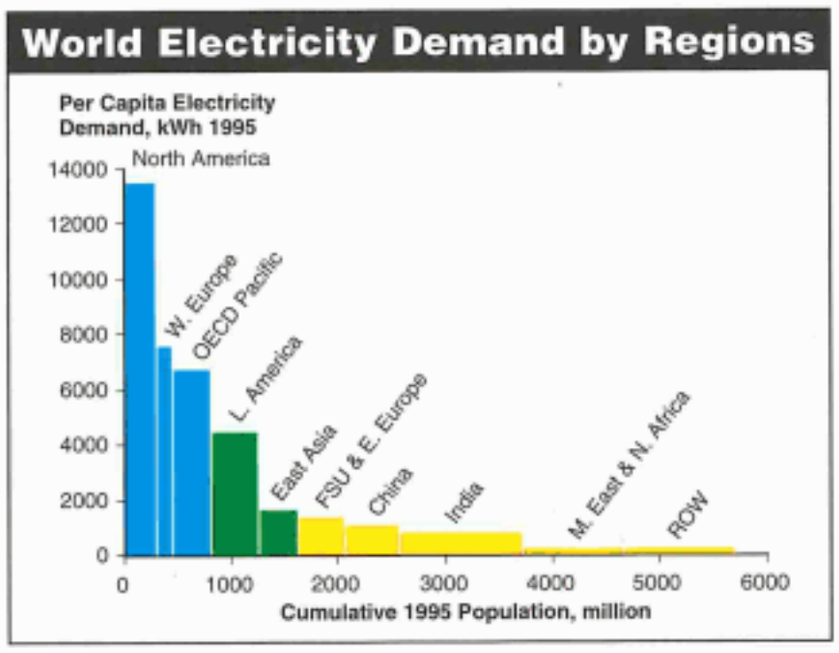
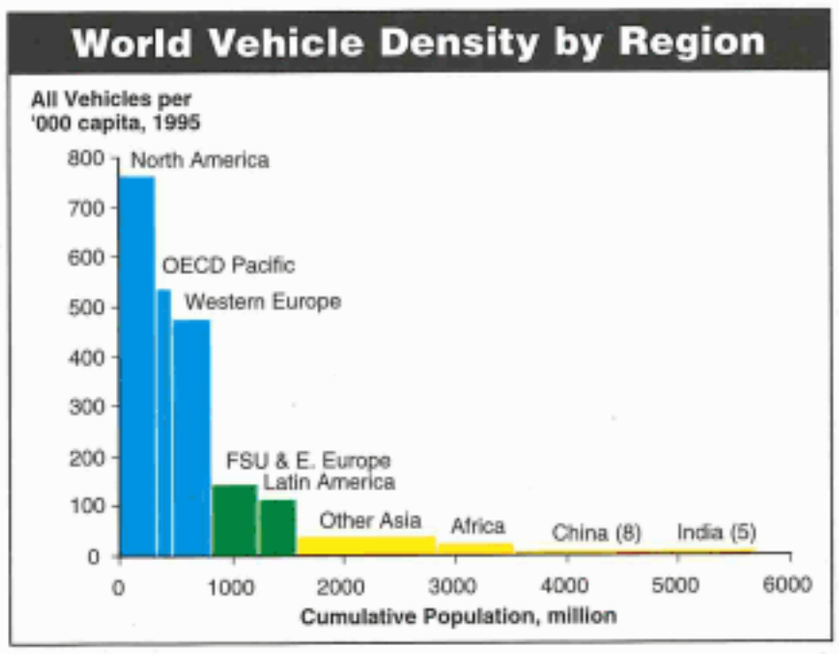
The Evolution of the World's Energy Systems

Over the last hundred years, energy demand per capita has more than trebled, from 3 to 13 boe/year, spurred by economic growth. However, major parts of the world's population have still little or no access to the comfort provided by electricity nor to the wider range of choices and opportunities linked to mobility. Meeting these needs, for today and tomorrow, will require increased and sustainable energy supplies. To reflect on this challenge, a study of the evolution of the world's energy system was conducted in 1994 in Shell Group Planning by Georges Dupont-Roc, Alexon Khor and Chris Anastasi. Extracts are presented in this paper.

