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Zero emissions future city

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1. Introduction

1.1 Some principal questions

It is necessary to reduce CO₂ emissions against global warming, and the activities are expanding all over the world. As the world continues its reliance on fossil fuels to meet its growing energy demand, the associated environmental and climate change challenges must be adequately addressed. The world is undergoing the largest wave of urban growth in history and this process is mainly a domain of developing countries. In Europe over 70 percent of population is urban. In many developed countries this concentration is also creating its counterforce: decentralization, urban sprawl, dispersal and splintering of urban space. According to the United Nations reports, the growth in human population is largest in the developing world, with Africa's and Asia's urban population projected to double between 2000 and 2030. With approximately 3.4 billion people (in 2009), more than 50 percent of the world population living in cities and both human activities and the use of energy also concentrated in cities, the urban areas have become the root cause of orientating societies toward mass production, mass consumption and mass dumping of waste. In the world-wide urbanization process a particular significance have *mega-cities* (i.e. metropolises with more than 5 million people). According to the UN reports (Kraas, 2007), in the year 2015 more than 600 million people will be living in about 60 mega-cities worldwide, see Fig.1. While megacities have captured much public attention, most of the new growth will occur in smaller towns and cities, which have fewer resources to respond to the magnitude of the change. Urban areas sprawl deeply into regions surrounding cities and towns. Increased income and wealth has enabled extensive new construction of infrastructures and transportation within functional urban regions.

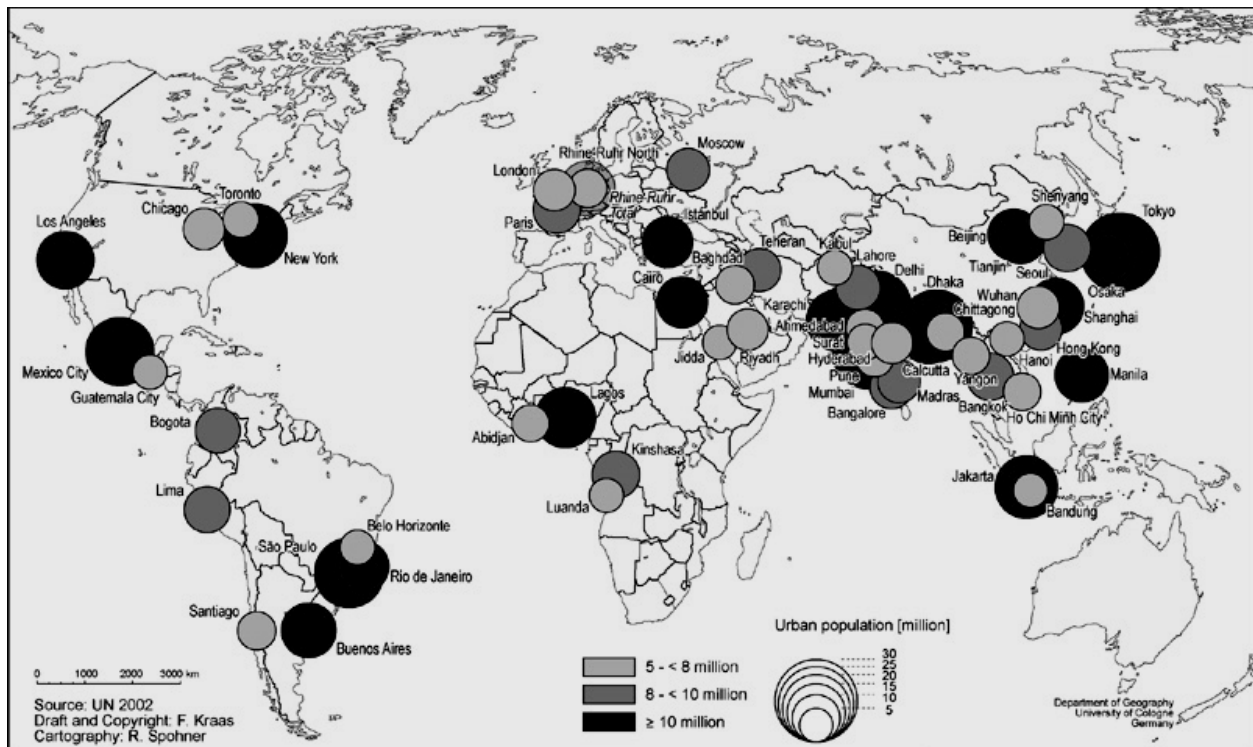


Fig. 1. World-wide urbanization: megacities in 2015

Since all sorts of human activities are concentrated in the city, it is essential to conduct such a reassessment from many viewpoints. This is why an interdisciplinary study approach has been expected, involving researchers in the fields of cultural and social sciences, to study the human and social aspects of local environmental changes such as human activities and lifestyles. In addition, researchers in the areas of natural science and engineering have been working to solve environmental problems and studying technical responses.

Many environmental problems have occurred in cities. The urban concentration of population, energy and information has expanded activities in cities beyond its limit. Because of this, the heavy car traffic in urban areas has brought about air pollution, noise and vibration. Attempts to make the most effective use of land have resulted in the cutting of trees and decreased open space. Rivers in the urban areas have been turned into culverts to secure safety and convenience in cities. A massive daily output of waste from city activities has been carried to neighboring municipalities or faraway places if required, because of the difficulty of finding sanitary landfills in the city areas.

1.2. Sustainable Development Dilemmas

In the *Brundtland Report* (WCED, 1987) alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. Published by an international group of politicians, civil servants and experts on the environment and development, the report provided a key statement on *sustainable development*, defining it as: *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. This Report laid the groundwork for the convening of the Earth Summit in Rio de Janeiro five years later. There is no doubt about the necessity of improving our societies to sustainable ones in the

beginning of this century. In order to build a sustainable world for the future, it will be necessary first to develop better models for cities, taking into account the multidimensional contributions of science and engineering, politics and social sciences, and many other fields for designing the improved cities of the future. City organization will have to drive our ecological efficiency as a species. Put simply, cities offer the best chance we have of minimizing our ecological impact.

