Green Cycles Economy and Factory

Dominik Rohrmus, Volkmar Döricht, and Nils Weinert

Siemens AG, Corporate Technology, Munich, Germany

Abstract

Climate change calls for answers beyond pure optimization of resources and energy consumption in production. Our presented green vision looks long-term at CO2 as raw material for new synthetic raw materials and products as well as markets, referred to as green cycle economy. Green cycles are defined as CO2 sinks, empowered by renewable energy used for synthesizing fuels and materials from carbon sources. Green factories are defined by applying the concepts of green cycles to manufacturing industries. The transformation of existing into green factories is achieved in an evolutionary way, successively applying the technology levels defined for green cycle economies.

Keywords:

Green cycles economy; carbon-based production vision

1 INTRODUCTION

The green cycles economy and factory vision presented looks at carbon (C) as a raw material for new materials, products, and synthetic raw materials. CO_2 as one of the principal agents of climate change [1] is an interesting source for carbon. The vision can open up new business models and new markets that use carbon to provide an answer to the world's hunger for materials [2]. We define "green" as a CO_2 sink, i.e. consuming CO_2 to provide green energy sources and green materials that can be used in a CO_2 based cycling production and businesses. The prerequisites will be CO_2 neutral forms of renewable energy and chemistry as well as petro-chemistry technologies. The applications available today have already been put to work cost-effectively in the fields of green fuels and the production of intermediate products for plastics. One motivation for the green cycles economy and factory vision is that the advancing climate change calls for answers that go beyond the currently ongoing optimizations of our use of energy and resources.

The Siemens AG sustainability goals are to establish a substantial equilibrium between the planet and the people. This equilibrium is to be achieved with a profit orientation from the business point of view (see Figure 1). The Siemens AG Sustainability Board defines and guides business activities for this purpose [3].

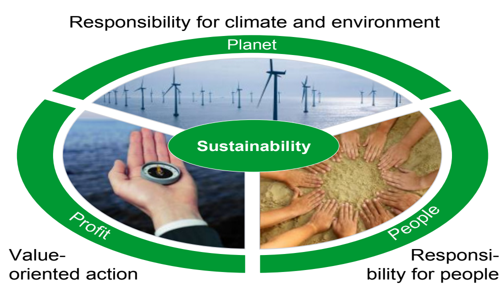

Figure 1: The Siemens AG sustainability definition.

2 REASONS TO "GO GREEN"

We face a worldwide energy dilemma (see Figure 2):

- The world's total energy demand will double by 2050. Demand for electrical energy will double as early as 2030. [4]
- The goal, in the sense of bringing global climate change to a halt, is to reduce CO_2 emissions by at least half within the same period. [5]

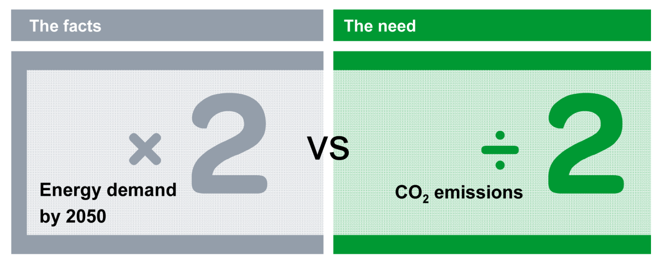

Figure 2: The energy dilemma. Source: [5],[4] (compared to 1990).

We address the energy dilemma in two dimensions: from the economical necessities of industry and production as well as from a climate change perspective.

The current global energy mix, which relies primarily on fossil fuels, cannot meet these challenges assuming that the necessary reduction in CO_2 emissions is to be achieved in the same time [5],[6].

The worldwide increase in prosperity, especially in newly industrializing nations like China and India, will steadily increase CO_2 emissions [7],[8] unless extensive countermeasures are taken, and at the same time will increase demand for materials, for products, and production (so called rebound-effect [9]).

At present, the challenge of achieving a secure energy supply – a central factor for industrialized nations - in combination with a secure supply of materials [10],[11], while at the same time reducing greenhouse gases has been met only in very isolated cases, for example in parts of Iceland [12]. Both decentralized and large-scale industrial solutions must be considered.