World Electricity Demand by Regions



World Vehicle Density by Region



Against the background of a world population growing from 5 billion people today to 8.5 billion by 2030, and stabilising at 10 - 12 billion by 2060, as envisaged by the World Bank, what energy system could sustainably fuel a continuing world economic growth of 3% per annum, similar to that experienced over the last hundred years?

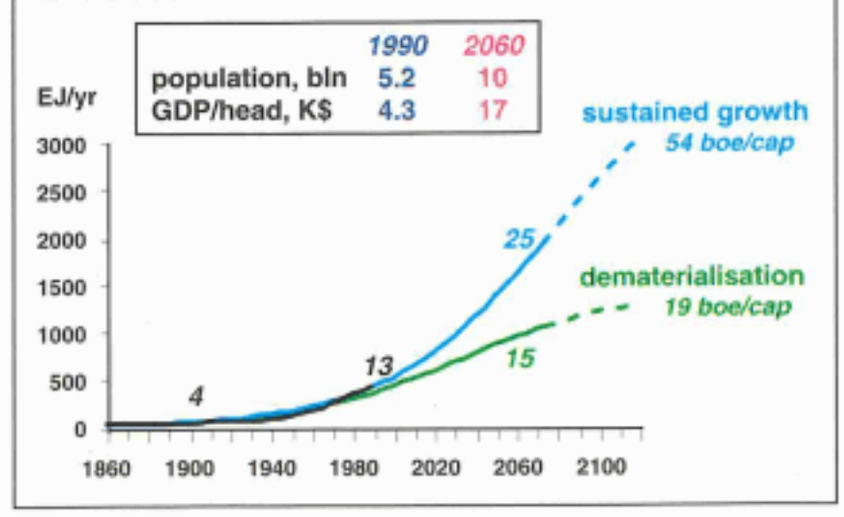
Building on historical patterns which have shaped economic development - inventiveness, competition, productivity, converging developments - two contrasted energy visions are explored for the future.

- In "Sustained Growth", abundant energy supply is provided at competitive prices, as productivity in supply keeps improving in an open market context. The growth pattern of the last century continues, with energy consumption per capita reaching 25 boe/yr by 2060, today's Japanese level.
- In "Dematerialisation", human needs are met through technologies and systems requiring a much lower energy input. A different pattern emerges, leading to an energy use per capita of 15 boe/yr by 2060.

For both scenarios, fossil fuels contribute to most of the growth over the next few decades, but renewable energy sources gradually take an increasing market share and their contribution becomes significant by 2020-2030. The Group is currently undertaking a small number of demonstration projects, focused on testing the commercial potential of biomass - growing trees for heat and power generation - and photovoltaics systems.

Waves of Technology

Two Simple Scenarios



What have we learnt so far?

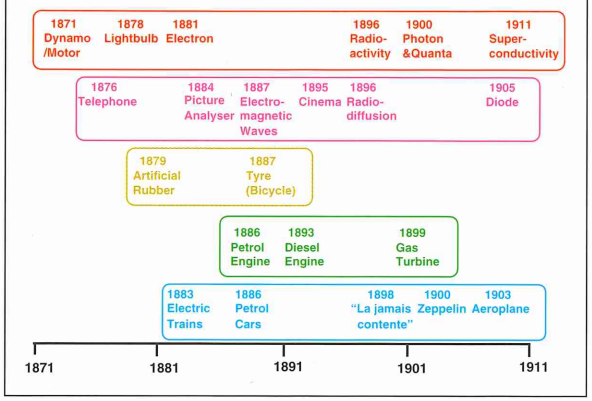
Key discoveries made 100 years ago have shaped today's life

Their history shows:

- Vigorously pursued concepts, like television;
- Surprises: it took some thirty years to understand the significance of radioactivity;
- Competitive development, like Zeppelin versus Aeroplane or petrol versus electric cars. For instance,
  "La jamais contente", an aluminium bodied and battery powered car, broke the speed record at 105 km/h in 1899 but never made it to the market.

Against this promising background, mankind was using mostly wood and coal to meet its energy needs. By 1890, oil market share was only 2%.

