Human Autotrophy

by Vladimir I. Vernadsky

translated from the French by Christine Craig

Translator's Introduction:

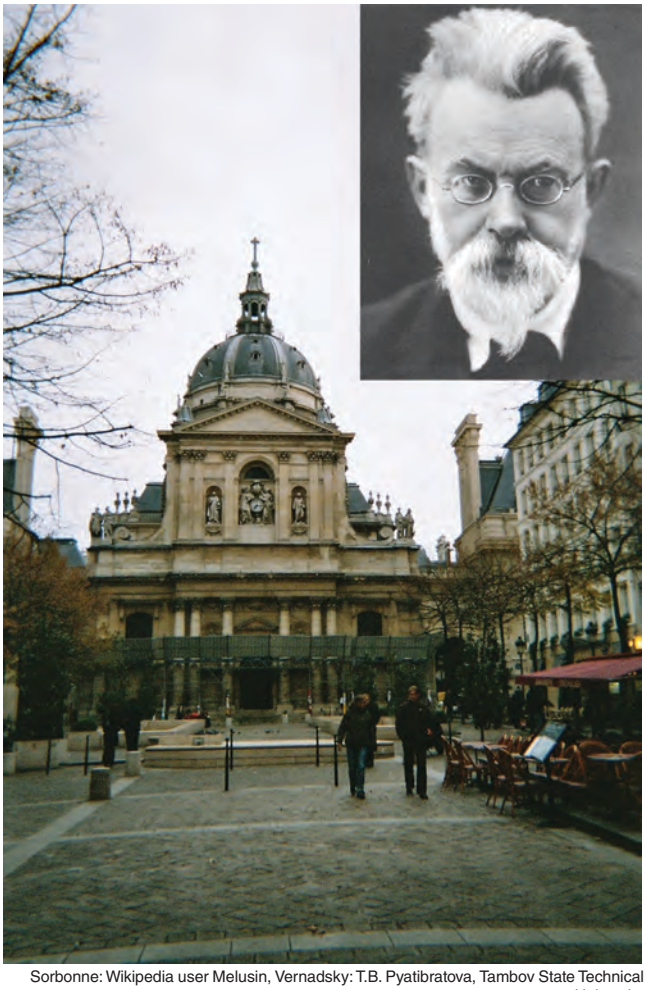
Paris held a special place in Vladimir Vernadsky's heart, and he visited it numerous times over the course of his scientific career. His longest stay in Paris was from 1922-1925, the time during which this article was written for the Revue générale des sciences pures et appliquées *(1925) in France.*

It was during this stay that Vernadsky began developing his concept of the noösphere. During this time period he also wrote his book Biosphere*, which he published in Russian in 1926 after returning to Russia.*

In Paris Vernadsky rubbed shoulders, not only with the French (and European) intelligentsia, but with many Russian émigrés who had fled the chaos of the Russian Revolution and its aftermath. The city, with its wealth of scientific and cultural institutions, was incredibly fertile ground for the growth of scientific and social ideas. It was here that the very word noösphere was coined, perhaps by Édouard Le Roy, or maybe Teilhard de Chardin, probably in response to having sat in on Vernadsky's lectures at the Sorbonne. Here, on the Left Bank of the Seine River, the Curies, Pierre and Marie were ensconced at the Radium Institute, while Louis Pasteur lay buried in a vault beneath his Pasteur Institute a few miles away.

Vernadsky had the opportunity to teach for several terms at the Sorbonne (founded in the 13th century), and these lectures may have formed the foundation of his Biosphere*. They no doubt also shaped the ideas he expounds in the present article, where he broaches the subject of the noösphere (a word he does not yet use) in a unique way, by focusing on the idea of human autotrophy: mankind, through scientific advances, freeing himself from reliance on the "ancient material forms of existence," to become "a third branch independent of living matter," along with chemoautotrophs and photoautotrophs.*[1]

I was inspired to translate this work after reading it in the (now-defunct) French magazine Fusion*, Jan.-Feb. 2006. Footnotes, unless indicated as Vernadsky's, are mine.*



Sorbonne: Wikipedia user Melusin, Vernadsky: T.B. Pyatibratova, Tambov State Technical University

1 There exists now on the terrestrial surface a great geological force, perhaps cosmic—although planetary action is not generally taken into consideration in concepts of the cosmos, in scientific ideas or those based on science.

This force does not seem to be a new manifestation or special form of energy, nor yet a pure and simple expression of known energy. But it exerts a profound and powerful influence on the course of energetic phenomena on the Earth's surface, and consequently has repercussions, smaller but undeniable, beyond the surface, on the existence of the planet itself.

This force is human reason, the directed and controlled will of social man.