In terms of the climate change perspective the current concentration of CO_2 in the atmosphere is about 392 ppm (parts per million) [13], and is increasing by about 2 ppm annually [14] (see Figure 3). The maximum 2ºC temperature increase currently targeted by the world community can be achieved with a 75% probability if the CO_2 concentration does not exceed 400 ppm (some sources assume as much as 450 ppm) [5],[15]. The 2°C increase has been chosen because this temperature represents the system limit for the climate models under which climate change appears to be manageable and major global climatic processes remain calculable [5],[15]. However, the current increase in concentration (the greatest in human history) will mean that this limit will be exceeded as early as 2020 [5],[6].

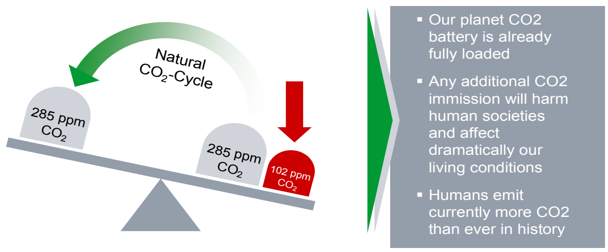

Figure 3: The CO_2 cycle and global climate change.

CO_2 has a crucial influence on the global warming, because it is responsible for about 64% of the effect, and unlike methane, it remains in the atmosphere for as long as 200 years [5],[16] (see Figure 4). Methane, at 20%, has considerably less influence on warming, and remains in the atmosphere for only 9 to 15 years.

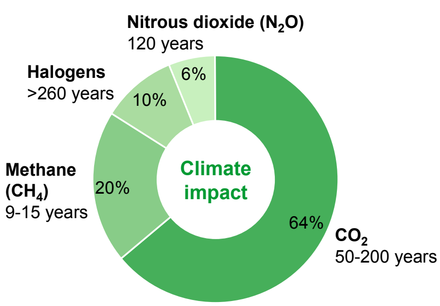

Figure 4: Residence time of climatic gases in the atmosphere. Source: IPCC 2007 [5],[16].

To achieve the 2°C goal according to [5], the worldwide CO_2 emission peak should be reached no later than 2020. In their words a 60% reduction of the energy-related CO_2 emissions should be accomplished in 2050, of the total CO_2 emissions 50% - 85% compared to the year 2000. By the year 2070 all CO_2 emissions must be reduced to zero. Moreover, after that point a negative CO_2 footprint must be achieved to "remove" the rising CO_2 concentration of the coming decades from the atmosphere.

2.1 Our Concept of Green

One answer to these climate challenges and the economical necessities of industry and production are newly introduced so called "green cycles": We conjecture that new technologies, which operate as CO_2 sinks, i.e. that have a negative carbon footprint, will come into use and that at the same time these new technologies will offer the necessary features for a positive economic performance. Green cycles actively consume CO_2, when considered in terms of a life cycle assessment. In other words, CO_2 is viewed as a raw material, which is often available cheaply for direct recycling, i.e. as an industrial waste product. Not every part of the economy will be able to achieve this goal. Therefore, primarily industrial production, which the Siemens AG serves, will have to provide a substantial overcompensation if the climate change perspectives are also considered. In case of the Siemens AG this is part of our sustainability definition [3] (see Figure 1).

As the term "green" is used in today's communication, "green" technologies are usually understood as environmental technologies. However, environmental technologies are primarily aimed at minimizing the impact on the environment. They provide usually solutions that represent improvements over conventional technologies in this regard and that aim to increase the solution's energy efficiency at reasonable costs. Ideally, CO_2 emissions will then be reduced zero (see Figure 5).

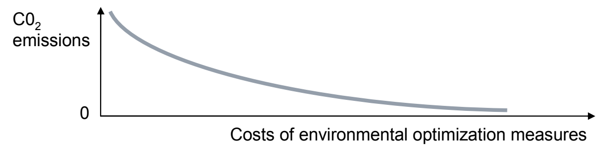

Figure 5: Environmental technologies cost perspective.

Here it is essential to take measurements using uniform criteria. But this is not assured, at least not in all cases. There is no unique definition of "green" in the current literature. However, the etymological derivation from the Indo-European term "gher" yield a definition starting point for "green" in terms of the meanings "to stick out", "grow" (like leaves), and "verdancy" [17] (see Figure 6).