Key Discoveries 1871-1911

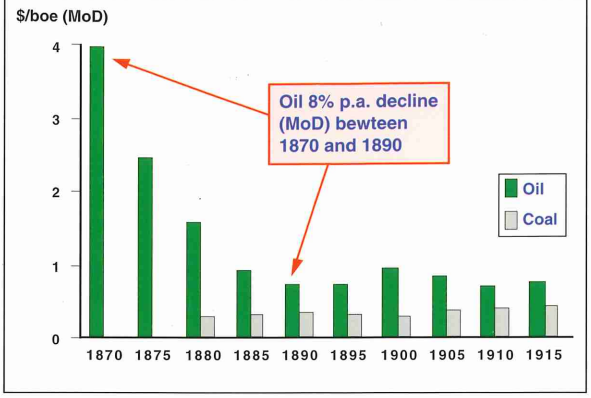


Oil came into the energy market through niches

Oil was first used in lamps and stoves. As industry learnt how to produce it, the average price decreased at a rate of 8% p.a. over 20 years and a 50 fold production increase was achieved from 1870 to 1910. Used increasingly in commercial ships, it became an established player when Sir Winston Churchill switched the British Navy from coal to oil, gaining a strategic advantage from increased power and less visible smoke emissions. By then, the oil price was in real terms close to today's level.

In the 1970s, sharp increases in oil prices led oil companies to develop resources at the upper end of the cost curve. When prices collapsed in the mid 1980s, competitive pressures forced engineers in the oil industry to stretch their imagination to propose competitive technologies.

Price of Oil (at well) and Coal (at mine) 1880-1915

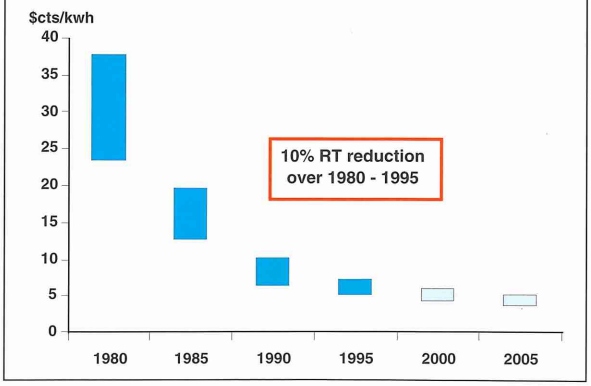


For instance, Troll - an oil and gas field offshore Norway, in some 300m water depth, declared commercial in 1983 - saw its capacity cost reduced by 7% p.a in real terms over 1983-1993. This trend can also be shown for many North Sea projects after 1985 and led to the development of completely new technologies and practices which have now become routine – sub-sea satellites, unmanned platforms, long range deviated wells.

Today, several renewable energy technologies are following a similar path down their learning curves

The cost of electricity from wind turbines fell by 10% p.a. in real terms over 1980 - 1995. Although based on an intermittent source, this technology is now commercially competitive in certain areas. This happened through improved reliability, optimising design, location and economy of scale in manufacturing and stimulated by "pump priming" policies of certain governments. There are now a dozen major manufacturers and a new industry is emerging.

Cost Reduction in Wind Turbines

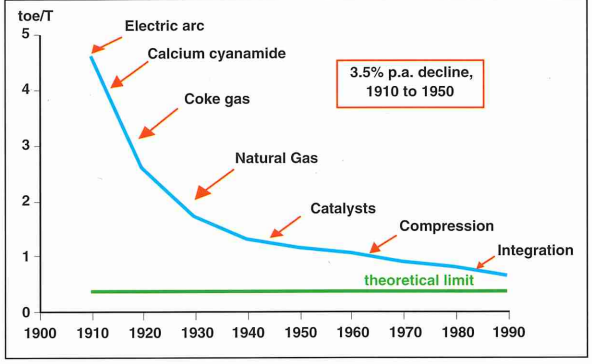


Between 1976 and 1988, the cost of making photovoltaic solar panels steadily declined at rates in excess of 15% p.a. in real terms, following an 80% experience curve (costs are reduced by 20% when the cumulative number of installations doubles).

Productivity also improved in the use of energy

There are many examples in industry. For example, the energy used in the industrial production of ammonia has seen a steady decline over an extended period of time through the adoption of new raw materials, processes and equipment. Today, only one-fifth of the energy required in 1910 is needed.

