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THE ROLE OF CATALYSIS IN SUSTAINABLE DEVELOPMENT

Aleksandra Milutinović-Nikolić[1,2], Željko Čupić[2] and Dušan Jovanović[2]

Abstract

In this paper basic concepts of sustainable development are given together with brief retrospective of development of catalysis. Impacts of catalysis on economic and particularly environmental sustainability are discussed. Basic concepts of "green" and "sustainable" chemistry are given. Various research activities in Serbia that has applying catalysis and catalysts as a goal towards sustainable development are enumerated.

Sustainable development - basic concepts

The climate change, deforestation, habitat destruction, soil problems such as erosion, salinization, soil fertility losses, water management problems, over-hunting, over-fishing… are identified as factors historically attributed to the collapse of ever-glorious, great ancient civilizations [1]. The same problems are facing nowadays civilization. Present situation is even worse because of today's larger population, energy shortage, integration of toxic chemicals in very daily life, more potent destructive technologies and the fact that global climate change and globalization posing the risk of a global rather than a local collapse.

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These trends need to change, to get away from an energy- and waste-intensive lifestyle and live more in concert with the production and assimilation capacities of the Earth. The core philosophy of sustainability lies in the appreciation of nature as the symbol of integrity, stability and beauty. Humans as a part of nature and the harmonious and peaceful coexistence among people as well as between humankind and natural world are advocated. It also implies the moderation in population reproduction, economic production and consumption [2].

UNESCO has defined sustainability as the ability to meet present needs without damaging or depleting the environmental, economic or social resources that future generations need [3]. Sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but in the indefinite future. The most often-quoted definition of sustainable development is: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [4].

The sustainable development is interdependent and mutual result of economic development, social development and environmental protection [5], therefore the field of sustainable development can be conceptually divided according to three aspects of sustainability: environmental, economic and sociopolitical sustainability. The sociopolitical sustainability leads in to peace, equity and democracy, ecological sustainability in to conservation of nature and its resources, while economic sustainability in appropriate economic development.

Environmental sustainability is the process of making sure that current processes of interaction with the environment are pursued with the idea of keeping the environment as pristine as naturally possible. An "unsustainable situation" occurs when natural capital (the sum total of nature's resources) is used up faster than it can be replenished. Sustainability requires that human activity only uses nature's resources at a rate at which they can be replenished naturally. Theoretically, long-term result of environmental degradation is the inability to sustain human life. Such degradation on a global scale could imply extinction for humanity.

To achieve sustainable development it is necessary to resolve the conflict between environmental, economic and sociopolitical sustainability and their competing goals. Simultaneous pursuit of economic prosperity, environmental quality and social justice can be regarded as three vectors with resultant vector being technology as continually evolving process. The process of achieving sustainability is the "journey" to a set of wishful characteristics of a future system [6].

Sustainability holds a philosophy of cooperation rather than competition with nature and with each other as in the four ethics of permaculture describes [7]: (i) care for the Earth, including all living and non-living things, such as animals, plants, land, water and air, (ii) care for people, (iii) share resources and surplus (labour, money, information, knowledge) to help others achieve their needs - our relationship with others becomes the basis of community caring, (iv) reducing and taking responsibility on consumption.

In a sustainable future, air, water and soil would be clean, uncontaminated by toxic chemicals. Food would be free from unacceptable and unneeded ingredients for instance: pesticide residues, synthesis fertilizers and growth hormones. This almost utopian future would mean living within the Earth's limits, reducing impact on the Earth's resources. The goal is that future generations would enjoy the same natural heritages and present quality of life [8]. Thus, sustainability refuses getting short-term gains at any prices but advocate the long-term vision.

Implying long-term vision, not only trying to fix the problems after they occur, sustainability deals much with creative designs and planning in harmony with nature. The understanding of the principles of organization that ecosystems have evolved to sustain the web of life – is the first step on the road to sustainability, and the second step is to move toward ecodesign [9]. From the perspective of sustainability, nature's design and technologies are far superior to human science and technology. Thus, sustainable design is also an ecological, regenerative design that mimics nature patterns, mindful of all species and see life in its wholeness, systematically. It chooses positive and cooperative approach to problems [10].

