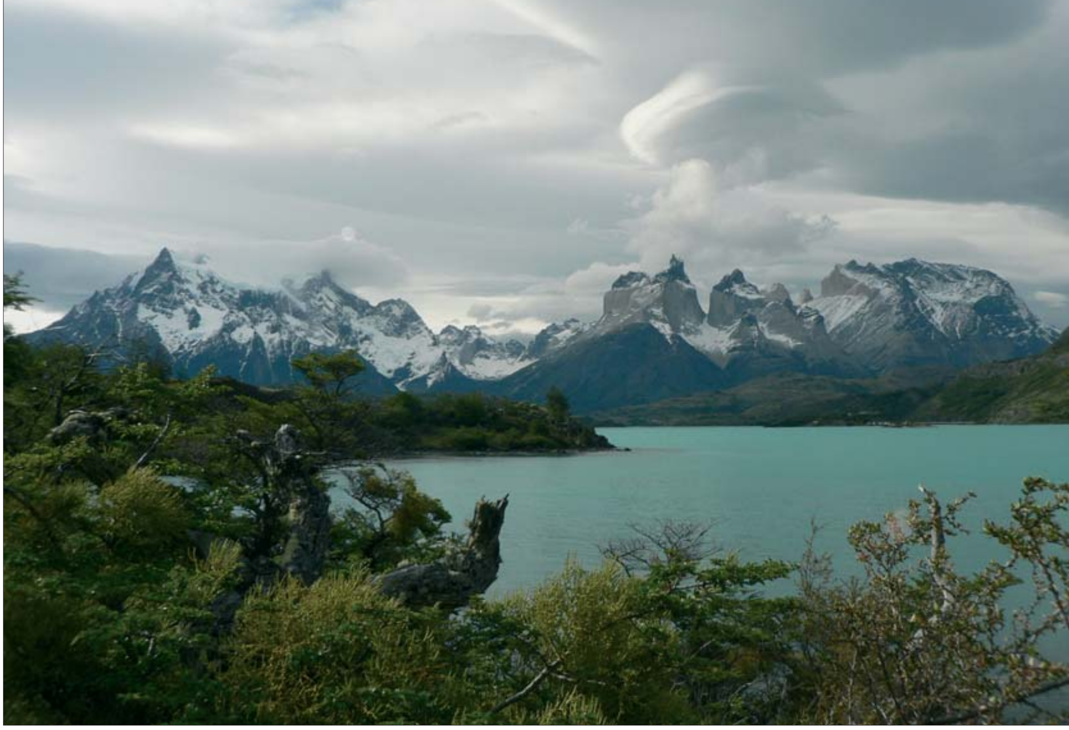
An indirect though powerful component of efficiency gains is the ongoing strong trend to products of lower (sometimes zero) weight; we are approaching the era of light. A few examples: renewable energies have no heavyweight primary energy raw material per se, their conversion chains are short, they lack the first conversion link and begin with primary energy; hydrogen is the smallest element in the periodic table, its ordinal number is 1; bulky and weighty postal parcels and letters are being replaced by zero-weight telecommunications; ceramics in appropriate applications weigh much less than steel; the same applies to high-strength carbon-fibre-reinforced plastics replacing aluminium parts of airplanes or steel bodies of motor vehicles. The German auto industry expects in 20 years' time an average fleet fuel consumption for both gasoline and diesel cars of 4 to 5 l/100 km (for comparison, today's gasoline cars consume an average of 8 l/100 km, diesel cars of 7 l/100 km); modern electrified vehicle designs such as hybrids or plug-in hybrids reduce the consumption further; and finally, building insulation drastically reduces the demand for heating fuel, in some cases down to zero; there are many, many more examples. Lightweight products save energy, in their production, their operation, their recycling.

Renewable energies

Of course, the aforementioned era of light applies to renewable energies, too: renewable energies have no weighty operational energy raw materials per se, hydrogen is the lightest element in the periodic table, most renewable energies utilize directly or indirectly the weightless light of the sun, utilization of renewables and hydrogen lightens the burden on environment and climate, and the aforementioned sheds light onto what is expected to becoming a basic criterion of the 21st century: energy sustainability.