Energy Use in Ammonia Production 1990-1990



In transport, very high speed trains, such as the French TGV, fulfil the same need as their steam ancestor but faster and using less primary energy. The weight per passenger remains an area of potential improvement.

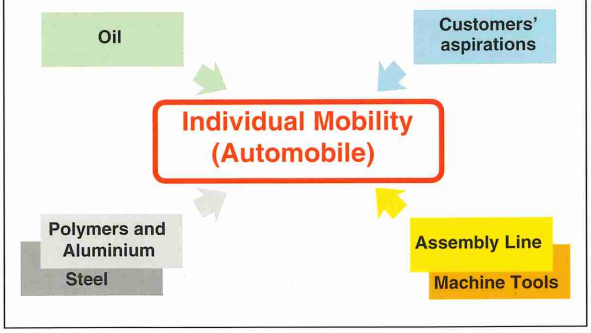
This process of continuous improvement is reflected at macro economic level. In the USA, energy intensity - the ratio of energy consumption to gross domestic product - has declined at an average of 1% p.a. over the last 100 years, with up to 2% p.a being achieved for a decade under extreme price pressure.

In the history of economic development, there are times when converging needs and resources can radically change life-style

For instance, individual mobility came about from the convergence of:

- A new energy source (oil with its high energy density);
- Improved and new materials (quality steel, polymers);
- New manufacturing techniques (assembly line production);
- Social needs, such as wider choices for dwelling, working and leisure.

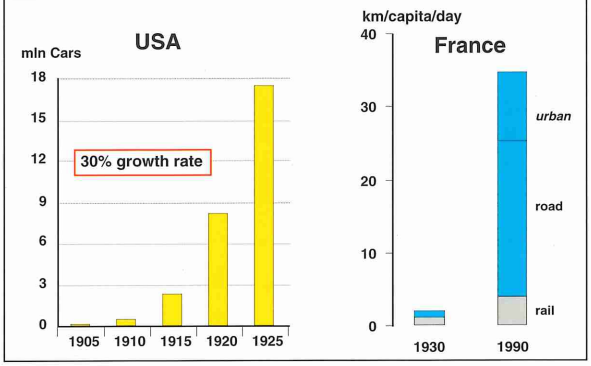
Converging Developments - 1920



Mass produced cars became affordable to many, growing, in the USA, from 8000 in 1900 to 17 million in 1925 -a sustained growth of 30% p.a.

John Watkins speculated in "The Ladies' Home Journal" of December 1900 that "automobiles will soon become cheaper than horses and be substituted for every horse vehicle now known ... including police patrols"

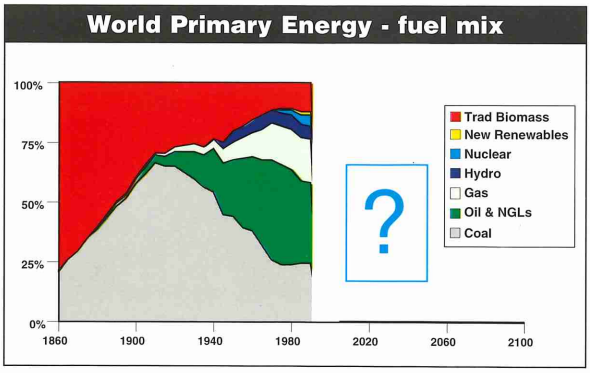
Growth in Car Population and Mobility



As demand grew, energy supplies became more diversified

As new needs appeared and economic development progressed, energy demand grew and consumption per capita in the world kept increasing over the last century, even during troubled periods. To meet these needs, energy supplies became more diversified:

- coal, oil, gas, hydro, nuclear.....and we may now be seeing the beginning of a new transition: - new renewables.



Waves of technological transitions will continue this process

One generation will make a discovery, perhaps explain the science and teach it to the next generation which, in turn, will develop it and bring it to our daily life. This process may take 40 to 60 years. Along this path inventions may abort or fail to become commercial. For some of the more robust, "pump priming" through limited grants may be needed to facilitate the progression along the learning curve through market niches.

Identified renewables - wind, biomass and solar photovoltaics - are clearly new technologies looking for market niches. Artificial photosynthesis and magma energy are at the stage of developing science. There are many other candidates and the unknown will no doubt bring "surprises".