In order to solve global environment problems such as global warming caused by human activities, it is necessary to change a society of heavy energy consumption to a recycling oriented society where thorough measures are implemented to save energy and resources. Founded in 2005, the *European Technology Platform for Zero Emission Fossil Fuel Power Plants* is a broad coalition of stakeholders united in their support for CO₂ Capture and Storage (CCS) a key technology for combating climate change. Indeed, if implemented without delay, CCS can reduce CO₂ emissions in the European Union by 400 million tonnes a year by 2030 even before its full potential is realized. CCS can be therefore the most effective measure for reducing European CO₂ emissions after energy efficiency and renewables. These citations show the great plans of EU in the field of *Zero Emission Power Plants* (ZEPP) developments. Not less ambitious plans are in USA and worldwide. ZEPP creation is very important to prevent the global warming and climate change. But not less or even more important is the problem to eliminate emissions of other (disseminated) sources of atmospheric emissions. For that matter is needed a programme of a complex solution, the creation of *Zero Emissions City* (ZEC). The paper is aimed at describing of the main elements of such a program, bearing in mind all the air polluters of our cities. It might be solution to the problem of violation of our human right to breathe. Along with fuel-fired power plants such polluters are industry, vehicles, heating of dwellings and incinerators.

2. Transportation Systems and Vehicles

2.1. Municipal Transportation

Over the next three decades, virtually all of the world's population growth is expected to be concentrated in the high level population urban areas (so called "megacities") in the developing world. According to the World Bank data (2008), these urban agglomerations in most rapidly developing countries account for at least 50 percent of the GNP, but this economic growth tends to accelerate the urban transportation problems. Without any doubt, a well-managed transportation system of a thriving metropolis makes the city functional. It is also the critical link between productive activities and almost all the town services.

2.2. Vehicles and Emissions

The fleet of half billion of piston engine -driven vehicles is a big and dangerous polluter. In favour of ZEC the well known old vehicle- electrical car is now within sight. The first in the world electrical car has been demonstrated by *Siemens* in 1896. However the batteries of that time were too weak to compete with such genial invention of the same year – the diesel piston engine. In hundred years the diesel engine had changed insignificantly, its main elements now are the same as by invention. However gradual success in electrochemistry lets develop the very compact batteries on *NiCl-Ni* process and even better the *Li-ion* accumulators. Many major automakers are demonstrated electrocars (*Mercedes, Toyota, General Motors* a.o.).

2.3. ZEMPES Concept

If for any reason the electrical car use is impossible or not justified economically there exists a possibility to build a *Zero Emission Membrane Piston Engine System (ZEMPES)*, see Fig.2 and Fig.3, (Yantovski et al, 2007, Ch.7). Here is used ordinary fuel, combusted in a piston engine just as in ZEPP in the mixture of oxygen and carbon dioxide. Oxygen produced from air, being separated from air in ceramic membrane reactor, whereas CO₂ is stored onboard and discharged in a central big tank on filling station.

In the scheme, Fig.3 presented there is no supercharger as the power is increased without pressure elevation in the piston engine. The turbocompressor is actually used to feed the ITMR with compressed air, which enhances the oxygen flux. The total system consists of two loops: the main closed loop 1-2-4-5-6-7-1 and an auxiliary loop 18-19-23-24. Fuel enters the mixer at 11, air is taken from the atmosphere at 18 and oxygen is transferred from heated compressed air in the AMR to the mixer at 28 and 29. The combustible mixture at 1 enters a cylinder of VM, is ignited by a spark and produces mechanical power. The auxiliary turbocompressor supplies compressed air to AMR and gives additional power through clutch KU. The sum is effective power N_e . Carbon dioxide with dissolved contaminants is deflected from the cycle at 9 to be discharged at a filling station and then sequestered.

