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THE EFFECTIVENESS OF ENERGY RESOURCES AND SUCCESSIVE TECHNOLOGICAL STAGES¹

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Abstract. *This article discusses criteria for comparing the effectiveness of energy resources. It focuses on the interrelationship between the effectiveness of energy resources and movement from one technological stage to another. What emerges is the consistent pattern of change in existing technologies, and increasingly evident is that, at their current stage of development, neither nano- nor biotechnology will lead to an evolution from the current and fifth technological stage to a sixth. Of note is that at present oil remains the key energy resource, which means that in the near future peak oil will force us to confront an unprecedented event in industrial history: energy degradation, which can be viewed as a regressive movement in the existing technological stage.*

Keywords: *technological stages, sixth technological stage, peak oil, effectiveness of energy resources, EROEI*

Contemporary civilization is unimaginable without energy. Energy is the single most crucial element for life and for the economy. Energy is used in all sectors of today's economy and is essential for the daily smooth functioning of society. Currently, fossil fuels are the major source of energy. According to data from British Petroleum, world energy consumption of primary resources in 2009 amounted to 11.1 billion tons of fuel equivalent, of which oil provided 35 %, coal – 29 %, gas – 24 %, hydropower – 7 %, and nuclear power – 5 %. At present, the contribution of alternative energy sources (with the exception of wood) remains insignificant. And so it is that fossil fuels continue as the primary source for global energy needs. Coal, oil, and gas make up 88 % of total consumption of primary energy resources.

Energy resources vary in terms of their utilization properties in that there is a slew of differing criteria for these resources. It follows, then, that one can delineate between those resources that are more effective, and those that are less effective. Andrei Gennadevich Korzhubaev notes that "oil is the energy resource with a global significance, while gas is primarily of regional significance, and coal is of local importance" [1]. One can add uranium to the list of local energy resources. It follows that since oil is the most sought-after energy resource in the world, we can make the empirical claim that oil is the most effective energy resource. One could say that thanks to its unique properties, oil won the competition with other energy resources.

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If we are to approach the issue of effectiveness in concrete fashion, then we must examine the criteria used to compare the effectiveness of energy resources. A plethora of criteria exist for this purpose [2]. When comparing oil with other energy resources we can identify the three that are most important:

1. The physical nature
2. Energy density per unit of volume and mass
3. EROEI

We will briefly describe each of these criteria.

Energy resources are not identical in terms of storage capacity. Because of this, energy resources in liquid form are currently the most preferable at the current level of technological development. While storable liquid energy resources are completely interchangeable in any sector without loss of effectiveness, by no means can they always be replaced by solid forms of energy--for example fuel for planes. Thus, of the fossil fuels--coal, gas, and oil, because it is a liquid energy resource, oil is the most effective.

An important criterion for effectiveness is the density of energy per unit of mass and volume. The principle for this is as follows: the greater the density, then the better the energy resource, because high energy density requires less storage space in the structure of machines and equipment operated by the given energy resource. The transition from wood to coal was effective because the energy density per unit of volume for the equivalent mass of coal was approximately two times higher than for wood (Fig. 1). Equally effective was the transition from coal to oil. Oil is more energy dense than coal, and therefore more effective, which cannot be said about renewable energy resources: ethanol fuel and biodiesel represent a step backwards.