"Sustained Growth"

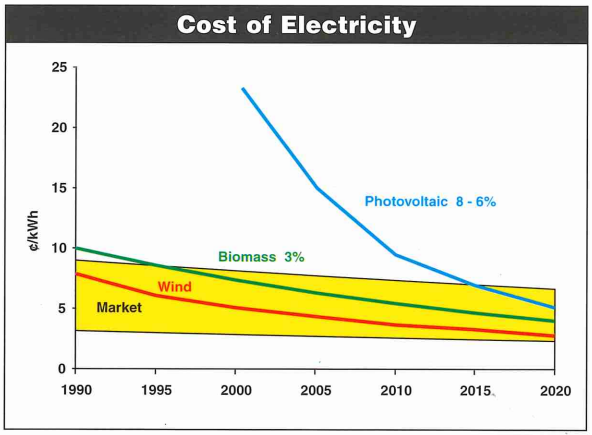
Abundant energy supply is provided at competitive prices, as productivity in supply keeps improving, in an open market context

Companies and universities active in the deployment of renewable energy technologies would be successful, stimulated by limited "pump priming" initiatives. This would occur not only in OECD countries, but also in developing countries. As a result, the challenge of providing abundant energy at competitive prices would be met over the next decades.

New technologies would steadily progress along their learning curves, first capturing niche markets and, by 2020 become fully competitive with conventional energy sources. Cost reductions reflect an 80% experience curve for solar photovoltaics and 85 % for biomass. This is not unlike the progression of oil 100 years ago (80%) and slower than that of electricity in the USA between 1926 and 1970 which followed a 75% experience curve (a 25% cost reduction for every doubling of cumulative production).

The cost of sustainably growing biomass could be reduced by advances in clonal propagation and genetic enhancement of plants, notably woody crops. Conversion, first into electricity, and later into liquid fuels, could become commercial through small scale replicable facilities. Over the last decade, Shell companies have developed experience in growing and enhancing trees (for pulp wood) and are now becoming involved in the development of biomass (trees) for heat and power generation.

The cost of photovoltaic panels would be reduced, first by advanced automation in manufacturing and improved light conversion efficiency in current crystalline silicon technology. It could be followed by the large scale deployment of one or several types of thin film technologies. A Shell company has recently developed an improved high efficiency cell, in cooperation with public research organisations and will implement industrial production.

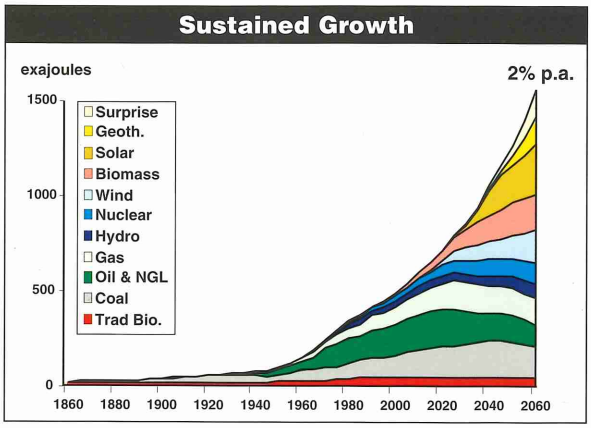


Renewable energy sources become significant by 2020

An attempt is made here to illustrate what energy supply could look like under "Sustained Growth". Primary energy grows at about 2%, supporting a 3% p.a. growth in GDP. This assumes an improvement in energy intensity of about 1 % p.a, as observed in the USA between 1880 and 1990, under free market conditions. Energy per capita continues its historical progression.