1. For a fascinating essay on Vernadsky in Paris, please read "Why to Paris," by A. V. Lapo, 2002. URL: http://vernadsky.name/wp-content/uploads/2013/02/Lapo-Pochemu-Parizh-angl.pdf

Its manifestation in the environment over the course of myriads of centuries is apparent as one of the expressions of the totality of organisms "of living matter"[2]—of which humanity constitutes but one part.

However over the last several centuries, human society has increasingly distinguished itself from [merely] living matter, by society's action on the surrounding environment. This society becomes in the biosphere, that is to say in the outer envelope of our planet, a unique factor, growing powerfully with great acceleration, a factor which changes—by itself—in a new and rapidly growing manner, the most fundamental mechanisms of the biosphere.

It becomes more and more independent of other forms of life and evolves toward a new vital manifestation.

2 Certainly man seems inseparably tied to living matter—to the entirety of organisms which now exist or which existed before him.

He is linked primarily by his genesis.

No matter how remotely we push into the past, we are sure to find living generations, which are without any doubt genetically linked with each other.

In this past, we can discover with certainty more than ten thousand successive generations, at least—father to son—of *Homo sapiens*, which in their essence cannot be distinguished from us, neither by their character, nor by their exterior, nor by their elevation of thought, nor by the force of their emotions, nor by the intensity of their spiritual life. More than 200 generations have already passed since the era of the birth within human society of the great constructs of religion, science, and philosophy. More hundreds of generations separate us from the times when were laid out the first broad outlines of the works of art, music, myths, magic, which gave birth to religion, to science, and to philosophy.

Francesco Redi (1621-1697)

But the origins of man must be sought even further back in the depths of time. Those ancestors are lost in the mists of the unknown. Their form, their organism, were different than ours; but the essential fact—the succession of generations linked materially, father to son—remains intact. Our connections with these beings so unlike us are concrete. Their past existence is not a fiction.

As far back as our thought or our scientific researches are able to reach into the geological past of the Earth, we encounter the same phenomenon of the existence on the terrestrial crust of one single block of life,[3] uninterrupted, unique. We observe life which is extinguished and renews itself eternally.

About 100 generations have passed since the thinking of the great Greeks focused on this phenomenon, which produced among them the effect of a profound cosmic mystery. It remains for us, their remote descendents, just as it stood before these wise men.

About ten generations before us, the great Florentine naturalist F. Redi—the doctor, poet, man of high morals, a great Catholic Christian—had first expressed a new idea which probably had, from time to time, sprung up in isolated thinkers of past generations, but remained hidden. This revolutionary idea was expressed without, however, coming to the attention of his contemporaries. Their mentality was evidently little prepared. Redi affirmed: All living organisms draw their origins from other living organisms—formally expressed in this form one or two generations after him, by another Italian naturalist, A. Vallisnieri.

This principle of F. Redi was not incorporated into our scientific concepts until the 19th century, almost eight generations after his death. It was a great Frenchman, L. Pasteur, a man of kindred spirit, soulmate of F. Redi, who introduced it definitively into our representation of the cosmos.

Certainly one must represent the genealogy of humankind by the millions of successive generations of beings, which follow, father to son without interruption, and wherein the morphology and functions become modified from time to time. Furthermore, it is extremely likely that life was quite brief for our long-gone ancestors. In measuring the past through the successive generations of man and his ancestors, we arrive at vast numbers surpassing our imagination.

3 Western man has followed the clear path of reason of F. Redi and L. Pasteur, only with reluctance and great effort.

Ideas relating to the eternity of life, to its lack of be-

2. On the notion of "living matter" as a group of organisms, see V. Vernadsky: Geochemistry, Paris, Félix Alcan, 1924, p.51. I give in this book a more detailed view of some problems relating to the subject of this article (author's footnote).

3. Throughout his article, Vernadsky used the terms *bloc de la vie* and *bloc vivant* (block of life and living block) to indicate the totality of organisms as a group under consideration. This is different from the concept of "life" in itself. I have translated his terms in various ways throughout the translation, while trying to remain faithful to his meaning.

ginning, to the insurmountable difference which exists within the framework of known physical-chemical phenomena, between inanimate matter and living matter, have been in radical discord with his [Western man's] thought-habits, with his worldview. Ideas relating to the beginning and the end of the visible cosmos, of the material universe, as well as to the true unity of all that exists, have profoundly molded his mind.

Oftentimes abiogenesis, that is to say, the genesis of living organisms from inanimate matter without another organism as intermediary, seems logical to the learned; it seems to be a necessary idea for the history of geology and of our planet, and for the scientific explanation of life. They have expressed—with a profound faith—the conviction that the direct synthesis of organisms from scratch out of the material elements will be the inevitable culmination of scientific progress. They don't doubt that there was a moment—if the process follows its course not just in our era—where an organism sprang from the terrestrial crust by a spontaneous change of inanimate matter.