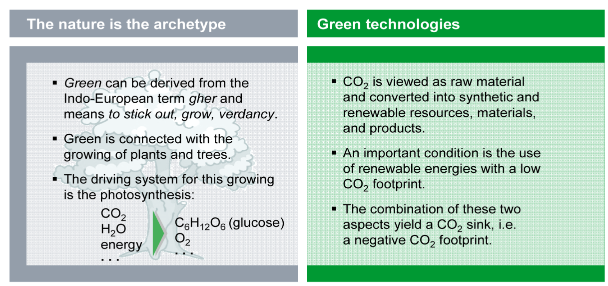

Figure 6: The two aspects of "green".

We define "green" in the sense of a "green cycle" analogously to the photosynthesis process in the vegetation, i.e. plants and trees (see Figure 6). Accordingly, any technology whose carbon footprint is negative over its life cycle is defined as a green technology. Green technologies in terms of green cycles include:

- Applying mechanisms to use and consume CO_2.
- Applying new methods to produce new raw and finished materials based on carbon (C) and CO_2.

Our understanding of "green", i.e. our proposal for an evolving Siemens AG vision can be grouped in a broader context as illustrated in Figure 7.

The first two items of the "green evolution", i.e. energy efficiency optimization and energy supply shift have already been partially attained and form the foundation of Siemens AG's environmental portfolio. The clean cycles cannot be achieved fully in any economically viable way with current environmental technologies. Today's products, which are increasingly produced from highly specialized materials and compounds are very expensive to process for material separation and recycling. In contrast, when combining environmental technologies (energy efficiency optimization and energy supply shift) with green technologies (meaning CO_2 sinks) the new green cycles offer the possibility of achieving economically viable solutions (including for clean cycles), because the materials for products and production are based on renewable hydrocarbon compounds.

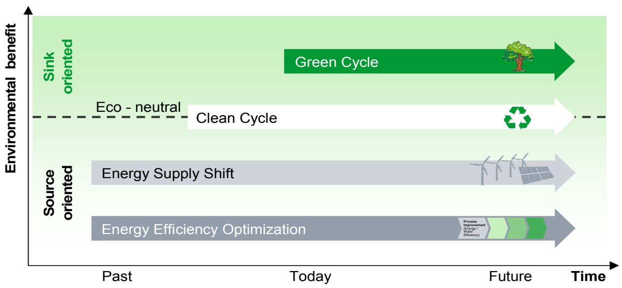

Figure 7: Grouping of green and environmental technologies and pointing out an evolutionary path to green cycles.

2.2 Green Cycle Economy

Green cycle solutions offer additional market potential, In other words, a complementary market to the existing energy efficiency optimization und supply shift markets that are drivers for current innovative products and production. Green cycles imitate natural processes from the biosphere by technical (synthetic) means. In nature, two cyclical processes are crucial: the water cycle, and the carbon cycle [18]. It is remarkable that in nature there are (almost) no heavy-metal cycles.

2.3 Green Cycle Definition

Our concept of green cycles with the chemical recycling of carbon (C) and CO_2 to synthetic hydrocarbons creates a new understanding of renewable energy usage to produce environmentally neutral carbon resources or raw materials. The hydrogen needed for the chemical processing of the carbon comes from water. The green cycle concept can utilize any form and any amount of renewable energy such as solar, wind, hydro, as well as geothermal sourced electrical energy.

It is increasingly necessary to find suitable new ways to capture, store, transport, and utilize renewable energy very cost efficient. Focusing on electric power generation clearly shows that in just a few years, renewable energy sources (primarily solar) will achieve price and grid parity with conventional energy sources like coal, oil, and nuclear [19].

The green cycle is shown in Figure 8. A considerable amount of electrical energy is needed to run the green cycle. The quantity of CO_2 fixed in a green cycle, i.e. converted from a gas to a liquid fuel can be demonstrated by an example: It takes about 8 MWh of electrical energy for water-electrolysis combined with a Methanol synthesis to fixate one metric ton of CO_2 in about 3/4 metric ton of synthetic raw material, e.g. fuels. This is equivalent to the annual power consumption of about 2000 three-person households, or the hourly production of two 4 MW wind turbines. This cycle approach generates all required aspects to shift to a 100% renewable energy economy. We call this the green energy cycle (see left part in Figure 9).

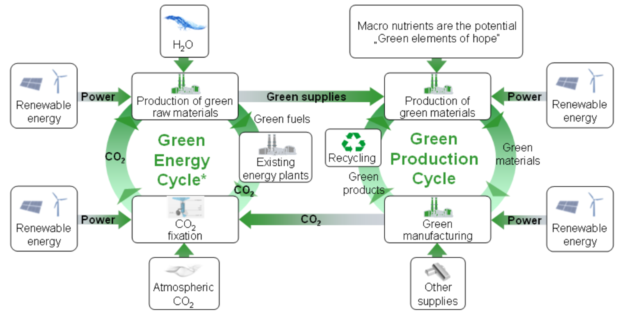

Figure 9: Green cycles.