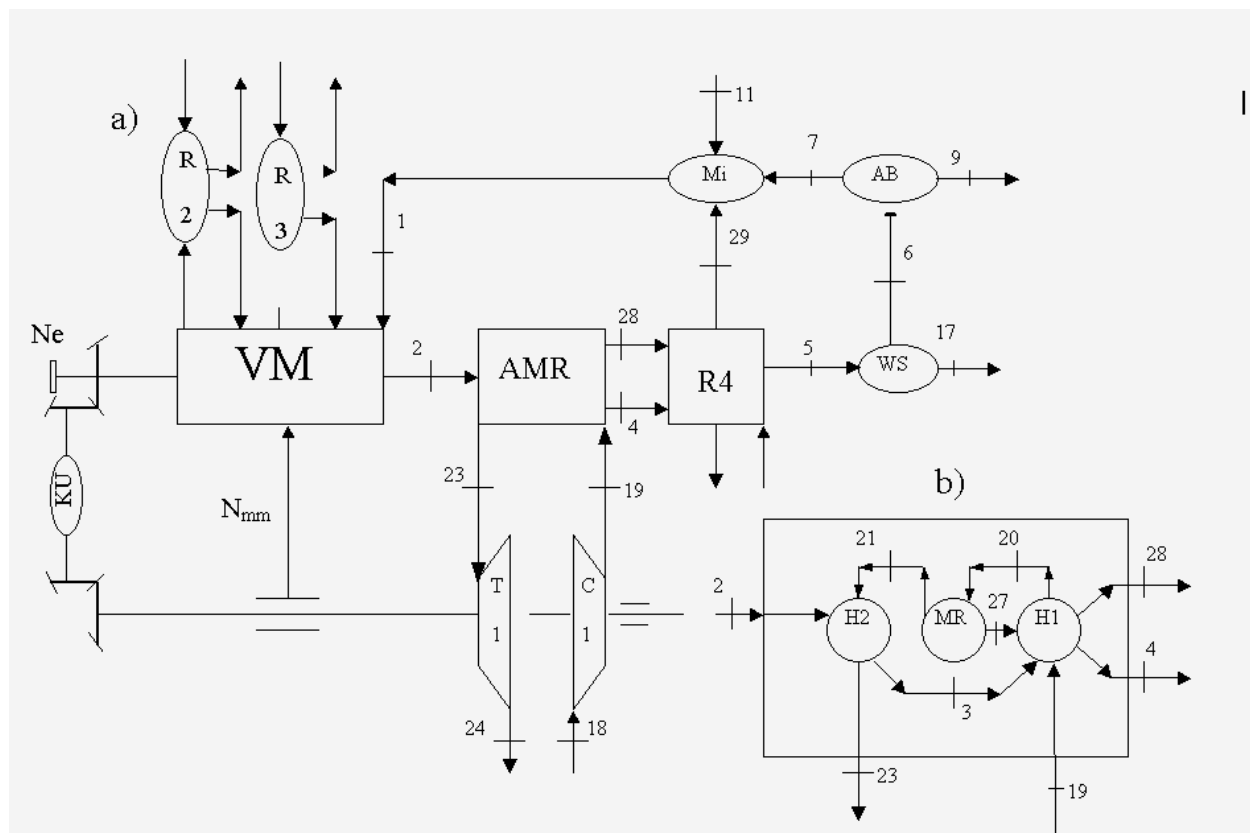


Fig. 2. Schematic of the ZEMPES with oxygen enrichment of an "artificial air" (O₂ + CO₂).

Symbols: AMR – ion transport membrane, VM – piston engine, N_e – effective power, R – radiator-cooler, WS – water separator, AB – splitter, Mi – mixer, KU – clutch, N_{mm} – heat flow from mechanical losses of turbocompressor. /Numbers reflect the node points/.

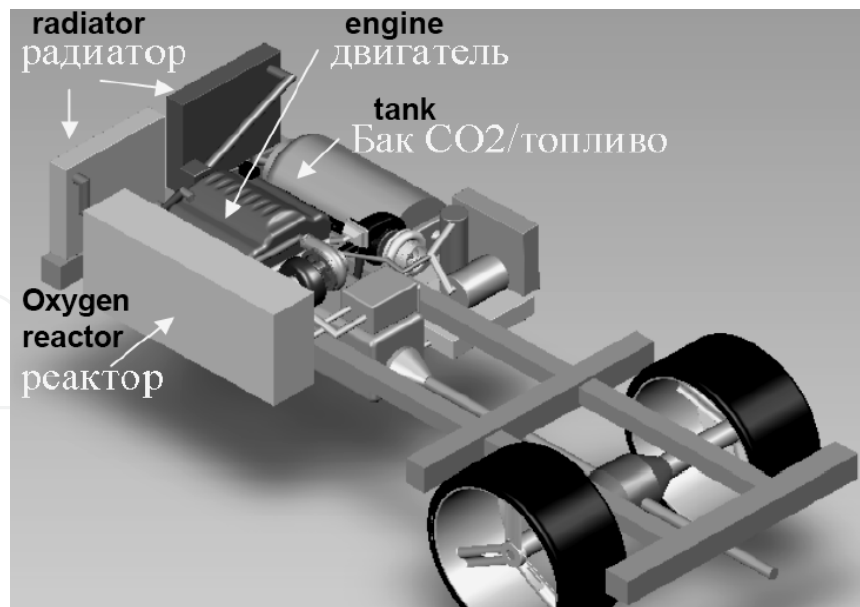


Fig. 3. ZEMPES outlook for a bus on compressed methane

This recently patented concept engine has been firstly proposed as a prime mover for an advanced “Zero emission bus” engine.

3. Heating and Cooling of Dwellings

3.1. Building and Household Energy

All buildings are individual from the energy consumption point of view. This is because each building has a unique combination of structure, occupation and local micro-climate conditions. Buildings account for 41 percent of the EU's total energy use and are Europe's largest source of emissions, so improving their energy performance would help reach CO₂ emission goals. The estimated potential of about 20 and 60 percent of the present energy consumption in this sector could be respectively saved by 2020 and 2050. To translate this potential into reduced energy consumption, the Energy Performance of Buildings Directive (EPBD) 2002/91/EC is intended to promote the improvement of energy performance of buildings. The same manner, the household sector, responsible for about 15 to 25 percent of primary energy use in OECD countries and for a higher share in many developing countries has been forced to an implementation of new rules for the energy labeling procedures. It should be added that our stock of household appliances is still far less energy efficient than would be economically optimal.

The major unknown factors in the space heating demands are the indoor temperatures used and national averages of hot water consumption. Based on the results of *Ecoheatcool* project (2005-2006), the most valuable measures to distinct the weather condition and average specific demands for the space heating and cooling in different regions of EU have been formulated. These two parameters: *European Heating Index* (EHI) and the *European Cooling Index* (ECI) are shown in the Figs.4a and 4b. A new European heating index (EHI) has been introduced in order to explain the geographical distribution of the average specific space heating demands in the European countries.