It is necessary to not lose sight of the fact that these conceptions have their root not in the notions of science, but in the domain of religion and philosophy.

Certainly it is *possible* that these conceptions correspond to reality. They cannot yet be considered as refuted by science. But nothing indicates their likelihood. There is nothing to indicate that the problem of abiogenesis is not of the same class as the problems of the quadrature of the circle, the trisection of the angle [by compass and straightedge], perpetual motion, and the philosopher's stone. The inclination of thought to solve these problems has had very important effects. Thanks to it great discoveries have been made—but still the problems are not solvable in the real world.

In order to remain in the domain of science we must declare that:

1. Nowhere have indications of abiogenesis been found in the phenomena which take place or have taken place on the terrestrial crust.

2. Life, such as it presents itself to us in its manifestations and variety, has existed without interruption since the formation of the most ancient geological layers—since the Archean Epoch.

3. Not a single organism exists—among the hundreds of thousands of different species studied—which was not ordered in its genesis exclusively by the principle of F. Redi.

If abiogenesis is not a fiction of the mind, it is only produced outside of known physical-chemical phenomena. Only the discovery of unforeseen phenomena would be able to demonstrate its reality, like the discovery of radioactivity had proved the mass defect in matter and the destruction of the atom, which were only manifested outside of the physical-chemical phenomena studied up until then.

At the present time we are not able to scientifically consider life on our globe otherwise than as an expression of a unique phenomenon which has endured without interruption since the most remote geological times whose clues we have been able to study. Living matter has endured throughout all this time separated from inanimate matter. Man is irrevocably linked to the same totality of life with all the living beings which exist or which have existed.

4 Man is also linked to this totality by his nutrition. This new connection, as intimate and as indispensable as it is, is not of the same order as the uninterrupted succession of the generations of living beings. This connection doesn't appear to us as a profound natural process, immutable, indispensable to life like that which is expressed by the Redi principle.

It is true that this connection is part of a great geochemical phenomenon—of the circulation of the chemical elements in the biosphere because of the nutrition of organized beings. This connection has perhaps changed, yet without affecting the stabilty of the totality of life. In the paleontological history of the biosphere, there are serious indications of an analogous shift which had already taken place in the course of time, in the evolution of certain groups of bacteria—invisible and minute beings, but with strong geochemical power.

Man's dependence on the living for his nutrition presently rules all of his existence. A change in regime, were it to come, would have immense consequences. The crucial fact, at the present moment, is the potential which is proper for man to preserve his existence, to construct and keep intact his unique body through the assimilation, either of other organisms, or of products of their life. The chemical compounds thus formed in the terrestrial crust are necessary and indispensable for existence, but the human organism does not have the means to produce them himself. He must look for them in his living environment, annihilating other living beings or exploiting their biochemical work. He dies if he finds himself upon the terrestrial surface in the absence of other living beings, which constitute his nourishment.

It is clear that all human life, all societies developed in the course of history, are controlled by this necessity. In the last analysis, it is this irresistible need which governs the human world, which shapes all of its history and all of its existence.

It is famine, in the end, which is the pitiless factor, the terrible agent of the social edifice. Social equilibrium is only achieved by incessant labor, and it is always unstable. The great disruptions of society, the crimes perpetrated on this terrain always have disastrous consequences.

Our civilization in this respect finds itself always at the brink of a precipice. At present hundreds of thousands of men die or languish in Russia because of lack of nourishment and millions of others—more than 10-15 millions—have been victims of social wrongs. Never has the precariousness of human existence been so clear and the specter of disgrace and decadence so alive in the spirit of disorder.

5 Only recently—less than five generations separate us from those times—has man begun to understand the intricate and very special structure of the living system in which he appears.

And as yet the consequences of this structure—enormous social and political consequences—have not penetrated his thought.

One can see this plainly in considering current social ideas that are promulgated around us and which set the world into motion. These ideas reside fundamentally outside of today's science. They are the expression of the past in the exact sciences, corresponding to the science of one hundred years ago! All the progress in science of the 19th- and 20th centuries have had but a feeble influence on contemporary social thought. The exact sciences have been transformed from the bottom up and their antagonism with social ideas has become greater and greater. Not just the masses—but those who lead and inspire as well—belong in their thinking and their scientific baggage to a long-past stage of scientific evolution. Humanity, in its actual social development is in large part governed by ideas which conform little to reality and express the scientific thinking and knowledge of vanished generations of the past.