In addition to the green energy cycle there is a green production cycle (see right part in Figure 9). The green production cycle takes hydrocarbons, oxygen, and hydrogen as well as so-called "green elements of hope" as input resources for the production of green materials and products, e.g. plastics. This green production cycle requires different ways of product design and production technologies that are focusing on molecular layers of the carbon materials and that need to be produced in these layers.

The growth of the world population and the associated consumption of natural resources yield increasingly the scarcity of materials [10],[20]. For instance the scarcity of specific metals is becoming one of the most urgent global problems, comparable with energy scarcity [10]. The peak oil situation is analogously transferable to certain mineral resources [21]. A particularly feasible approach is the substitution of scarce metal elements by most abundant elements [10]. This requires advanced engineering sciences as well as disciplines like agriculture and biosciences.

The green elements of hope are environmentally friendly and sustainable as they contain all macronutrients of life and lack heavy metals. We propose that carbon-based materials are a complementary source of interest for alternative green materials and alternative production processes.

2.4 Green Factories

A green factory is a plant that has no negative impact on the global or local environment, i.e. a production site or a network of productions that attempt to meet the triple bottom line of the sustainability definition of the Siemens AG [3]. Green factories focus on environmental and economical targets. In general, business is described as green if it matches the following four criteria:

1. It aims to supply environmentally friendly products or services that replace demand for non green products and/or services.
2. It uses high energy efficiency solutions in all of its business processes.

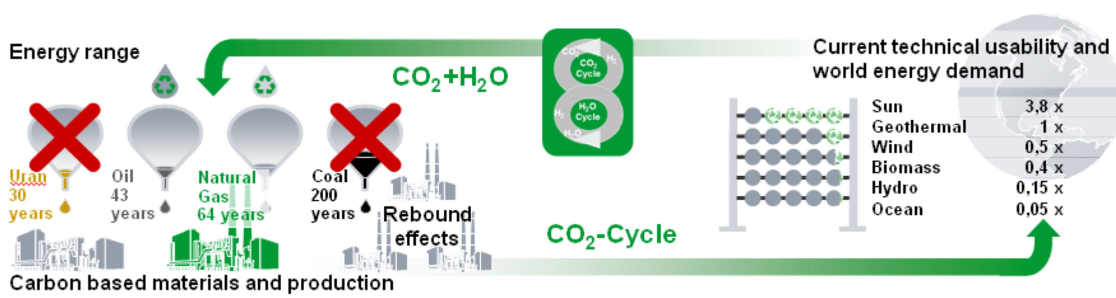

Figure 8: Green cycle economy.

3. It uses mainly renewable power and supplies based on renewable energy.
4. It emphasizes on the implementation of recycling of heat, water, and energy supplies of the factory.
5. Green factories use exhaust gases like CO_2 as a resource.

The green factory supports to meet the needs of the present world without compromising the ability of the future generations to address their own needs [3],[22]. It emphasizes the transformation process of achieving the design of products and production processes that use the advantages of carbon, hydrogen, oxygen, and additional green elements. The most important elements of a green factory are depicted in Figure 10. These are renewable, CO_2-neutral electrical energy sources, suitable production processes and facilities, and additional chemistry processes that enable the recycling.

2.5 The Evolution of Green Factories

The concept of “green factories” is to be achieved on an evolutionary path as illustrated in Figure 7. Tree fundamental stages of evolution can be described. Each stage is essential for the next stage in the overall concept.

The first stage is the energy efficiency optimization. This covers the current activities regarding production, logistics, buildings, etc. The main goal of energy efficiency optimization is to use the limited energy resources more effectively. Since efficiency optimization processes in general are a key driver for economic growth and improved competitiveness of companies operating in global markets, the existing methods form a basis for evolutionary extension of these processes, methods, and solutions for the new and additional aspect of energy. The methods and solutions aim at emitting less CO_2 than comparable predecessors while guaranteeing similar product and operation performance compared to the not energy optimized solutions. However, the goal of zero CO_2 emissions at reasonable costs cannot be reached by these approaches (recall Figures 5 and 11).