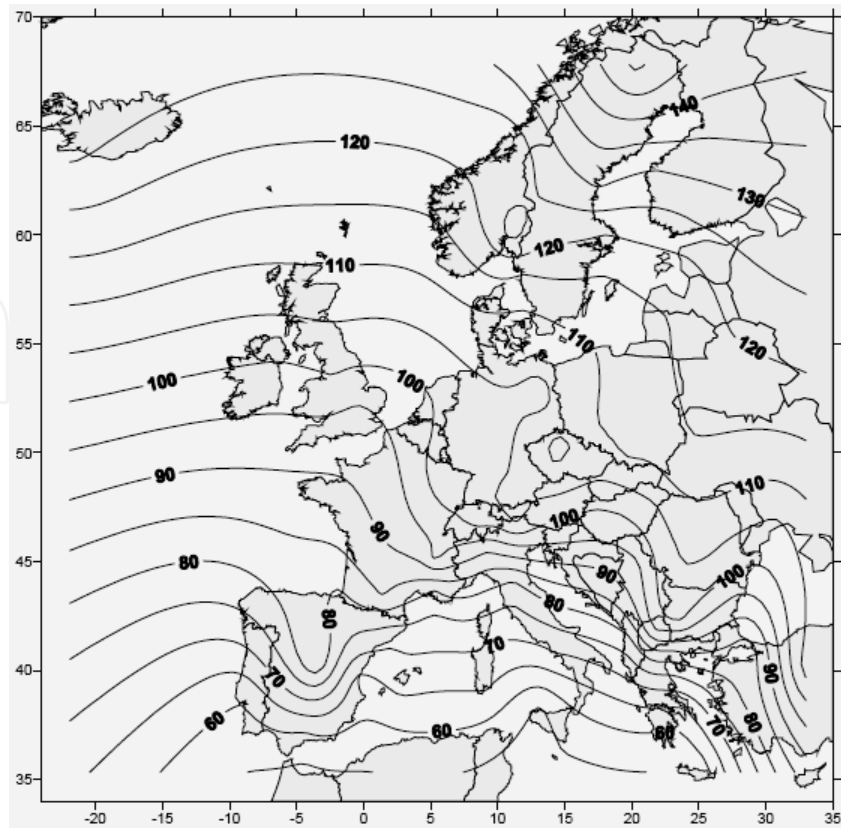


Fig. 4. a European heating index (EHI)

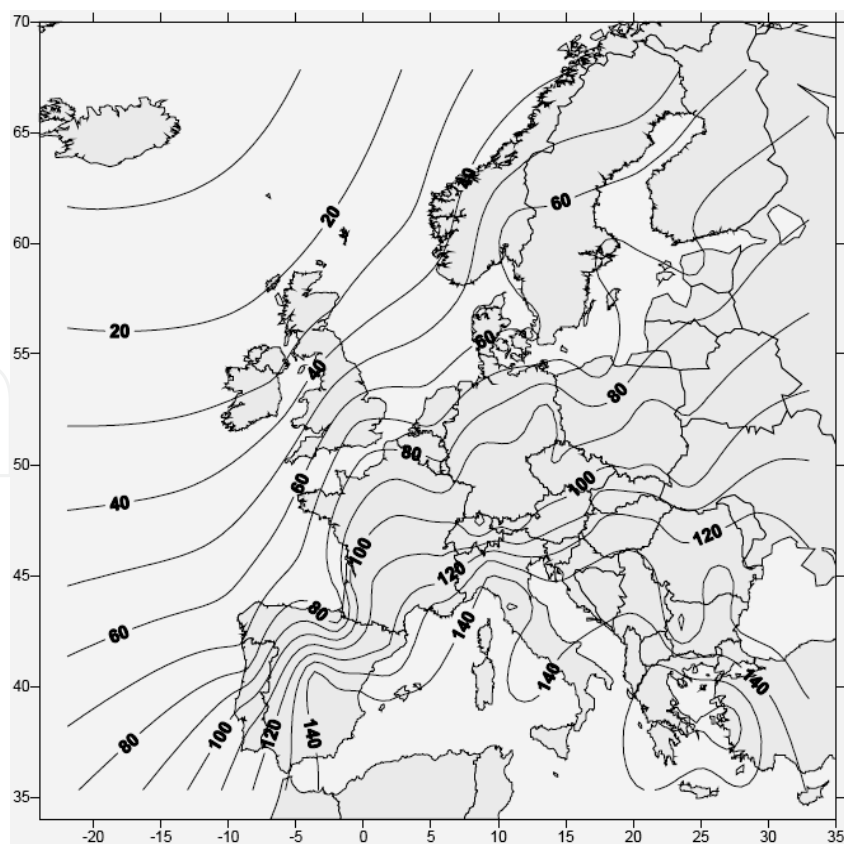


Fig. 4. b European cooling index (EHI)

A market of heat supply systems was developing by many ages. The ancient Romans using "hypocausts" for distribution of flue gases below floors in buildings managed the first more organized space heating (see, Wikipedia). In the middle of XIX century *William Thomson* (afterward *Lord Kelvin*) had claimed that he can heat our dwellings (even in rather cold Scotland) using only 3% of firewood by a "heat multiplier" in comparison with ordinary stove. He offered the use of machinery: to expand air with work production and air cooling below ambient air, then to heat this air by ambient air through appropriate heat exchanger, then to compress this air to the normal or slightly higher pressure by a compressor having temperature high enough for a dwelling. As work of compression exceeds the work of expansion the additional work is needed to drive compressor. But amount of this additional work so small that it is equal about 3% of energy income into dwelling due to much heat from ambient air.

This brilliant idea was considered as an unrealistic dream about half a century. Then it was materialized in the two large industrial branches: cooling machines and heating machines (the last are called "heat pumps", HP). The only change from the first idea was the use a special low-boiling fluid "Freon", instead of air in a closed loop. In some cases it might be the carbon dioxide either. Now in the world exist tens of millions small heat pumps, taking low-grade heat from ambient air (as it was mentioned by inventor) or from the ground, the layers some meters below the heated building. As usual their compressor is driven by an electric motor, which makes it very good for the ZEC concept. Due to accepted ambient heat the electrical energy is about 30% of the delivered heat to dwelling. If to use direct electric heat for the same matter the 100% of electrical energy is needed. That is why the direct electrical heating of dwellings is considered as barbarism and is admitted in rare special cases. If a ZEC prefers the district heating, there the heat pump stations (HPS) should be used with powerful HP of about hundred megawatts, taking heat from a near water basin, like a sea or river. An example is one of many Swedish HPS, taking heat from *Botany Bay* (2 °C in the winter).