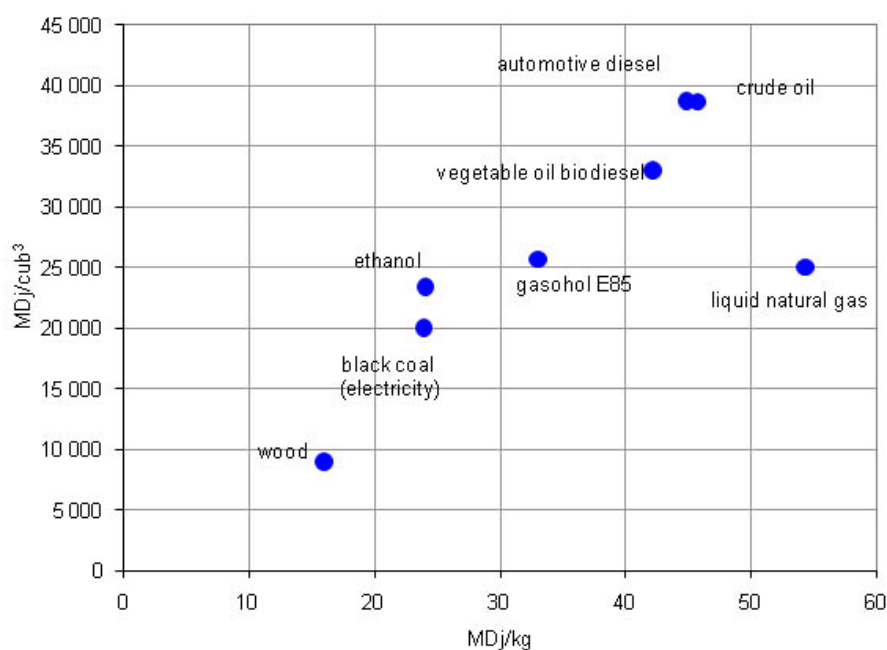


Fig. 1. Specific energy density per unit of volume and mass

EROEI is energy returned on energy invested, or profitability of excavation or production of the energy resource as calculated in energy units [3]. It is given that any production should be profitable: Proceeds from activity should be greater than total cost. The percentage ratio of this difference is called the "cost-effectiveness". With regard to the excavation of energy resources and further production of fuel, in addition to monetary income the process should be profitable in terms of energy. This is obvious: energy expended on excavation, transportation, and processing of raw materials should be less than the energy received from the excavated resources. This can be called "energy cost-effectiveness", or EROEI (energy return on energy invested). This idea was first introduced in the 1970s by the American scholar Charles Hall [4].

EROEI = energy return/energy invested on excavation (production).

When EROEI = 1 – this means that for each unit of energy received from the production of the raw material an equal amount of energy was expended, meaning that energy production resulted in no net gain and is essentially null in terms of results. When the value is less than 1, this means that production of the energy resources is unprofitable in terms of energy and therefore unacceptable. When the value is greater than 1, this means that production results in additional, "profitable" energy (Table 1).

Table 1. EROEI for various energy resources
(using data from Charles Hall)

Energy resource	EROEI
Oil and gas	35
Coal	80
Nuclear power	15
Tar sands	2 - 4
Sugarcane ethanol	0.8 - 10
Ethanol from corn	0.8 - 1.6
Biodiesel	1.3

According to this criterion, coal is the most effective. It is worthwhile to look at the lowest biofuel in terms of EROEI. In conjunction with this, several scientists and specialists, including Robert Hirsch, have expressed the opinion that biofuel will not play a significant role in the future, and thus to replace fuel as a liquid energy resource, the first focus should be on perfecting gas to liquid (GTL) and coal to liquid (CTL) technologies [5].

It is obvious that economic effectiveness depends on the quantity and quality of the accessible raw material. The greater the ease of access to quality raw materials, then the less is the effort spent on their excavation, and the greater their economic effectiveness. The same can be said about energy resources: The more plentiful and effective the resource, and the less the effort required to excavate and produce it, then the greater the quantity of energy provided to society – energy that is then channeled into scientific and cultural development.

The interrelationship between available energy resources and the development of society is examined in the theory of succeeding technological stages expounded upon by Sergei Yurevich Glazev, Yurii Vladimirovich Yakovetz, and others. In accordance with this theory, historical technological and economic development is the process of the successive substitution of major technologically-connected production processes--of technological stages ([7]. Yakovetz defines a technological stage as several interrelated and subsequently successive generations of technology that make viable a general technological principle [8]. Each technological stage comprises three elements:

– Fundamental innovations that define critical areas in the development of the new technological stage are called the **key factors**.

– The complex of critical areas in development forms the **core of the technological stage**.

– Industries where the critical areas of development are applied are called **backbone industries**.