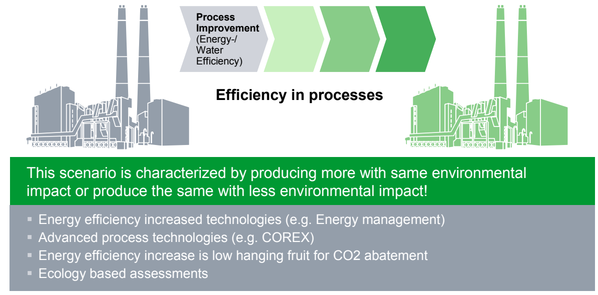

Figure 11: Energy efficiency optimization.

The second stage is the energy supply shift. Shifting to renewable energy means primarily to switch the factory electricity supply with the related purchasing processes from fossil thermal power plants to renewable power plants. The aim is a complete replacement of the energy input by renewable energy sources and adequate decentralized grid technologies (see Figure 11). All aspects of renewable energy production and stable supply of factories including the distribution, the storage, and the demand response issues need to be addressed here [23].

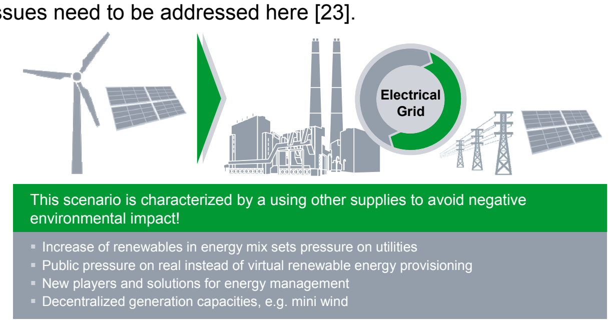

Figure 12: Supply shift.

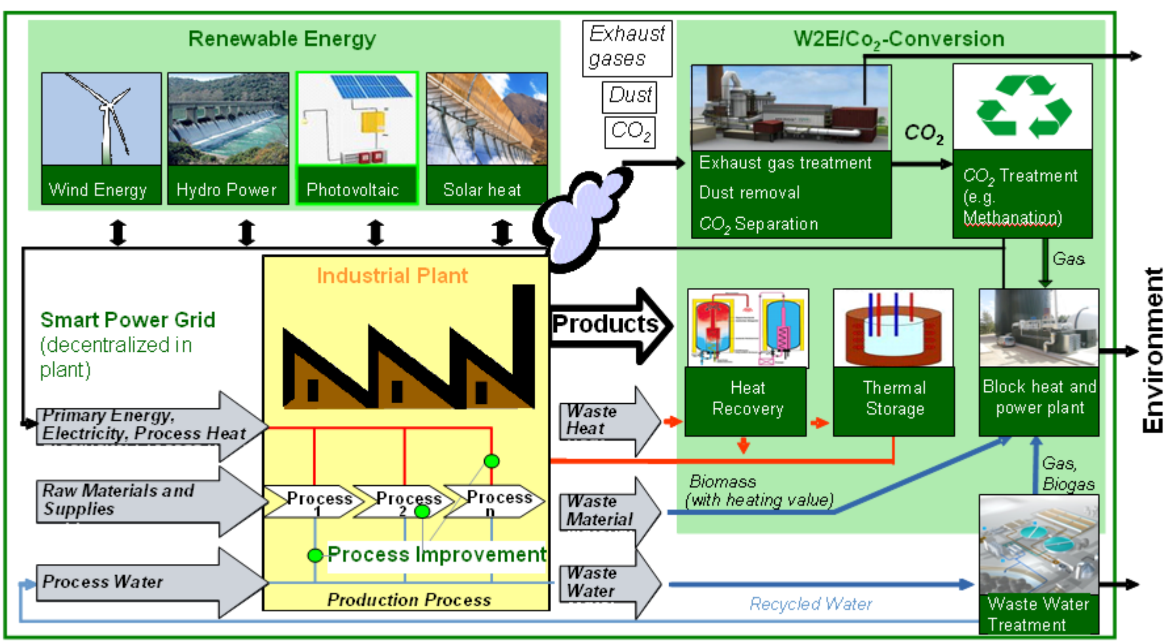

Figure 10: Green plant elements.