3.2. District Heating and Cooling

Typically a district energy system provides thermal energy in the form of hot water or steam from a central heat-generating plant, distributing the energy through the pipe system to the end-users. District energy systems are retrofitted to comply with the new country and EU regulations. These systems have a big potential to be important part of evolving strategies for global climate change. Projections of district energy future are possible with the use of energy consumption forecasts and trend setting concepts involving: cogeneration and trigeneration, geothermal and waste heat systems, renewable energies, gas turbines, fuel cells, chillers, and carbon capture.

In the next Fig.5 (IEA-DHC, 2002) is presented the recent approach how to use heat pumps technology to adaptation to cool dwellings, if needed. In European climate this equipment is in work all year-round, replacing many small air conditioners and boilers .

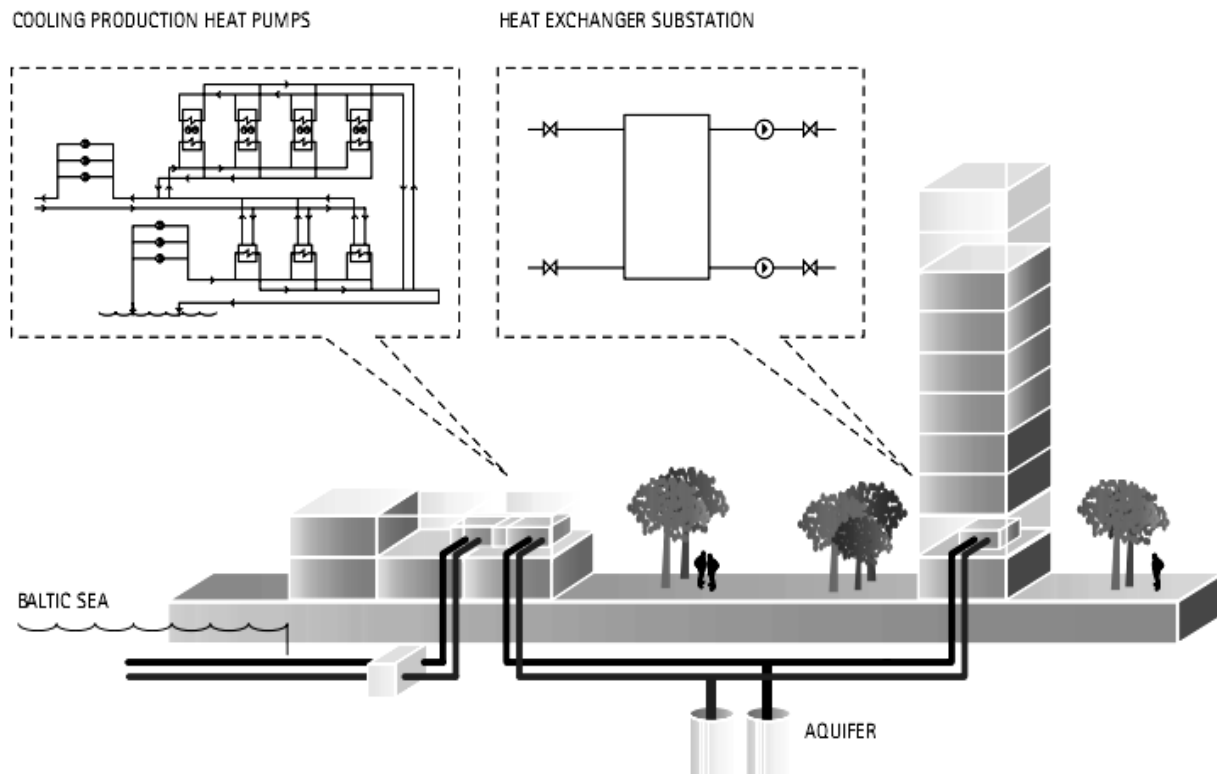


Fig. 5. District heating and cooling (DHC) heat pump station

This modern district heating and cooling (DHC) system is operating by using water of Baltic Sea as low-grade heat source and gives an example of efficient zero emissions climatization in large cities near to the shore heat pump station. It should be mentioned, that an input of secondary and renewable resources to the district heating and cooling systems can replace mainly fossil primary energy supply (coal and oil). Hence, more district heat in the European energy system will generate more electricity in CHP plants, extend the use of renewable resources, and reduce the final demand of natural gas and fuel oil.

3.3. Zero Emissions Power Plants

The domination of fossil fuels in the energy supply of this Century is seen from the *World Energy Forecasts of International Energy Agency (IEA, 2004)*. Only to the very end of the Century might be implemented Renewable energy in massive scale. The ZEPP are unavoidable for many decades as a bridge to that time.

Among many schematics, including the first one by *C. Marchetti (1979)* the most popular is "Oxy-fuel" one, with combustion of arbitrary fuel in the artificial air, the mixture of oxygen and carbon dioxide, recirculated to be mixed to oxygen from an air separation unit. First experiments of combustion of coal powder in CO₂ and oxygen belongs to *A. Wolsky (1985)* in *Argonne National Lab.*, see *Foy and Yantovsky (2006)*. The first in the world brown coal-fired ZEPP of 30 MW commissioned 9-th October 2008 by *Vattenfall* in Germany. Due to successful test it in a year (*Rolland, 2008*), it is worth to be depicted in Fig.6.