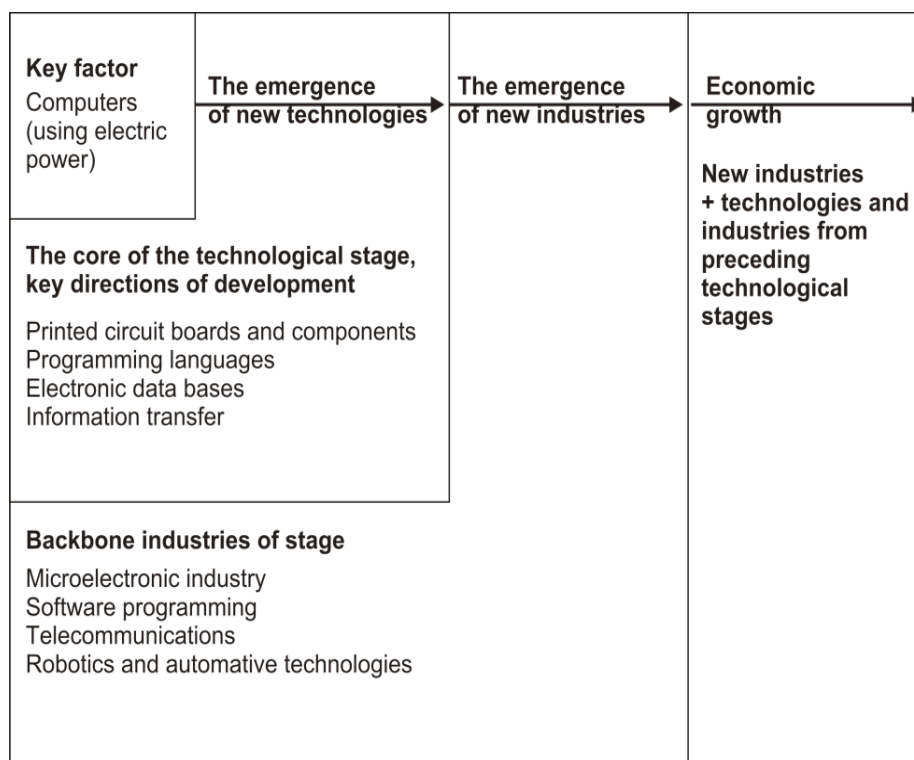


Fig. 2. Structure of the fifth technological stage

It is evident that leadership in the global economy belongs to that country which most intensely develops the technology of the current technological stage. In this, the fifth, technological stage this status is shared collectively by the U.S.A., Japan, and Germany. But in order to be assured of leadership in the future, accurate forecasting of the appearance of new epochal and fundamental innovations is essential, as are earlier moves in the direction of these innovations.

To use Yakovetz's terminology, the key factor to each technological stage is epochal and/or fundamental innovation. For example, the key factor to the fifth technological stage is derived from the epochal innovation of electric power and the fundamental innovation of the computer. Fundamental innovations initiate a great deal of scientific and engineering activity, resulting in the appearance of numerous secondary innovations of a beneficial nature. Such secondary innovations are "engines" for business, and, in fact, it is their introduction that is overwhelmingly responsible for economic growth.

Every technological system faces a watershed in its development when progress is replaced by decline. The phenomenon of a gradual decline in possibilities for further improvement in any given industrial-technological system is well-known in theory and in practice, and is reflected in various laws of diminishing effectiveness [7]. Thus, with time the potential of fundamental innovations diminishes, economic growth slows down, and a period of pseudo-innovation begins. "Pseudo-innovation" is a very subjective term. For example, the author of this article considers computer notebooks to be a secondary innovation, and iPads and Netbooks to be pseudo-innovations, but there are other examples. The important thing is that pseudo-innovations are not capable of providing notable economic growth, and it is precisely the stage of pseudo-innovation, in this author's opinion, that is the locus of the current—and fifth—technological stage.

The studies carried out by Glazev enabled him to identify and describe five technological stages (Fig. 3, Table 1).