Use of fossil fuels increases steadily over the next 30 years, fuelling the economic development of a majority of the world population. By 2020-2030, they reach their maximum potential and no longer contribute to growth, being limited by the rate of production and commercialisation of resources

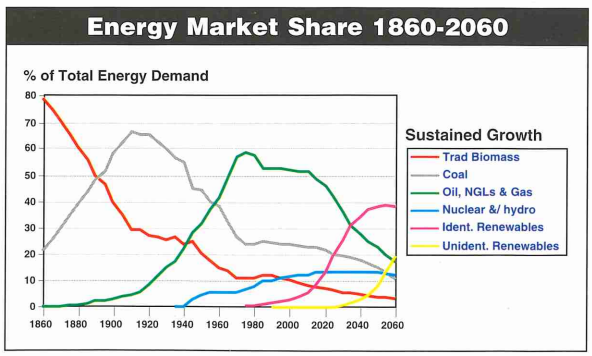
economically competitive with renewable energies. At that time a number of developing countries (e.g. China and India) - having reached a sufficient level of industrial development - increasingly turn their attention towards renewable energy sources. Some of them may be able to leapfrog, as illustrated by rapid growth of wind power in Asia-Pacific countries and India.



Having gradually become commercial over the next two decades, renewable energy technologies increase their market share as total energy demand grows. This allows growth in energy supplies to be sustained at a time when fossil fuels reach a plateau. It is not necessary, for this argument, to determine which renewable technology has the best prospects. Technologies will compete but the market will decide.

However, by 2060, sources of supply are likely to be more diversified than today. Perhaps ten different sources will each have a market share between 5 and 15%.

In this scenario, the rate of market penetration for identified renewable technologies - wind, biomass, photovoltaics - is similar to that of coal or oil and gas in the past. A second wave, possibly including magma energy and/or a surprise, might take-off by 2050.



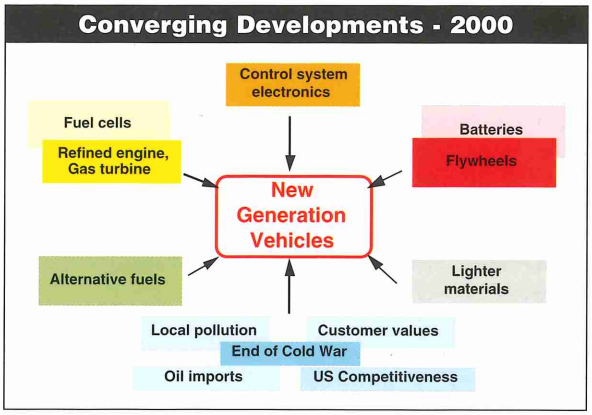
"Dematerialisation"

Human needs are met through technologies and systems requiring a much lower energy input

For instance, data highways and virtual reality may be a harbinger of a different lifestyle, a signal perhaps similar to the emergence of the automobile and individual mobility at the beginning of this century.

Thanks to advances in materials and design capabilities, objects and equipment will fulfil their function using ever less or lighter material. Carbon fibres are four times lighter than steel and yet twice as strong.

Certainly in road transport one could see a possible convergence of social and economic issues, new technologies - some of them developed for space application - alternative fuels and lighter materials. The result would be "New Generation Vehicles", three times more fuel efficient than today's vehicles. The challenge is to integrate these technologies, lower their cost and develop a manufacturing infrastructure, probably along an evolutionary path.



"... new technologies, such as advanced electronics, ultra light materials, CAD and a host of others could change cars more radically in the next 10 to 20 years than in the last 100"

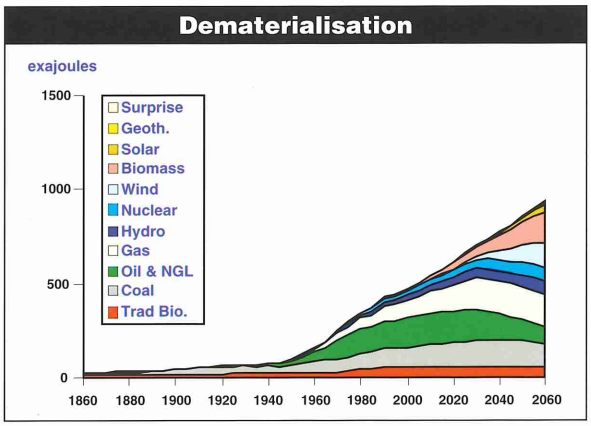
A. Trotman, Chairman of Ford Motor Co.