Germany is not greatly blessed with renewable energies. Of the seven forms mentioned above, wind is the most powerful, particularly offshore wind, second in the row is solar, then, after quite a gap, come biomass, hydro and the others. Although 27,000 MW wind converters and 17,000 MW photovoltaic generators were in place in Germany as of 2010, it is, however, an illusion, a *chimera*, to expect the indigenous renewable sources to be able to provide the country's complete demand, particularly in the extremely short time period until 2022 when nuclear will have disappeared. To be reminded, it is not the megawatts of the installations that really counts, it is the megawatthours or, even better, the megawatthours per time of the day (the week, the year), and they suffer from the painful discontinuities of the renewables' supply. But, since import of energy has tradition in Germany, it is not too difficult to develop a scheme importing instead of coal or oil or gas, hydrogen energy electrolysed with the help of, say, Patagonian wind or Australian solar. Here is one of the centrepieces of the forthcoming hydrogen energy economy: make nonstorable and nontransportable renewable energies storable and transportable via water electrolysis, liquefaction, hydrogen pipelines, and LH_2 cryotankers. Practice this scheme already in pre-hydrogen times by extracting through reformation hydrogen from natural gas at the entrance of the gas field, sequester and store CO_2 and pollutants on the spot, and ship clean hydrogen instead of natural gas, thereby avoiding circulating potential CO_2 and pollutants around the globe. Remember, it so happened that the energy supplier simply ships energy raw materials and leaves it to the energy customer to remove the pollutants and potential greenhouse gases prior or in parallel to the energy usage. Hydrogenation of the material already at the mine mouth starts a clean energy trade, which will become mandatory anyhow when renewable energy is globally traded.

»Desertec«, the name of a project aiming at utilizing the powerful sun in North Africa or the Middle East, a factor of two to three more powerful than in Europe, through solar thermal power stations and shipping the electricity via high voltage direct current (HVDC) power lines or via hydrogen pipelines or tank ships to Europe, is another modern example for the well tested means of importing huge amounts of energy into energy poor countries, this time clean solar energy. The stations are reasonably efficient, of higher efficiency than photovoltaics; the daytime heat of the sun can be stored in air/stone, salt or sodium heat storage facilities to meet nighttime demand, the electrolyser can nicely respond to the ups and downs of the available sunshine, and a few energy lines across the Mediterranean Sea are already in operation, others will soon follow. You may even use the operational natural gas pipeline from Tunisia to Sicily to ship pick-a-back without major modifications gaseous hydrogen in an amount of some 10 to 15 % of the total pipe capacity, and upon arrival at its destination separate it out by means of membranes (www.naturalhy.net).



Windswept landscape in Patagonia: It is not too difficult to develop a scheme importing instead of coal or oil or gas, hydrogen energy electrolysed with the help of, say, Patagonian wind or Australian solar Source: Böhmer

Transport

All three transport branches need two things: hydrogenation and lightweight structures, on land, in the air, at sea. Prevailing aims at sea are generating the ship's electricity needs by means of fuel cells, in particular when mooring in harbours in order to avoid fumes and pollutants near high density dwellings, and taking liquefied hydrogen (LH_2) on board cryotankers linking heavy renewable energy supply zones with globally distant heavy energy demand zones, say sunny Australia with Japan, or windy Patagonia with Europe. Liquefied hydrogen transport benefits from the ongoing well established liquefied natural gas (LNG) transport which went on duty whenever installing gaseous natural gas (GNG) pipelines was not possible, e.g., over transoceanic distances.

Hydrogen in air transportation has two facets: Hydrogen at the airport and hydrogen aboard the plane. Airport authorities aim at installing hydrogen fuelled fuel cells as a reliable, clean means of uninterruptible electricity supply, supplementing and later replacing the present noisy, polluting and comparatively inefficient diesel gensets. And they are interested in all sorts of hydrogen fuel cell service vehicles on the airfield and at the ramp.

Hydrogen aboard the airplane comprises a variety of technologies: One of the early installations may become the undercarriage electric nose wheel, its electric motor powered by an onboard hydrogen fuelled fuel cell (www.dlr.de). It enables forward and backward motion without the need for a towing vehicle; the main engines are cut, no noise, no fumes, no pollutants bother passengers and airport staff and airport surroundings. The other medium-term project brings liquefied hydrogen aboard, regasifies it by cooling the surfaces of wings and empennage, thereby shifting the more efficient laminar flow zone further along the wing's cord and getting lower drag by avoiding the early onset of turbulent flow; the regasified hydrogen serves as fuel for fuel cells meeting the overall electricity demand of the plane. The fuel cell's hydrogen/oxygen (air) recombination provides potable water for crew and passengers, and for the pantry and toilets. The major advantage of this medium term project is the removal of the jet turbine as auxiliary power unit (APU) at the rear of the plane, the cause of so much unpleasant noise and exhaust pollutants and greenhouse gases from the plane when taxiing or waiting at the ramp.

Using hydrogen as the propellant for the main engines is not in sight yet, although it has been studied intensively for a number of decades. It is a longer term project, since it involves the adaptation of entire fleets and the ability of airports to refuel planes at the ramp with large amounts of liquid hydrogen fuel.