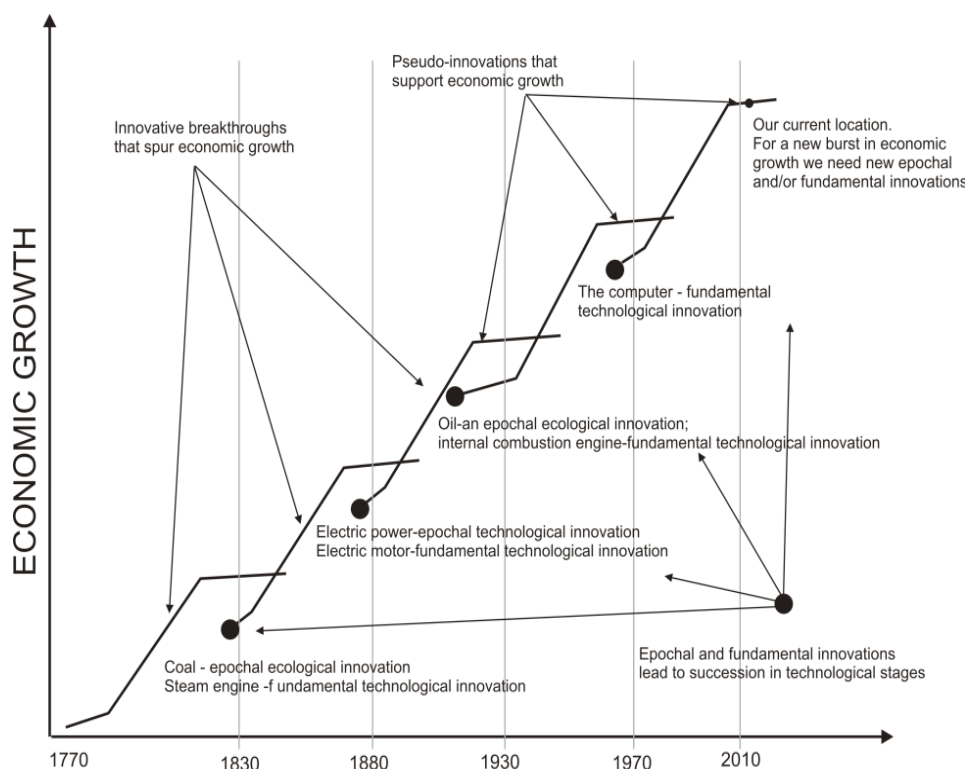


Fig. 3. Successive technological stages and economic growth

The periodicity of transition from one technological stage to another, which occurs approximately every 50 years, has led to the concept of major economic cycles known as Kondratiev waves. In this view, such a transition takes place according to the following scheme:

1. The current technological stage faces potential decline
2. Economic growth slows down
3. Companies lose profits, and this nudges management toward investment in research and development
4. The onset of massive investment begins in new developments and technologies
5. New fundamental innovations spur new economic growth

As regards this, it is assumed that the necessary volume of investment in new research and development is enough, and results will appear in and of themselves, and such is the 50-year cycle.

In the view of this author, the 50-year periodicity is more a matter of chance, as, basically, a transition from any given technological stage to a new one depends on the effectiveness of existing, exploitable energy resources.

Table 2. The chronology and characteristics of technological stages according to S. Yu. Glazev

Technological stage	Period	Key energy resource	Key factor	Supporting industries
First	1770-1830	Water, wind, wood	Textile machinery	Textile industry, iron processing, water engine
Second	1830-1880	Coal	Steam engine and locomotive	Locomotive and railway construction, transportation, steam engine construction, ferrous metallurgy
Third	1880-1930	Electric power, coal powered power plants	Electric motor	Electrotechnical, basic engineering industry, steel production and rolling, electric power lines
Fourth	1930-1970	Oil	Internal combustion engine	Auto industry, aviation industry, ferrous metallurgy
Fifth	1970-2010	Electric power oil, coal, gas, uranium, hydro	Computers	Microelectronics industry, software, telecommunications, robotics, automatic production

We will take a look at succession in technological stages from the point of view of discovery and introduction of new energy resources, which Yakovetz regards as epochal and ecological innovations. Note that the discovery of new energy resources precedes the development and adoption of technologies using the given energy resource. For example, the discovery of a liquid energy resource, namely oil, preceded the invention and adoption of fundamental innovative technologies that relied on oil and oil products. These innovative technologies led to succession in the technological stage, radically altering the face of civilization. They also were catalysts for massive economic growth. Generally speaking, the discovery of a new, more effective energy resource creates for both the scientist and engineer the practical task of making use of that resource. In this way the discovery of the new energy resource enables the development of science and technology and leads to the emergence of new industries that then serve as the source of long term economic growth. And yet, the discovery in the 20th century of gas and uranium, new energy resources, did not lead to a transition to a new technological stage. This is because gas and uranium are less effective fuels than oil.