The core ideas of sustainable principles always involves with nature: letting nature do the work, is principle about optimum production with minimum nature's intervention. Natural living solutions operate within the ecological framework as much as possible. By limiting the scale and intensity of human activities to that is actually necessary, the likelihood of disturbing the ecological balance is greatly reduced. Letting nature do the work means to use and value biological and renewable resources and services instead of fossil fuels and chemicals. This can increase the general health and yield of a system over time and decrease the need for external inputs.

One essential characteristic of nature systems that helps maintaining stability in constantly changing conditions is diversity. The great diversity of forms, functions and interactions in nature and humanity are the source for evolved systematic complexity. Another principle of nature that should be applied is: integrate rather than segregate, symbiosis. This principle provides the thinking of multiple pathways to achieve one goal as well as a common solution to disparate problems; problems are solved simultaneously.

Nothing is waste in nature, then, another emphasis of sustainable planning is the elimination of the concept of waste. Waste from one process can be and should be a resource to another. There is a give and take between elements that circulates inputs and outputs within systems. In order to be sustainable, from observing ongoing-regenerative natural processes, supply systems for energy and materials must be continually self-renewing in their operation. This concept is practically implemented in many techniques, from waste recycling in sustainable agriculture to renewable energy and regenerative water system [11].

If there is to be any chance of creating a peaceful, sustainable world, its economy will have to be very different from at present. [11]. Envision of this changed economy is summarized in Table 1 where the main characteristics of an ideal eco-economy (almost utopian) versus the current one are given [12].

In order to summarize all previously mentioned characteristics of unsustainable and sustainable development their schematic comparison is given in Fig. 1 [13].

Table 1. Today's Economy vs. Tomorrow's Eco-Economy[12]

Today's Economy	Tomorrow's idealistic Eco-Economy
Competitive, hierachy relationship	Co-operative, network relationship
Throwaway, linear flow-through model, creating huge wastes while depleting resources	Nature's cycle model, reducing wastes, promoting regenerative resources
Shaped by money-based, market forces	Respects principles of ecology
Favors of mass production, mass consumption, mass disposal	Favors of production according to people and the environment needs not only lies on human greeds
Maximizes own profit regardless of consequences to the ecosystem and others	Cares for the Earth and people, respecting, carrying capacity of ecosystem
Energy system: carbon, fossil fuel based	Energy system: renewable like solar, wind, biogas, fuel-cell…hydrogen based
Pollutes the environment by toxic chemicals	Refresh the environment
↓	↓
Unsustainable, likely to decline in not-too-distant future as natural supplies deteriorate; causing social breakdown and alienation	Sustainable, healthy and peaceful