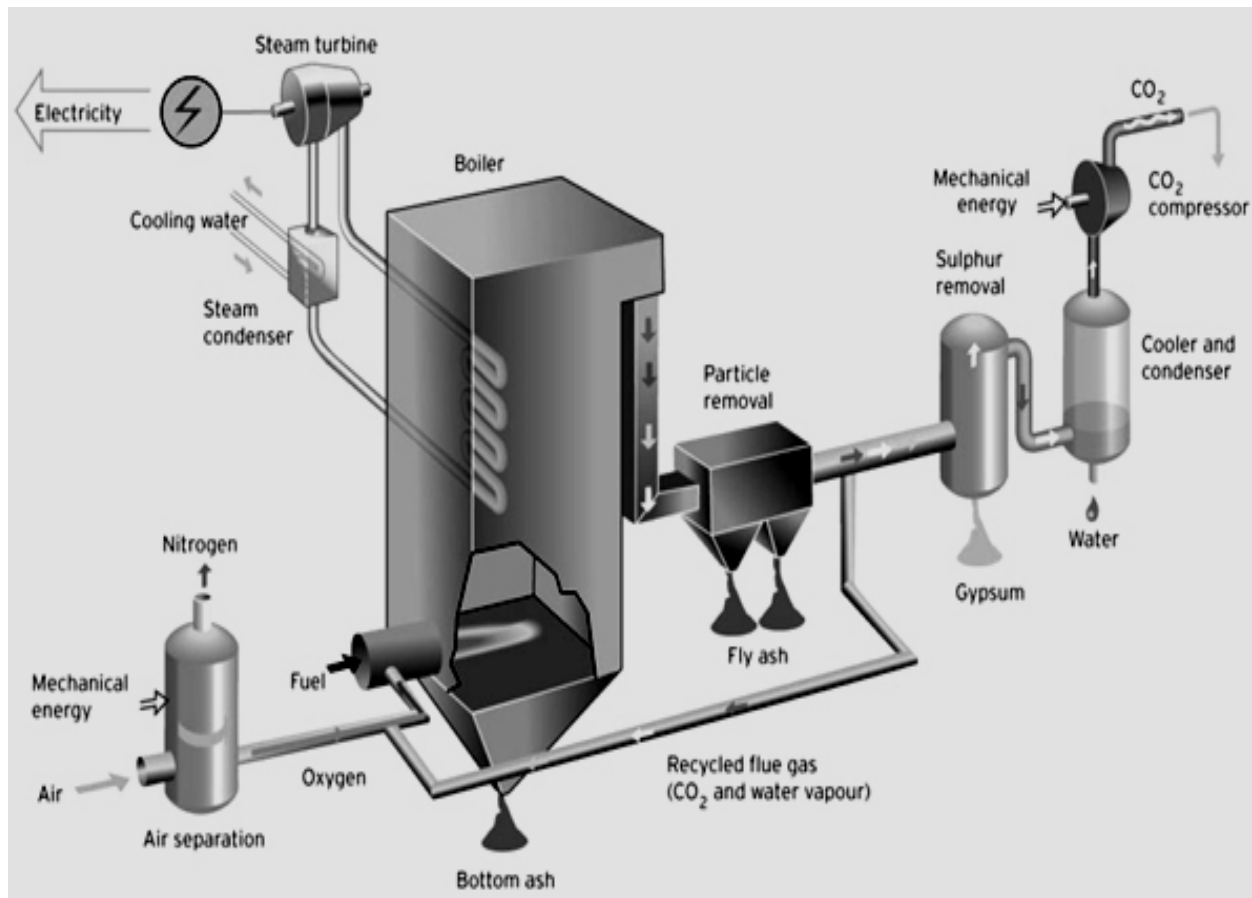


Fig. 6. Schematics of the first ZEPP coal-fired power plant of 30 MW by Vattenfall

4. Municipal Wastes Treatment

4.1. Solid Wastes Incineration

Worldwide population growth, urbanization, technological development and growing economic activity generate large quantities of waste. Since the waste streams contain sometimes the raw material and energy resources, waste management decisions must be tied to their conservation, recovery and utilization issues (recycling). Space for landfills has been plentiful in the past, but is becoming harder to find in large urban areas. Recycling programs have reduced the amount of matter going into landfills, but combustion may become more viable in some urban areas where the landfill sites become scarce or if energy prices make combustion more economically viable. The combustion of municipal wastes is extremely detrimental for atmosphere due to very dangerous combustion products. Some wastes contain the plastic materials with Chlorine, heavy metals and others; giving poisonous exhaust gases with very toxic dioxins and furans. However, burning waste at extremely high temperatures also destroys chemical compounds and disease-causing bacteria. Even after many stages of cleaning the discharge of incinerators into atmosphere is harmful and the problem of *Zero Emission Incinerator (ZEI)* is still very urgent and difficult. The best way seems to be the combining of an incinerator and ZEPP, proposed by *Yantovsky* (1998). Well known are incinerators with rotary kiln, see Fig.7.