Truly dominating modern, clean, safe, reliable and efficient transport are the numerous aims at producing lightweight vehicles with hydrogen fuelled fuel cells aboard. In order to reduce fuel consumption, steel as the prevailing material of autos since the times of *Gottlieb Daimler*, *Karl Benz* and *Henry Ford* is being complemented piece-by-piece by lightweight aluminium, magnesium, fibre-reinforced plastics or ceramics, without safety losses and sometimes with even higher design strength and stiffness. Engine and gear box casings are aluminium foundry constructions.

Residences and buildings

End energy demand in Germany is rather evenly distributed among three areas
1. industry and power,
2. transport and
3. homes and buildings;

only a small remainder goes to trade and military. The first two are in the hands of professionals, in number 3 only buildings such as hospitals, office complexes, computer centres or large apartment houses are managed by professionals; single family dwellings are typically run by amateurs.

In all three areas two things are demanded: heating and/or cooling and electricity. Electricity comes from the central grid, increasingly also from photovoltaic generators on roofs or walls. The demand for heating or cooling is a direct function of the insulation quality of the house's envelope; historically, roofs, walls with windows and doors, and basement ceilings are poorly insulated. The requested heat is supplied by district heating, by gas or light-oil fuelled boilers in the house's basement, or more and more by solar thermal collectors or electrical heat pumps.

Let us take a look at the house of the future: the insulation envelope is closed, heat losses are very small, windows have double or triple glazing; if the windows are hermetical shut, an air supply and heat exchange system is installed, the rest of the required heat being provided by an efficient low temperature fuel cell, a solar collector system, or a heat pump; electricity comes from the roof's photovoltaic generators, surplus electricity is fed into the central grid. The house nears the criterion of a zero energy house which purchases only a minimum amount of energy from the market, or even sells energy to it. Today's energy-self-supplying family home has become part of a distributed district energy system which is run by professionals.

Conclusion I: Activate what lies dormant

- Utilize indigenous or imported renewable energies;
- the first and second solar civilizations are, of course, no different as to their global solar input, perhaps at best there are some local or regional differences; the distinction rather lies in the conversion technologies and in particular in those man-made technologies which on principle did not exist in the first civilization, e.g., photovoltaics and fuel cells;
- strive to exploit the immense potential of energy efficiency gains;
- make more energy services available from less energy raw materials by always putting efficient energy technologies first;
- fight exergy destruction by avoiding irreversibilities, particularly in boilers, combustion chambers and heat exchangers, thereby making more exergy from the available energy, less anergy: energy = exergy + anergy;
- turn the heating system in place, which provides only a little technical work (exergy) into a technical work system which also provides the demanded heat at appropriate temperatures;
- foster the energies-of-light: supposedly nonenergy related technologies strongly influence the energy system, e.g., lightweight moving structures need less energy for acceleration and deceleration, closed insulation envelopes of buildings and their southerly orientation diminish their need for energy from the market;
- follow-up the historical development line from coal via oil and natural gas to hydrogen, i.e., from high carbon/low hydrogen via decarbonization/hydrogenation finally to high hydrogen/low carbon, i.e., the atomic relation H/C varies from < 1 via 2 and 4 to ∞. Keep in mind that already to date two thirds of all atoms burnt are hydrogen atoms: The way to go is well defined;
- in parallel to the electricity grid install the second secondary energy grid, the hydrogen energy grid;
- with the help of hydrogen store and transport otherwise nonstorable and nontransportable energies such as wind and solar;
- fuel exergetically efficient low temperature fuel cells with hydrogen for transport and for industrial and residential energy;
- complete energy knowledge by adding the electrochemistry of electrolysers and fuel cells to the thermodynamics of heat engines.

Conclusion II: Remove barriers

- Convince people that German energy without nuclear is doable and affordable;
- strive for nuclear-free energy without negatively affecting anthropogenic climate change;
- get agreement for wind-electricity high-voltage north/south overhead transmission lines near people's backyards;
- obtain public approval for highly efficient new gas or coal plants as well as hydro and underground hydrogen or compressed air storage;
- tell people that there is no absolute safety, never, nowhere and under no condition, and that hydrogen, like any other energy, is to be operated responsibly under secured hydrogen-specific safety standards;
- install and finance the national hydrogen grid, including LH_2 disembarked from abroad;
- as a showcase, engineer, build and operate the first »Desertec« plant in North Africa and bring the HVDC electricity or hydrogen to Europe;
- Start altering the global energy supplier/demander process, thereby shifting the removal of greenhouse gas and pollutants from energy demanders to energy suppliers, with the consequence of circulating clean hydrogen instead of dirty fossil material around the globe.

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