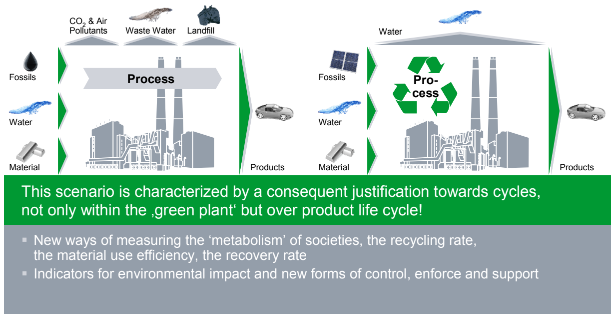

Figure 13: Clean cycle.

The third stage is the clean cycle (recycling processes). The goal is to generate few or no waste products outside the production processes (see Figure 12). In terms of today's limitations of the environmental technologies, productions, and products, clean cycles cannot be fully achieved in an economically feasible way, except for certain areas like the waste water treatment.

The fourth stage is the green cycle factory. It is based on synthetic imitation of natural processes from the biosphere, i.e. plants and trees. It combines technologies that provide a negative CO_2 footprint over their whole life cycle and thus form the technical core of a green cycle production.

Raw materials as well as energy carriers are synthesized from carbon (C) sources like CO_2, using renewable electricity. Synthesized energy carriers, such as artificial natural gas (methane), are used for storing and transporting energy until the production processes take place, transferring carbon based raw materials into products. Figure 14 illustrates how to create a green energy cycle. The following development path characterizes green cycle plants:

- The electrical energy to maintain the cycles comes entirely from renewable, CO_2-neutral energy sources.
- The water from the atmosphere (assuming certain purity) is split into hydrogen and pure oxygen.
- The resulting hydrogen is enriched with the CO_2 from industrial waste products, processes, or best of all in long-term directly from the atmosphere [24]. It is used to produce hydrocarbon compounds.
- The hydrocarbon compounds are used, among other possibilities, for the petrochemical industry, new carbon industries, e.g. to produce new materials like carbon-fiber composites, and to generate green fuels, like methane and methanol.

An example is given by the Island based company Carbon Recycling International, which shows that this can already be achieved cost-effectively today assuming specific energy and raw-material cost situations [12]. Another example is the "CO2rrect" project (CO_2 reaction using regenerative energies and catalytic technologies) from Bayer AG, Bayer MaterialScience AG, Siemens AG, and other partners. Yet another example is a Bayer AG pilot plant at the Leverkusen chemical park that uses CO_2 as a chemical intermediate product in the polyurethane production (an intermediate product for producing plastics).

Furthermore, hydrogen can be used in a large industrial scale, for steelmaking processes like COREX. However, this application is not part of a Green Cycle.

There will be also new possibilities for producing clean water, an important raw material for the entire Green Cycle.

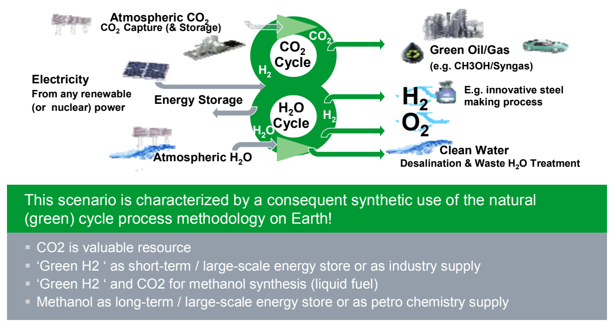

Figure 14: Green Cycle.

Not only raw materials, but also emissions and wastes become more expensive as the international Trading Scheme for emission and waste matures [2]. In the first phase green cycle factories will be in the position to derive revenues from the carbon credit and renewable fuel markets, e.g. since green methanol [12] has higher margins that fossil based methanol.

3 CONCLUSION AND OUTLOOK

A systematic approach to define green technologies and to point out an evolutionary path that structures environmental and green technologies related to production is presented.

The developed green vision offers economically attractive new areas of market potential that opens new opportunities for green products and green production under the assumption of renewable energy supply as the main supply for energy.

The existing plants and even fossil power generation plants can be well integrated in the novel concept in an evolutionary way so that existing infrastructure can still be utilized. The goal to achieve zero emission plants in an economical feasibly way requires a paradigm shift from primarily fossil and/or metal based products to carbon based products including the necessary new production processes. However, the existing product and production technologies and solutions play an important role during the green transition process so that only economical green technologies will be considered at each development stage. Green fuels are among the first products to be considered. CO_2 fixation is a goal that might not be economically feasible at the beginning of the green transition. Rather other carbon sources from existing plants and factories will be the first carbon suppliers. The increasing speed of renewable energy technologies and renewable supply supports the green transition process and sets the transition speed.