Returning to a comparison of the effectiveness of energy resources and, analyzing the key factors in successive technological stages, we can summarize our conclusions as follows:

1. The discovery of new, **more effective energy resources** leads to a transition from one technological stage to another: coal is more effective than wood, and oil is more effective than coal (currently coal, gas, and uranium are used only because there is not enough oil);

2. The discovery of energy resources that are less effective than oil – gas and uranium, did not lead to a new technological stage. Other, even less effective alternative energy sources, such as biodiesel, ethanol, tar sands, and oil shale, do not even rate mentioning.

3. The discovery of a new form of energy (electric power) and the adoption of innovative machines using this energy led to a new technological stage.

It becomes clear that, fundamentally, succession in technological stages depends on the discovery of new energy resources that are more effective than the existing ones.

Let us focus further on electric power, which in and of itself is an epochal technological innovation. If the second and fourth technological stages are directly related to the massive development of a newly discovered energy resource, then the third and fifth are connected with the development of electric power: The electric motor and electronic computer are technologies using electric power in similar fashion to how the internal combustion engine uses oil, and the steam engine – coal.

Electric power is a form of energy that developed along the path of the transformation of steam energy first into kinetic energy of rotation, and then into the rotation of generators into electric power, followed by its use in electric motors or other electronic machines. Electric power is a new link in the chain of the transformation of

energy into work that is useful for society. In the case of the internal combustion engine, the transformation takes place in two stages: chemical energy is transformed into kinetic energy and from there into useful work. In the case of electric power, the internal combustion chain is extended: chemical energy is transformed into kinetic energy, and then into electric power, and from there into useful work (Fig. 4).