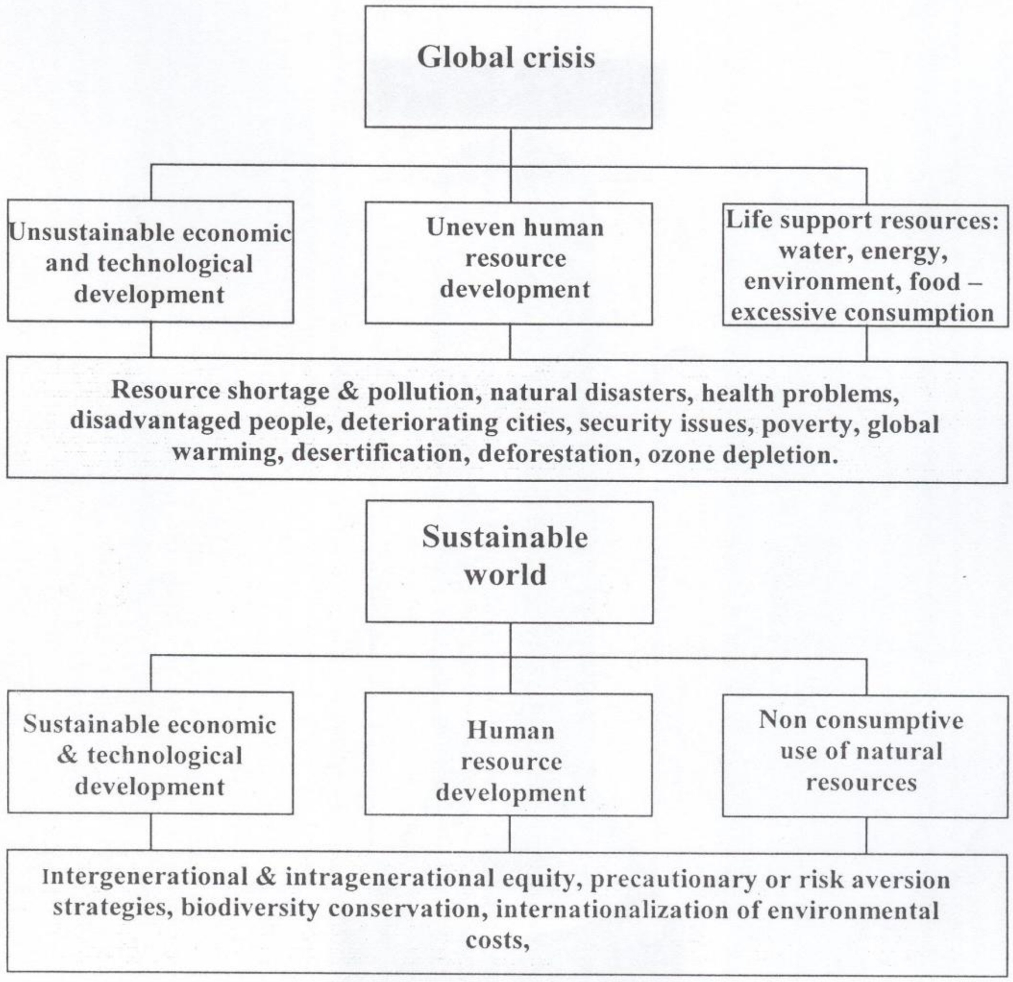

Figure 1. Unsustainable vs. sustainable development [13]

Well known characteristics of nowadays global crises are quoted in the highlighted rectangular box within the upper part of the scheme On the other hand in the highlighted rectangular box of the lower part of the scheme are presented major characteristics of sustainable world.

Every part of a progressive society should be actively engaged on achieving these goals and the leaders in their accomplishment should be scientists of different profiles. Researchers in the field of catalysis should therefore focus their scientific activities on subjects that lead to sustainable world. The fact that Dr. G. Ertl (awarded in 2007 with the Nobel Prize in Chemistry) emphasized the relevance of catalysis for chemistry, science, sustainable development and quality of life [14] shows that thinking and speculations in the scientific world are going in that direction.

Bearing in mind the well known ecological philosophy "think globally – act locally" in this paper the attempt was made to introspect various possibilities of applying catalysis towards sustainable world. Various research activities in Serbia that has applying catalysis and catalysts as a goal towards sustainable development are enumerated.

Catalysis and development

Ability to perform chemical transformations is one of basic characteristics of life and all living organisms. It is also the key process in manufacturing of many man made industrial products. The extent to which a chemical reaction could possibly transform one kind of molecule into another kind of molecule is governed by the principles of thermodynamics - some reactions are in principle possible, whereas others can, at most, occur to only an immeasurably small extent. But, the reactions that are thermodynamically possible may take place at such low rates as to be essentially stymied. These reactions are limited by kinetics. When the reaction is thermodynamically possible but too slow to be useful, then a catalyst is needed. A catalyst increases the rate by intervening in the chemical change to open up a new, quicker, or energetically more favored pathway for change [15].

The catalysis dates back to the dawn of civilization, at a date lost in time when mankind began to produce alcohol by fermentation. Since than the man activity concerning catalysis consists mainly of isolated observations that were sporadically documented without any effort made to explain these phenomena. This phase ended stridently when Jöns Jacob Berzelius systematically investigated the recorded observations and classified them as catalysis in 1835 [16, 17].