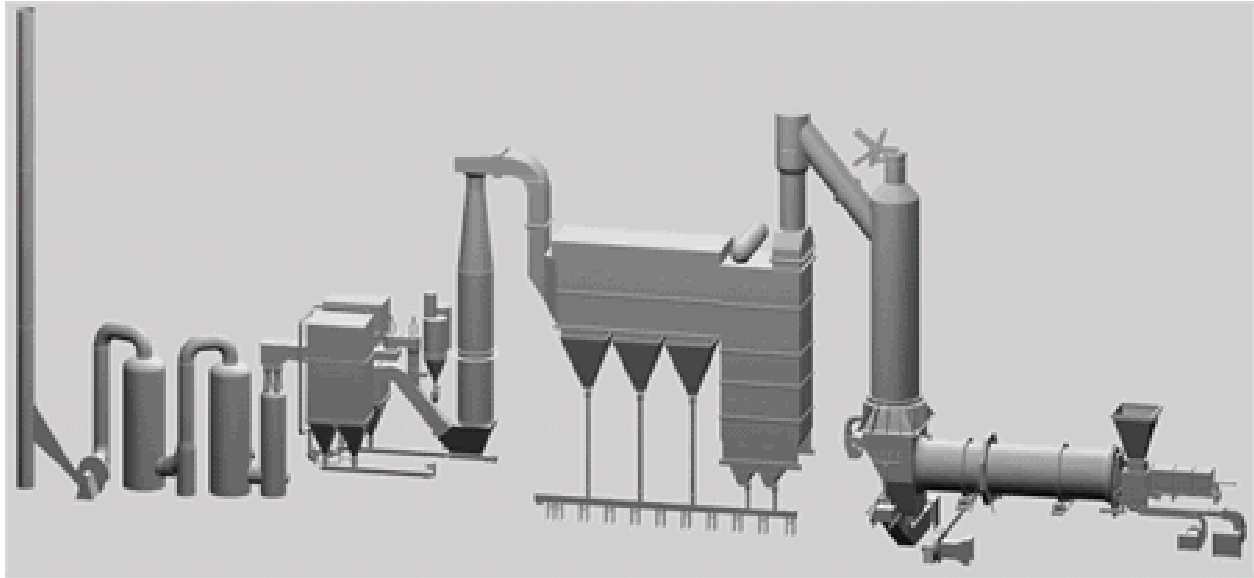


Fig. 7. Schematics of a rotary kiln incinerator

Rotary kilns provide long retention, good thermal isolation, and because of the rotation excellent bed rollover. All systems are configured for continuous operation and can have many types of waste streams such as: boxed, containers, drum, and shredded. In this schematics the total flow goes from right to the left, rotating kiln is almost horizontal cylinder, and after some cleaning reactors the exhaust gases are going through a vertical stack upward into atmosphere. Just this is a sore point, inadmissible for ZEC. Looking at a coal-fired ZEPP (Fig.7) we see that if combustion in rotary kiln is in "artificial air", (a mixture of recirculated gases with oxygen), the incinerator might become Zero Emissions just like coal-fired power plant. It is a possible matching, giving ZEI. Rotary kiln here plays the role of combustion chamber of the boiler of power station. This equipment, with corresponding post-combustion chamber is a universal unit, a proven and versatile process for the incineration of solid "hazardous waste". All the poisonous contaminants of exhaust gases are dissolved in the liquefied carbon dioxide and sequestered in depth without harm.

5. Energy System of Zero Emissions City

5.1. Environmentally Sustainable Society

Without any doubts we can tell, that for humans to live sustainably, the Earth's resources must be used at a rate at which they can be replenished. From the global point of view the sustainability is a state of balance between resource and the regenerative capacity of the earth.

An environmentally sustainable society satisfies the basic needs of its people without depleting or degrading its natural resources and thereby preventing current and future generations of humans and other species from meeting their basic needs. During the preparatory meetings for the URBAN21 Conference (*Berlin, July 2000*) the following definition was developed to define sustainable urban development: *"Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations. A burden which is the result of a reduced natural capital and an excessive local debt. Our aim is that the flow principle, that is based on an equilibrium*

of material and energy and also financial input/output, plays a crucial role in all future decisions upon the development of urban areas." However, many more definitions can be very easily found in the all open sources.

5.2. Zero Carbon Future Town

Many scientists and politicians now throw around the terms "zero-carbon economy" or "low-carbon society", not explaining the tools and introducing not well-defined conditions to achieve these goals.

As problems of industry and incineration are not still elaborated enough, here is presented schematics for a city without them, see Fig.8. The main energy system of this "Zero Emission City" will be operating with the carbon dioxide capture and sequestration at the Oxyfuel ZEPP. The public city-bus transportation is equipped with modern and ultra-low emissions engines (ZEMPES), small electrical/fuel-cell cars. It will be mentioned that the oxy-fuel combustion takes place in ZEPP and ZEMPES with nearly zero emissions. In Fig.8 (see, *Yantovsky and Gorski, 2008*) the only emission is water vapour from cooling tower. Any stack is absent.

Individual domestic heating systems should apply the geothermal or water/air heat pumps, biomass boilers and solar panels (thermal and PV's), depending on the local weather conditions and resources. Each house represents the highest level of EPDB class and displays its zero-carbon energy certificate.

All household appliances and electric lighting bulbs are energy-save systems (A++ units) and can be connected to the central control processor, integrating the internal system operation (especially for cold and hot water closed loops, and the ventilating air circulation with the heat recovery).

The urban-drainage and sewage systems are capable for selection of recoverable liquid components and catch some poisoning substances. All solid wastes and garbage are initially segregated, and partially incinerated or recycled.

Local travel, as a principle is covered by public bus and light tram transportation network, bicycle paths and walkways (close to riverside). The majority of private cars and taxis are electric. The community centre with the offices, sport and cultural halls will be easy and fast accessible by public routes.

The long-distance land travelling (for example between megacities and provinces) will be reorganized in order to extend the very fast continental networks with magnetic levitating ("Maglev") technology railways. It should cover a main needs for future connection needs.

In 2006, 15-17 May in Stockholm there was the *European conference for local governments on climate protection, energy efficiency and the promotion of renewable energy* under a motto: "A Future with Zero CO₂ Emissions". There are erroneously no one word on carbon capture and sequestration (CCS), only prayers on efficiency increase and coal elimination. It is a sharp contrast to policy of European Union, formulated in the beginning of Introduction.