The authors recommend investigating the green areas further, in particular in terms of the consequences for the production.

4 REFERENCES

[1] Sekretariat der Klimakonventionen (Ed.) (1997): Das Protokoll von Kyoto zum Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen, http://unfccc.int/resource/docs/convkp/kpger.pdf, accessed 11.12.2011.

[2] Müller, E.; Engelmann, J.; Löffler, T.; et. al. (2009): Energieeffiziente Fabriken planen und betreiben, Berlin Heidelberg: Springer.

[3] http://www.siemens.com/about/en/index/strategy.htm, accessed 11.11.2012

[4] International Energy Agency (2010): World Energy Outlook 2010, IEA Publications, 2010.

[5] IPCC (Ed.) (2007): Climate Change 2007: Synthesis Report, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf, accessed 22.11.2012.

[6] European Commission (2007): World Energy Technology Outlook - 2050, Office for Official Publications of the European Communities.

[7] http://www.berlin-institut.org/online-handbuchdemografie/bevoelkerungsdynamik/auswirkungen/bevoelkerungsprojektionen.html, accessed 21.10.2011.

[8] GLOBAL 2000/SERI (Ed.) (2009): Ohne Mass und Ziel? Über unseren Umgang mit den natürlichen Ressourcen unserer Erde, in: http://old.seri.at/documentupload/SERI%20PR/ohne_mass_und_ziel--2009.pdf, accessed 16.10.2011.

[9] Binswanger, M. (2001): Technological progress and sustainable development: what about the rebound effect?, Ecological Economics, Vol. 36, p.119-132.

[10] Diederen, A. M. (2009): Metal mineral scarcity: A call for managed austerity and the elements of hope, in: http://www.tno.nl/downloads/Metal_minerals_scarcity.pdf, accessed 22.11.2012.

[11] McKinsey & Company Inc. (2007): Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland. Study by McKinsey & Company for BDI initiativ – Wirtschaft für Klimaschutz, Berlin.

[12] http://www.carbonrecycling.is, accessed 24.11.2012

[13] http://scrippsco2.ucsd.edu/data/atmospheric_co2.html, accessed 21.10.2011.

[14] Tans, P. (2010): Trends in Atmospheric Carbon Dioxide. www.esrl.noaa.gov/gmd/ccgg/trends, accessed 18.01.2010.

[15] Held, T. M.; Kriegler, E.; et al. (2008): Tipping elements in the Earth's climate system, Proceedings of National Academy of Science of the United States of America, Vol. 105, No. 6,

[16] http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/016.htm, accessed 18.12.2011.

[17] Pfeifer, W.; et al. (2004): Etymologisches Wörterbuch,dtv, Munich.

[18] Olah, G.; Goeppert, A.; Surya Prakash, G. K. (2009): Beyond Oil and Gas - The Methanol Economy, 2. Edition, Weinheim:Wiley-VCH.

[19] Nitsch, J.; Pregger, T.; Scholz, Y.; et al. (2010): Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung und Europa und global - „Leitstudie 2010"; http://www.bmu.de/files/pdfs/allgemein/application/pdf/leitstudie2010_bf.pdf, accessed 07.03.2012.

[20] http://www.berlin-institut.org/online-handbuchdemografie/bevoelkerungsdynamik/auswirkungen/bevoelkerungsprojektionen.html, accessed 21.10.2011.

[21] BP (2011): Energy Outlook 2030, in: http://www.deutschebp.de/liveassets/bp_internet/germany/STAGING/home_assets/assets/deutsche_bp/broschueren/broschuere_bp_energy_outlook_2030_dt.pdf, accessed 19.12.2011.

[22] Anderson, D. R. (2006).: The critical importance of sustainability risk management, Risk Management. Vol. 53, no. 4.

[23] Fischer, J.; Rohrmus, D.; Weinert, N. (2012):Investigation on adapting production strategies for a Smart Grid environment, Proceedings of the 10th Global Conference for Sustainable Manufacturing, Oct. 31st – Nov. 2nd, 2012, Istanbul, Turkey, p. 611-616.

[24] Lackner, K. L. (2009): Capture of carbon dioxide from ambient air, The European Physical Journal Special Topics, Vol. 176, p. 93 – 106