During the nineteenth century systematic research and the discovery of new catalytic processes have been done. It became quite clear that catalysis was applicable in most chemical processes and that by implementing catalysis in an industrial process there could be significant financial gains [16, 18]. By the end of the nineteenth century the number of catalytic processes that had been developed had grown into hundreds and the economic potential of some of these processes were highly feasible. There was also a general growth in the demand for bulk chemicals and therefore minimization of by-products, by catalysis, had evident economic advantages. The industrial production of bulk chemicals of this period was at an all time high during World War I [16], when the demands on explosives based upon nitric acid reached preposterous proportions.

After the First World War, when the demand for explosives diminished, and the industrial production shifted towards the manufacturing of synthetic fuels and new innovative processes such as Fisher-Tropsch [19, 20] and the FCC (Fluid Catalytic Cracking). Period from World War II to the beginning of the 1970s, was strongly characterized by the petrochemical industry and various catalytic processes for the manufacturing of synthetic polymers [21- 23].

In this period in Serbia the research activities focused on catalysis began. The Project „Catalysis and catalyst" in 1959 financed by Fund of Republic of Serbia for Scientific work and accomplished in Division for Physical chemistry and electrochemistry of the Chemical institute of Republic of Serbia officered by dr Paula Putanov was the first in the line of projects involving catalysis and catalyst in Serbia [24]. Unfortunately in this paper only those R&D activities that can link catalysis and catalyst and sustainable development during last decade will be mentioned and thus a number of significant results accomplished in earlier period will be omitted.

During the next phase of catalysis development, from the early 1970s until today, the main stream leads to the environmental catalysis. Environmental catalysis was the first step towards the modern chemical industry where catalysis is applied to almost every process, including the production of fine chemicals for pharmaceutical applications to the production of bulk chemicals and exhaust gas catalysts. The first commercial exhaust after-treatment system was developed by Engelhard in the mid sixties [25]. The development of exhaust gas catalysts has led to incredibly large reductions in emissions and has also governed the evolution of the combustion engine. The exhaust gas catalyst system is now the most common catalytic reactor in the world.

Here the cooperation of Belgrade school of catalysis and particularly DCCE with US Environmental Protection Agency (in period from 1970's to 1990's) should be mentioned [26]. The mutual project "Reduction of CO and HC emission" among other results led to patent of catalyst based on ruthenium in perovskit matrix for exhaust gasses of internal combustion engines [27].

And to conclude historical survey several important catalytic process will be emphasized. The most notable new processes using zeolites are Mobil Oil's methanol-to-gasoline process which operates with a ZSM-5-zeolite catalyst (1976) [28] and the oxidation of benzene to phenol over a Fe-ZSM-5 zeolite catalyst (1990). One of the most important process developments during 1980's was the introduction of Selective Catalytic Reduction (SCR) for controlling the NOx emitted from nitric acid and stationary power plants [29]. SCR technology is today implemented in several mobile applications ranging from large ships to heavy-duty trucks. In 1980 Shell and Union Carbide developed a process for producing linear low-density polyethylene. The process was revolutionary as it gave the producers total control over the material properties of the product. The process was later extended to the production of polypropylene [30]. The improvements in ammonia process and investigations into the nature of the process are constantly being carried out. In 1982 Ertl's group defined the energy profile of the synthesis of ammonia and in 1992 the first commercial use of a catalyst without iron was presented [31]. Other process developments worth mentioning are the introduction of Reduced Crude Cracking (RCC) by Ashland Petroleum., the use of Fischer-Tropsch as a source for producing alpha-olefins and UOP's Cyclar process for the production of aromatics from Liquefied Petroleum Gas (LPG) [32].

The last few decades were characterized by continuous invention of new catalytic processes, particularly the ones that that prevent negative impact of human economy on environment. This period of catalysis development has been characterized and influenced by environmental driving forces and the Science's integration with new technologies, such as super computers. The development of rapid inexpensive computational systems has in fact created a new branch of catalysis, namely mathematical modeling, which has had a significant impact on the methods used today for developing new catalytic systems. Section "Research activities in Serbia" will provide more information about how researchers in Serbia during last decade followed these trends and how they contribute in "catalysis for sustainable development".