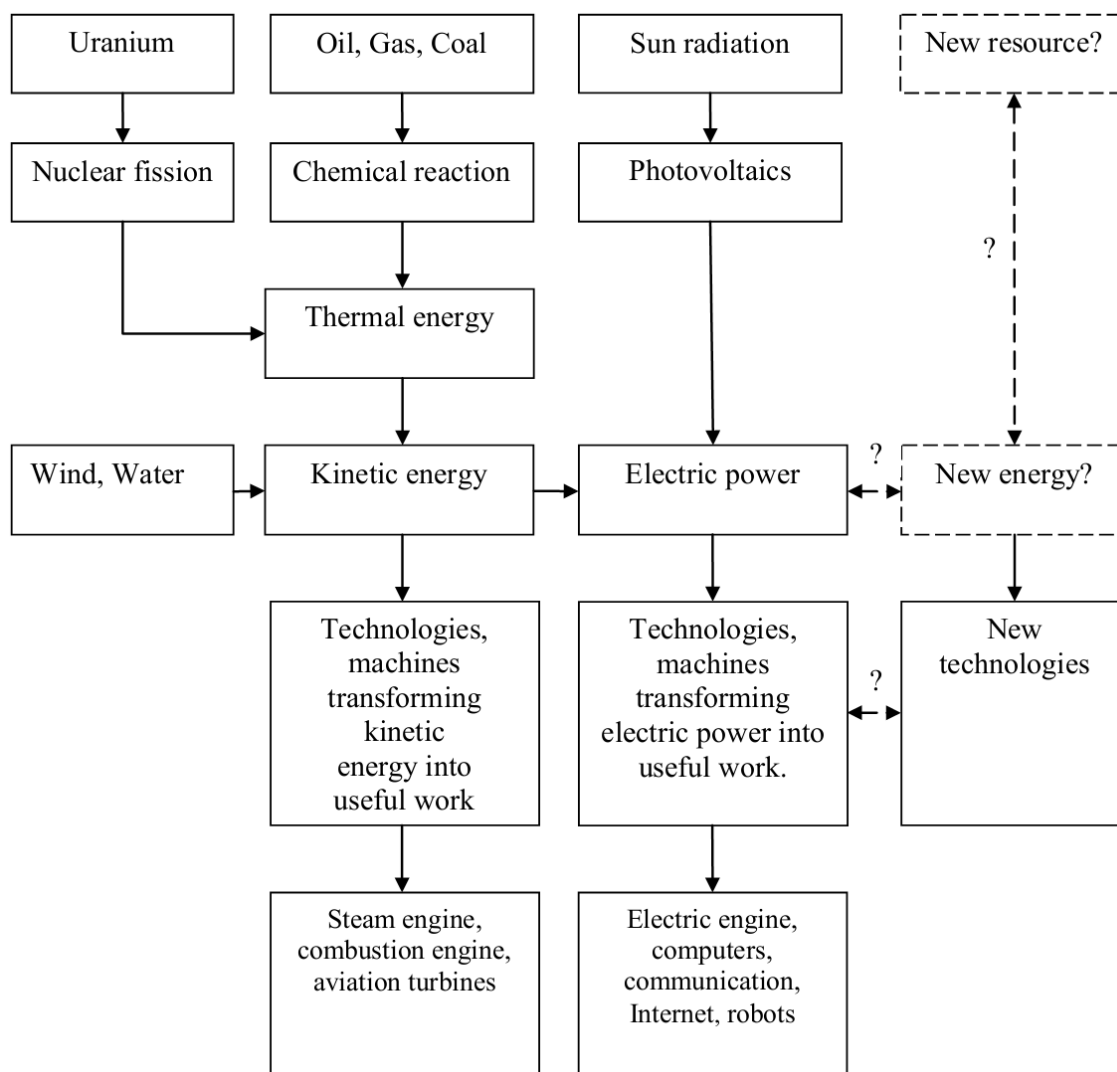


Fig. 4. The interrelationship of energy resources and technological development

The third and fifth technological stages are connected with the invention and adoption of machinery and equipment that use the new method of energy transformation. However, keep in mind that, fundamentally, these two technological stages rely on the use of oil, gas, and hydro resources; and later uranium and gas, which are used in the production of electricity. Electric energy does not exist on its own in nature. Energy resources provide the power plant with heat, which is then transformed into electricity (and in the case of wind and hydro power kinetic energy is immediately transformed into electricity).

Thus, taken as a whole, movement from one technological stage to another can be seen as a natural succession that takes place under two different scenarios:

1. The discovery of a new, more efficient energy resource, and the technological absorption of the resource (second and fourth technological stages).
2. The discovery of a new method of transforming energy and the technological absorption of the energy (third and fifth technological stages).

According to this pattern, we can suggest that a successive change in the current technological stage – the fifth – should take place as a result of the following:

1. The discovery of a new energy resource that is more effective than oil (for example more energy dense than oil, in times more plentiful in terms of reserves, and which also can easily be changed to and from liquid form to solid and gaseous states);
2. The discovery of a new method of transforming energy.

There is nothing surprising in the fact that new energy resources or new forms of energy lead to succession in the technological stage, and, on a wider scale, enable scientific and technological progress. Life as a whole and human activity are energy exchanges in various forms. The production and movement of commodities, culture, recreation – all these involve energy consumption. Therefore, the more effective the energy resource, the more efficient the technology, then the better, faster, and qualitatively improved is the functioning of human labor. This is what defines progress.

Glazev and a series of others say that the emergence of the sixth technological stage will be connected with nanotechnology and biotechnology [7]. The thinking is that the key factor in the sixth technological stage will result from nanotechnology, cellular technology, and methods of genetic engineering that rely on electron scanning and nuclear microscopy. Under this train of thought, nanotechnology will initiate a multifold increase in production efficiency, as well as a reduction in energy and material consumption. That is, in essence, nanotechnology will improve the machinery and equipment of preceding stages, and in this sense is neither fundamental nor epochal, but does qualify as a secondary innovation of a beneficial nature. Therefore, following the logic of successive technological stages, we find that nanotechnologies only extend the fifth technological stage, exerting due influence on economic development. Of course, nanotechnologies are in the early stage of development, and so it is premature to draw any final conclusions. It is entirely possible that nano- and biotechnologies will develop into a connecting link, a bridge to the discovery of new energy resources that then will be connected to a new technological stage.

It is important to note that at this stage of their development nano- and biotechnologies do not present a solution to the problem of society's dependence on fossil fuels, the first of which is oil. This means that we must grapple with problems arising from peak oil. A reduction in oil production will mean that the most effective energy resource in the economy will diminish, and must be replaced by one that is less effective. Such energy degradation is unprecedented in the industrial history of our civiliza-

tion. Thus, it requires separate examination, and at first glance, it is a regressive movement in the existing technological stage.