Energy consumption per capita remains virtually stable for the next 30 years

An attempt is made here to illustrate what energy supply would be consistent with "Dematerialisation". Improvement in energy intensity gradually reaches a sustained 2% p.a. To support a 3% p.a. growth in GDP, primary energy increases at about 1.3% p.a. until 2030, as developing economies expand. Thereafter, energy growth slows down to 1% p.a., as "Dematerialisation", started in the more advanced regions of OECD countries, gradually spreads to industrialising and developing countries, once infrastructure has been built and GDP per capita is high enough. Countries restructuring their economies would improve their energy efficiencies drastically.

Coal and oil growth is lower in "Dematerialisation" than in "Sustained Growth". However, more gas is being used to compensate for the delayed take-off of PV solar, postponed from 2020 to 2050. This technology remains a niche application until nanotechnology becomes widely applicable!

A 2% p.a improvement in energy intensity has only been seen for limited periods in the past. In "Dematerialisation", relentless advances in information technology, telecommunication, materials and biotechnology would enable high energy intensity improvements to be sustained for several decades.

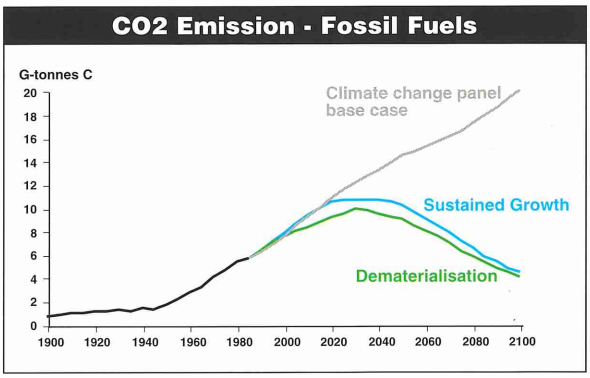


A different life style, possibly linked to changing individuals' and customers' behaviour, could emerge. Signs may already be perceivable such as virtual reality, but consequences are difficult to anticipate fully, perhaps similar to the scale of changes brought about by the automobile and individual mobility during the 20th century.

In "Dematerialisation", the rate of market penetration for identified renewable energy - wind, biomass, PV solar - is lower than in "Sustained Growth". The second wave of renewables is not needed until 2060.

Conclusions

- Hydrocarbons are needed for economic development
- Productivity improvement in supply and use will continue
- Energy needs will be met by more diverse sources
- "Carbon free" newcomers can become competitive through market mechanisms. Markets will decide which technology is best.
- CO2 emissions from fossil fuels peak at around 10 GtC before the middle of the next century and decline to 4GtC/year by 2100, leading to stabilisation of CO2 content in the atmosphere at about 550 - 600 ppm, according to current models, or 60% above today's level.



Among many different possible paths along which the world energy system could develop, "Sustained Growth" and "Dematerialisation" are two sustainable and plausible archetypes which could happen through market mechanisms and with minimum stimulation. These scenarios provide low economic cost options to policy makers and are genuinely "no regret".

Like 100 years ago, there are many talents in the world. Provided governments maintain a framework in which inventiveness, competition and productivity are encouraged and rewarded and where decisions are the result of a rational and open debate, business can do a lot to support sustained economic growth, supplying and using energy in an environmentally responsible manner.

WHAT MAY HAPPEN IN THE NEXT HUNDRED YEARS

By John Elfreth Watkins, JR.

Extracts from Ladies' Home Journal - December 1900

America with Five Hundred Million People. There will probably be from 350,000,000 to 500,000,000 people in America and its possessions by the lapse of another century.

Hot and Cold Air from Spigots. Hot or Cold air will be turned on from spigots to regulate the temperature of a house as we now turn on hot or cold water from spigots to regulate the temperature of the bath. Central plants will supply this cool air and heat to city houses in the same way as now our gas or electricity is furnished. Rising early to build the furnace fire will be a task of the olden times. Homes will have no chimneys, because no smoke will be created within their walls.

Trains One Hundred and Fifty Miles an Hour. Trains will run two miles a minute, normally; express trains one hundred and fifty miles an hour. To go from New York to San Francisco will take a day and a night by fast express. There will be cigar-shaped electric locomotives hauling long trains of cars. Cars will, like houses, be artificially cooled.

Everybody will Walk Ten Miles. Gymnastics will begin in the nursery, where toys and games will be designed to strengthen the muscles. It will be compulsory in the public schools. Every school, college and community will have a complete gymnasium. All cities will have public gymnasiums. A man or woman unable to walk ten miles at a stretch be be regarded as a weakling.