Where Catalysis and Sustainable Development meet?

Among three aspects of sustainability only the impact of catalysis on the sociopolitical sustainability is blur and insignificant. The impact on environmental sustainability will be analyzed more thoroughly, while its importance on economical sustainability will be briefly discussed.

Catalysts are a big business since approx. 80 % of processes in chemical industry of 21st century depend upon catalysts. For example catalyst sales in 2000 were worth 8 to 10 million US $, with growth in catalyst sales increasing between 5 % and 10 % annually. Turnover in industry using catalysts in 2000 was about 14 trillion US $. For example a 0.5 % to 1 % increase in selectivity of catalyst can lead up to 1 million US $ savings. Areas of major impact of catalysis today are fuel and material production, environmental protection, health, agriculture, food, etc. [33].

There is a pressing need for cleaner fuels (free or aromatics and of minimal sulfur content) or ones that convert chemical energy directly to electricity, silently and without production of noxious oxides and particulates; chemical, petrochemical and pharmaceutical processes that may be conducted in a one-step, solvent-free manner and that use air as the preferred oxidant; and industrial processes that minimize consumption of energy, production of waste, or the use of corrosive, explosive, volatile, and nonbiodegradable materials. All these needs and other desiderata, such as the in situ production and containment of aggressive and hazardous reagents, and the avoidance of use of ecologically harmful elements, may be achieved by designing the appropriate heterogeneous inorganic catalyst. These catalysts ideally should be cheap, readily preparable and fully characterizable, preferably under in situ reaction conditions. A range of nanoporous and nanoparticle catalysts meets the most of the stringent demands of sustainable development and responsible (clean) technology [34].

The main objectives in environmental protection by catalysis are [33]:

- Pollution prevention by developing energy-saving processes free of pollution formation
- Decreasing pollution by achieving higher selectivity in fuel and chemical manufacture
- Decreasing pollution by developing new and improved catalytic processes for removal of pollutants
- Developing competitive processes for production of hydrogen, chemicals and energy sources, providing reduced CO_2 production
- Finding new catalyst that enable production of major products with greater energy and feedstock efficiency and with improved environmental issues.

These objectives can be reached by designing catalysts that increase energy efficiency, minimize waste, enable wastewater cleanup and NO_x and SO_2 removal. The production of H_2 without CO_2 formation as a co-product is among most important trends that research in catalysis should follow. Among the processes that catalyst scientist should focus on are replacement of corrosive liquid acids by benign solid acid catalysts, reduction of number and quantity of by-products and elimination of voluminous by-products etc. From the environmental sustainability point of view the most important tasks are minimization of hazardous products and greenhouse gases and development of "zero-waste" processes.

The "green chemistry" concept was introduced in the early 1990s as the new approach of chemistry in opposition to the pollute-and-then-clean-up approach considered the common industrial practice [35]. A good definition of "green chemistry" is that of the US Environmental Protection Agency (EPA): use of chemistry for pollution prevention, and design of chemical products and processes that are more environmentally benign [36].

Green chemistry and engineering is the design of chemical manufacturing systems to minimize their adverse affects on the environment. Thus, a primary goal of green chemistry and engineering is to reduce the environmental impact of chemical processes and chemical manufacturing while simultaneously enhancing the overall process performance. Although it is beneficial to simply reduce the use of organic solvents in chemical processes, green chemistry and engineering goes further, in that it evaluates the entire manufacturing operation to identify techniques that can be applied to minimize the overall process hazard, while maintaining economic practicality. Evaluation of the environmental impacts of the manufacturing process requires a systems approach and appropriate metrics that permit quantitative assessment of environmental hazards [37].

Anastas et al. in 2000 [38] defined 12 principles of green chemistry. In Table 2 for each principle a solution applying catalysis or catalyst is given

Table 2. Principles of green chemistry and "catalysis" examples [33, 38].