In the scope of this article, one can say that since the consumption of energy resources is closely connected with economic growth [1], then a forced reduction in energy consumption will lead to a decrease in the size of the global economy. These negative processes will be dictated by the objective deficit in oil (closely followed by gas and coal), and in conjunction with this the tendency of the global economy to decline will be profound. Therefore, along with further development of prospective technologies, we must simultaneously resolve what, in essence, is a new economic issue: What are the principles and laws that will form the basis for the functioning of the economy in conditions of energy degradation and a decline in energy resources? It is evident that if we manage to solve the problem of an energy deficit, then this will be accomplished only through scientific and technological innovation. This was emphasized by Nikita Nikolaevich Moiseev: “The dialectics of our life are as follows: Because of the development of technological innovations we find ourselves on the brink of a precipice; but without them we cannot build a bridge to the future and move away from the brink, and therein lies the contradiction of anthropogenesis.”[9]. Therefore, the first priority of any existing nation must be the development of science.

Conclusions

1. A transition from one technological stage to another is conditioned by the discovery and introduction of either a new energy resource that is more effective than currently existing resources, or by the discovery of a new form of energy. As a new, highly effective energy resource, oil played a key role in the fourth technological stage. As a new form of energy, electric power played a key role in the third and fifth technological stages. At present, a new energy resource that is more effective than oil has not been found; likewise with the discovery of a new form of energy.

2. It has been proposed that the sixth technological stage will be connected with nano- and biotechnologies. However, at their current stage of development these technologies serve only to improve innovations, and therefore cannot function as key factors to successive change in the technological stage. It is entirely possible that nano- and biotechnologies will turn out to be a bridge to the discovery of either a new energy resource or form of energy, and this will lead to a new technological stage.

3. Lacking a new energy resource or a new form of energy, soon the global economy will be faced with the problem of a reduction in the supply of oil, followed by a similar situation with gas and coal. Therefore, along with a search for new energy resources and energies, when analyzing the consequences for the global economy of a reduction in the supply of energy resources, it will be necessary to formulate and implement new rules and laws for the functioning of the economy in conditions of an ongoing energy deficit.

References

1. Korzhubaev A.G. Oil and Gas Complex of Russia in the Context of Transformation of the International Power Supply System. Novosibirsk, INGG, GEO, 2007. 270 p.
2. Goloskokov A.N. Kriterii sravneniya effektivnosti traditsionnykh i al'ternativnykh energoresursov (Criteria of effectiveness of traditional and alternative sources of energy). *Electronic scientific journal "Neftegazovoe delo - Oil and Gas Business"*, 2011, Issue 1, pp. 285 - 299. http://www.ogbus.ru/authors/Goloskokov/Goloskokov_5.pdf
3. Safronov A.F., Goloskokov A.N. EROEI kak pokazatel' effektivnosti dobychi i proizvodstva energoresursov (EROEI as efficiency index of energy recourses recovery and production), *Burenei i neft'*, Issue 12, 2010, pp. 48 - 51. <http://burneft.ru/archive/issues/2010-12/13>
4. Charles A.S. Hall. Cutler J. Cleveland. EROI: definition, history and future implications, *ASPO-US conference*, Denver, November 10, 2005. URL: <http://www.esf.edu/efb/hall/talks/EROI6a.ppt> (Last accessed 10.09.2010).
5. Interview with dr. Robert L. Hirsch. The Impending World Energy Mess / The Energy Crash Blog. URL: <http://energycrash.blogspot.com/2010/09/impending-world-energy-mess-with-robert.html> (Last accessed 10.09.2010).
6. List of common conversion factors. URL: http://astro.berkeley.edu/~wright/fuel_energy.html (Last accessed 10.09.2010).
7. Glaz'ev S.Yu. Strategiya operezhayushchego razvitiya Rossii v usloviyakh global'nogo krizisa (The strategy of accelerated development Russia in the the global crisis conditions). Moscow: Ekonomika, 2010. 255 p.
8. Yakovets Yu.V. Epokhal'nye innovatsii XXI veka (Epochal innovations of the XXI century). Moscow: Ekonomika, 2004. 444 c.
9. Moiseev N.N. Sud'ba tsivilizatsii. Put' razuma. (Fate of civilization. Wisdom's Path). Moskva, MNEPU, 1998. 228 p.