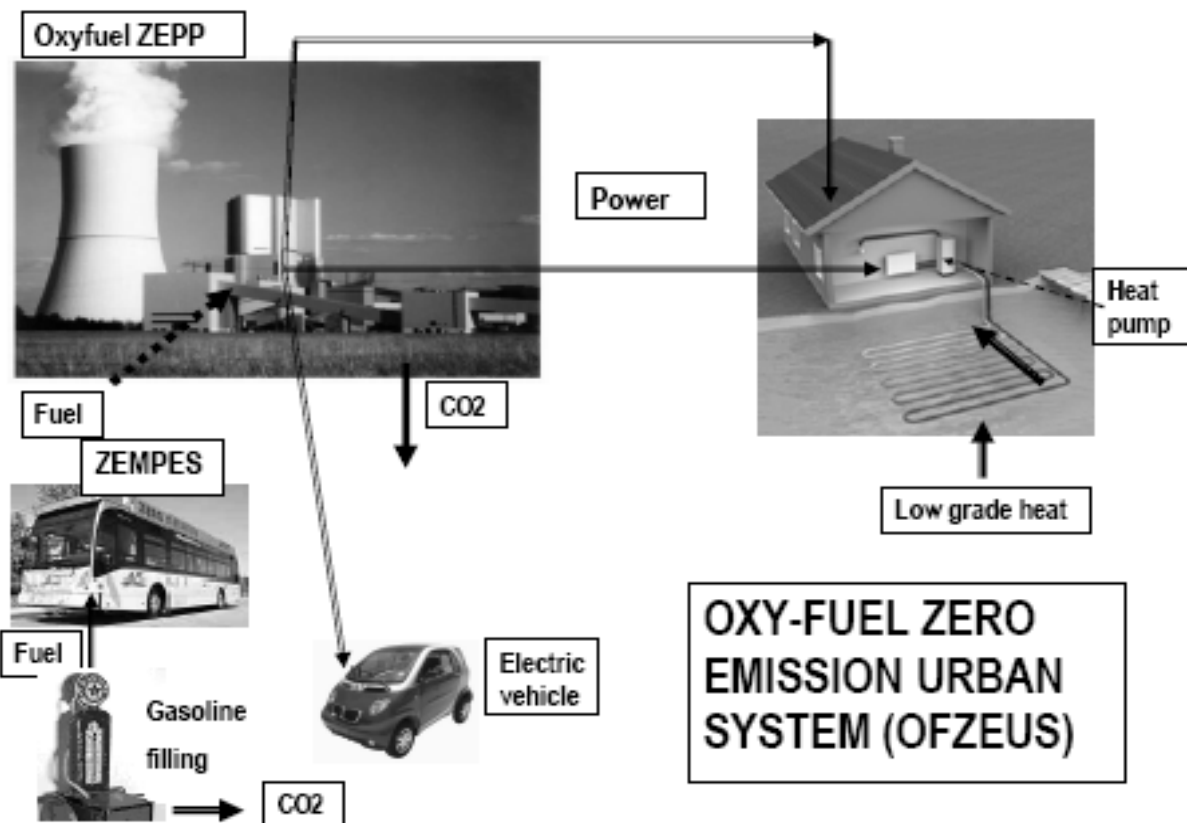


Fig. 8. Energy system of "Zero Emission City"

6. Concluding Remarks

In 2007 the IPCC climate scientists concluded that there was at least a 90% probability that the atmospheric increase in CO₂ was human-induced - essentially due to fossil fuel combustion and, to a lesser extent, the CO₂ released from changes in land use. Projections for the end of 21-st century indicate that a minimum of 500 ppm can be expected. Stabilizing the world's climate will require high income countries to reduce their emissions by 60-90% over 2010 levels by 2050. This should stabilize atmospheric carbon dioxide levels at 450-650 ppm from the current level of about 392 ppm (April 2010). Above this level and temperatures would probably rise by more than 2 Centigrade to produce "catastrophic" climate change. Reduction of current CO₂ levels must be achieved against a background of global population increase and developing countries aspiring to the energy-intensive and high consumption lifestyles.

The human consumption should be related to the biologically productive land needed to provide the resources, and absorb the wastes of the average global citizen. The sustainability goal is to raise the global standard of living without increasing the use of resources beyond globally sustainable levels; that is, to not exceed "one planet" consumption. This requires us to change the way we design, produce, use and dispose of the goods at a very constrained world.

The main questions today concerning urban space energy systems are their economical and environmental impacts. Conversion of a city into zero emission one seems to be possible using known and recently developing technologies. Even without industry and incineration

(so far require a number of improvements), amount of cities is quite enough to begin with. The price of dwellings in such cities might be higher than in cities with polluted air. The consumption of oil will be drastically reduced, which is essential in view of world oil decline. Major or alternative energy supply is to be from coal-fired ZEPP. These combined power plants will assure an alternative way for supplying the heat and electricity based on still popular solid fuels and avoid large CO₂ emissions associated to the classical combustion technologies. The described zero emissions coal-electrical energy system of an eco-city with Oxy-fuel ZEPP should attract attention of the *World Mayors Council on Climate Change*.

In the long run, the development and widespread adoption of new technologies can greatly ameliorate what, in the short run, sometimes appear to be overwhelming conflicts between economic well-being and environmental quality. With existing technology, problems such as emissions of green-house gases and disposal of hazardous wastes pose difficult choices between potentially irreversible damage to the environment and high economic costs of control. But if history is any guide, we know that over a period of decades changes in technology can alter dramatically the nature of these tradeoffs. Therefore, the effect of public policies on the development and spread of new technologies may, in the long run, be among the most important determinants of success or failure in environmental protection (Kneese & Schultz, 1978).

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This book reports the latest developments and trends in "clean energy systems and experiences". The contributors to each chapter are energy scientists and engineers with strong expertise in their respective fields. This book offers a forum for exchanging state of the art scientific information and knowledge. As a whole, the studies presented here reveal important new directions toward the realization of a sustainable society.

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