Principle	Explanation	Example
1. Prevention	It is better to prevent waste formation than to treat or clean up after it is formed	Oxicarbonylation of methanol to diethylcarbonate: No organic by-products or salts formed
2. Atom economy	Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment	Synthesis of ibuprofen by HF: From six steps synthesis to three step, environmentally safer
3. Less hazardous chemical synthesis	Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment	Zeolite catalyst for cumene manufacture: Zeolite is enviromentally inert, replaces solid acid catalysts (less waste, less energy required, less corrosive catalyst)
4. Designing safer chemicals	Chemical products should be designed to preserve efficacy of function while reducing toxicity	Enzyme-catalyzed synthesis of insecticides
5. Safer solvents and auxiliaries	Avoid unnecessary use of auxiliary substances (e.g. solvents, separation agents, etc.)	Microwave activation of alcohols to carbonyls: solvent-free conditions
6. Design for energy efficiency	Minimization of energy use	Thermoplastic resin production by catalysis: 25 % less energy, 90 % less organic waste
7. Use of renewable feedstock's	Change from non-renewable to renewable feedstock's	Biocatalysis for biomass to ethanol conversion: change from crude oil to cellulose biomass
8. Reduce derivatives	Minimization of unnecessary derivatives	Cross-linked enzymes in organic reactions
9. Catalysis	Use of catalysts instead of stoichiometric solvents	POM catalysts for wood delignification
10. Design for degradation	Environmental degradation of products at the end of the function	Synthesis of biodegradable polymers
11. Real time analysis of pollution prevention	Analytical methodologies need to be developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances	Catalysts for environmental control, very efficient and selective on traces of pollutants. They have to operate at low concentrations and high flow rates.
12. Inherently safer chemicals	Avoiding chemical accidents, explosions, fires, releases	Enzymatic production of acrylamide: Unwanted by-products avoided

"Sustainable chemistry" is the concept sometimes opposed and sometimes confused with "green chemistry" [35]. There is a key difference in the definition: while green chemistry indicates that a not risky and polluting chemical production process may exist, the sustainable chemistry concept links eco-efficiency, economic growth and quality of life in terms of a cost/benefit analysis. The sustainable chemistry approach emphasizes the concept of sustainable risk, i.e. that there does not exist a good "green chemistry" opposite to a dirty chemistry, but simply that each chemical process has a risk associated with production. The role of chemists and engineers is to minimize this risk and reduce the impact on the environment to a level sustainable by the environment, assuring a good quality of life. From the changes that have occurred in the chemical industry over the last two decades, it can be seen that all new processes introduced were motivated by a need to reduce the environmental impact or hazardous risks, and achieve better use of resources. None of the changes were possible however without better process economics, including environmental and social aspects in the cost evaluation. Protection of the environment is not necessarily in contrast with economic growth, but certainly the use of new improved chemical technologies is required to combine these two factors otherwise in contrast. R&D is thus the key for sustainable development. Recent examples, furthermore, indicate that new eco-efficient processes can give companies the opportunity to gain new market positions [35].

Catalysts offer a great opportunity to provide greater global energy efficiency (via new processes and alternative feedstock's). By increasing energy efficiency in existing technologies and facilities leads to reductions in CO_2 emissions. The alternative new catalysts or processes must be more energy efficient than the existing approaches [39]. There are enough ways that catalysis can be used to implement greater energy and carbon efficiency. In applying biomass as attractive alternative to the standard fossil fuels the catalyst are facilitating hydrolysis of cellulose, conversion of lignin to aromatic carboxylic acids, selective hydrogenation and deoxygenation of cellulose, selective functionalization of carbohydrates. Catalysts needed to depolymerize a variety of mixed polymers for recycling and waste minimization efforts.

Modern biocatalysis is developing new and precise tools to improve a wide range of production processes, which reduce energy and raw material consumption and generate less waste and toxic side-products. Biocatalysis is also achieving new advances in environmental fields, from enzymatic bioremediation to the synthesis of renewable and clean energies and biochemical cleaning from various pollutants. Despite the obvious benefits of biocatalysis, the major hurdles hindering the exploitation of the repertoire of enzymatic processes are, in many cases, the high production costs and the low yields obtained [40].

Although maybe less challenging the necessity of assuring that the used catalysts should be recycled as much as possible, must be ever existing task.