There will be No C, X or Q in our every-day alphabet. They will be abandoned because unnecessary. Spelling by sound will have been adopted, first by the newspapers. English will be a language of condensed words expressing condensed ideas, and will be more extensively spoken than any other. Russian will rank second.

Automobiles will be Cheaper than Horses are To-Day. Farmers will own automobile hay-wagons, automobile truck-wagons, ploughs, harrows and hay-rakes. A one-pound motor in one of these vehicles will do the work of a pair of horses or more. Children will ride in automobile sleighs in winter. Automobiles will have been substituted for every horse vehicle now known. There will be, as already exist to-day, automobile hearses, automobile police patrols, automobile ambulances, automobile street sweepers. The horse in harness will be as scarce, if, indeed, not even scarcer, than as the yoked ox is to-day.

Ready-Cooked Meals will be Bought from establishments similar to our bakeries of to-day. They will purchase materials in tremendous wholesale quantities and sell the cooked foods at a price much lower than the cost of individual cooking.

Man will see Around the World. Persons and things of all kinds will be brought within focus of cameras connected electronically with screens at opposite ends of circuits, thousands of miles at a span. American audiences in their theatres will view upon huge curtains before them the coronations of kings in Europe or the progress of battles in the Orient. The instrument bringing these distant scenes to the very doors of people will be connected with a giant telephone apparatus transmitting each incidental sound in its appropriate place. Thus the guns of a distant battle will be heard to boom when seen to blaze, and thus the lips of a remote actor or singer will be heard to utter words or music when seen to move.

Telephones Around the World. Wireless telephone and telegraph circuits will span the world. A husband in the middle of the Atlantic will be able to converse with his wife sitting in her boudoir in Chicago. We will be able to telephone to China quite as readily as we now talk from New York to Brooklyn. By an automatic signal they will connect with any circuit in their locality without the intervention of a "hello girl."

Photographs will be Telegraphed from any Distance. If there be a battle in China a hundred years hence snap-shots of its most striking events will be published in the newspapers an hour later. Even to-day photographs are being telegraphed over short distances. Photographs will reproduce all of Nature's colors.

Grand Opera will be Telephoned to private homes, and will sound as harmonious as though enjoyed from a theatre box. Automatic instruments reproducing original airs exactly will bring the best music to the families of the untalented. Great musicians gathered in one inclosure in New York will, by manipulating electric keys, produce at the same time music from instruments arranged in theatres or halls in San Francisco or New Orleans, for instance.

The American will be Taller by from one to two inches. His increase in stature will result from better health, due to vast reforms in medicine, sanitation, food and athletics. He will live fifty years instead of thirty-five as at present - for he will reside in the suburbs. The city house will practically be no more. Building in blocks will be illegal. The trip from suburban home to office will require a few minutes only. A penny will pay the fare.

Coal Will Not be Used for Heating or Cooking. It will be scarce, but not entirely exhausted. The earth's hard coal will last until the year 2050 or 2100; its soft-coal mines have become more and more expensive. Man will have found electricity manufactured by water-power to be much cheaper. Every river or creek with any suitable fall will be equipped with water-motors, turning dynamos, making electricity. Along the seacoast will be numerous reservoirs continually filled by waves and tides washing in. Out of these the water will be constantly falling over revolving wheels. All of our restless waters, fresh and salt, will thus be harnessed to do the work which Niagara is doing to-day: making electricity for heat, light and fuel.

There will be Air-Ships, but they will not successfully compete with surface land and water vessels for passenger or freight traffic. They will be maintained as deadly war-vessels by all military nations. Some will transport men and goods. Others will be used by scientists making observations at great heights above the earth.

Peas as Large as Beets. Peas and beans will be as large as beets are to-day. Sugar cane will produce twice as much sugar as the sugar beet now does. Cane will once more be the chief source of our sugar supply. The milk-weed will have been developed into a rubber plant. Cheap native rubber will be harvested by machinery all over this country. Plants will be made proof against disease microbes as readily as man is to-day against small-pox. Soil will be kept enriched by plants which take their nutrition from the air and give fertility to the earth.

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