Research activities in Serbia

The research activities in field of catalysis are conducted mainly in following institutes and faculties: Institute of Chemistry, Technology and Metallurgy - Belgrade, Faculty of Chemistry - Belgrade, Faculty of Physical Chemistry - Belgrade, Faculty of Technology and Metallurgy - Belgrade, Faculty of Technology - Novi Sad, Faculty of Science - Novi Sad, Institute "Vinča" - Belgrade, Faculty of Technology - Leskovac.

In the current cycle of projects (2006-2010) the Ministry of Science and Technological Development of the Republic of Serbia supports eight projects [41-48] that are entirely or partially focused on catalysis.

The investigations in catalysis for renewable energy have two main streams: fuel cells and biofuel. New generations of the electrode catalysts that can be applied in the fuel cells are investigated. Metallic nanoparticles and transition metal macrocyclic complexes supported electrodes are synthesized with aim to decrease the amount of noble metal for a given level of activity as well as to increase the activity by synthesizing bi- or triple- metallic catalysts. Electrocatalytic activity is investigated for reactions taking place in fuel cells like oxidation of methanol or formic acid, reduction of oxygen etc. [49-51]. The implementation of modified zeolites for fuel cells application are also studied [52-54].

Heterogeneous base catalysts for the transesterification of vegetable oils to produce biodiesel are synthesized using sol-gel method and drying in supercritical CO_2 [55]. Kinetics of sunflower oil methanolysis at low temperatures and production of biodisel from tobacco seed oil are among pathways in biodisel investigation [56, 57].

Beside investigations in renewable fuels the scientific efforts are focused on catalytic reactions of total oxidation of CO, CH_4 and propylene. The catalysts are perovskite oxide based, synthesized by ceramic, citrate and mechanochemical procedure. By introducing Pd in perovskite lattice its thermal stability and catalytic activity are enhanced [58-60]. Deep oxidation of CO, n-hexane and toluene over Pt/Al_2O_3 catalysts were investigated [61-64]. These catalytic reactions enable clean combustion processes.

Different modifications of bentonite: acid activation, organo-modification, pillaring, and synthesis of materials based on bentonite like nanocomposites, composites, electrode materials and particularly catalysts are performed [65-67]. Pillared clays (PILCs) are applied as catalysts in the catalytic wet peroxide oxidation (CWPO) of organic pollutants (mostly phenols) in water [68-71]. The CWPO on Fe-ZSM-5 as catalyst is tested [72] as well as decomposition of nitrous oxide on AlFe-PILC catalyst [73].

After energy and pollution topics the catalysis in food industry should be mentioned. The Pd/Ag promoted nickel catalyst on activated natural silicate material (diatomite) and commercial (water glass) supports for partial hydrogenation of edible oils are one of research activities [74-78]. These catalyst enable lowering a total amount of trans isomers in final products and therefore can be considered as important tool for production of healthy food, one of previously neglected tasks in devious journey to sustainable world.

Conclusion

Some of the ways of creation of a sustainable society using catalysis as the main tool are pointed out in this paper. Catalysts play key roles in the production of clean fuels, the conversion of waste and green raw materials into energy, clean combustion engines including control of NO, and soot production and reduction of greenhouse gases, production of clean water and of polymers, as well as reduction from polymers to monomers. Catalysts are also of prime importance in the developing H_2 and syngas production technology, aimed at producing clean fuels for the coming decades.

Many of aforementioned objectives that involve catalysis and catalysts and before all lead to environmental sustainability are subjects of research activities in Serbian science. Unfortunately these activities are incoherent and isolated. In the future more efort should be put on connecting scientists and projects internaly in Serbia and externaly with scientists and researches and thear institutes, universities and companies all over the world.

Catalysis is important factor in enabling technology for society, but the associated development and applications require multidisciplinary competences (engineering, chemistry, physics, applied catalysis, materials science, etc.), and present interesting challenges in areas ranging from fundamental studies (surface science, theory, and modeling) to industrial applications. Tackling such challenges in the future will require further efforts on interdisciplinary and multidisciplinary approaches and on bridging the gap between fundamental science and technology.

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