A profound change of social and political ideas, because of fundamental new acquisitions in natural science, in the exact sciences, is imminent, and it is already making an appearance. The problems of nutrition and of production must be reexamined. This change will necessarily be followed by an upheaval in the very social principles which direct opinion. The slow infiltration of scientific acquisitions into life and into thought is a habitual and general trait in the history of science.

6 The new foundations of our present representation of nutrition were achieved in the years before the end of the 18th century by the efforts of a small elite of humanity who transformed our conception of the world without having been understood or valued by their contemporaries.

They were, first, Lord H. Cavendish of London, the richest man in his country, misanthrope and ascetic of science; A. L. Lavoisier, financier and experimentalist, a profound and lucid thinker, whose assassination is an indelible shame for humanity; the ardent theologian and radical Englishman J. Priestly, persecuted and misunderstood, who by luck escaped death when the mob burned and destroyed his house, his laboratory, and his manuscripts, and who had to flee his country; the Genevese aristocrat, representative of a family where high scientific culture was hereditary, Th. de Saussure; the profound Dutch naturalist and doctor J. Ingen-Housz who, because he was Catholic, could not make a career in his country and worked in Vienna and England…. They were followed by many researchers in all countries.

Wilhelm Pfeffer, German plant physiologist (1845-1920)

One or two generations after these pioneers—around 1840—their thinking had definitely penetrated science and was expressed lucidly and fully in Paris by J. Boussaingault and J. Dumas, and at Giessen in Germany by J. Liebig.

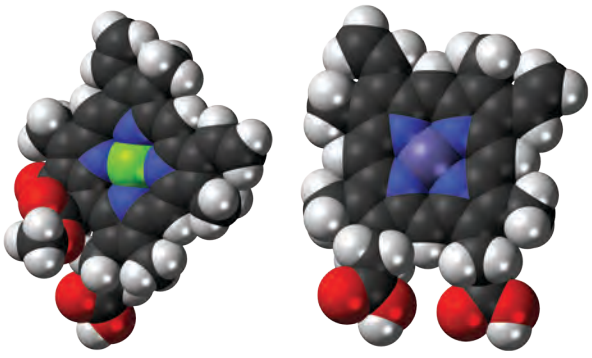
A major effect of immense impetus was unleashed by this labor.

7 The living system—the world of organisms—seems *double* in function and position in the crust.

The greater part of living matter, the world of green plants, depending only on inanimate matter, is independent of other organisms. The green plants are able to create for themselves the necessary substances for their life in utilizing the inorganic chemicals in the crust. They take the gasses and aqueous solutions from the surrounding environment and construct for themselves innumerable carbon and nitrogen compounds—hundreds of thousands of different substances—which are incorporated into the composition of their tissues.

German physiologist W.[4] Pfeffer distinguished organisms which possess these abilities by the name of *autotrophic organisms*, because they were only dependent on themselves for their nutrition. He named *heterotrophic*

4. Vernadsky mistakenly had Pfeffer's first initial as J., but is clearly referring to the great German pioneer in plant physiology, Wilhelm Pfeffer.

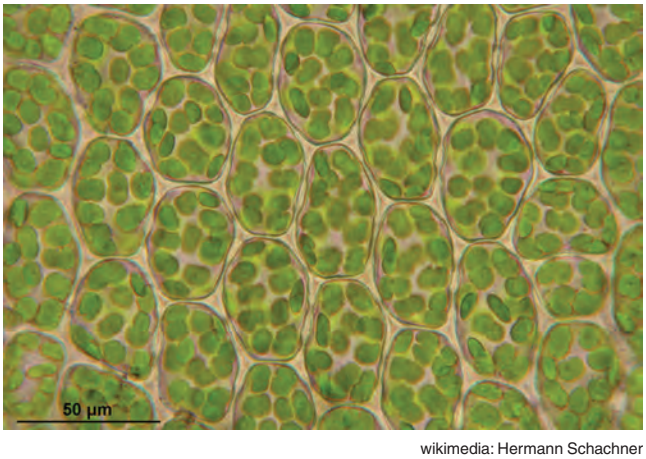


Three-dimensional space-filling images of the porphyrin molecule common to both chlorophyll and hemoglobin. On the left is the chlorophyll-a porphyrin molecule with its magnesium center. On the right is the heme porphyrin molecule with its iron center.

those organisms which depended, for their nutrition, on other organisms, utilizing their chemical products. They are able only to change chemical compounds made outside themselves, which they appropriate for their life, but cannot construct for themselves.

There exist green organisms whose nutrition is mixed, organisms which in part make the necessary chemical compounds, and use the substances of inanimate matter, and in part obtain it—as with parasites—by exploiting other organisms. These beings, numerous in living nature, are the *mixotrophs* of Pfeffer. Mistletoe is a well-known example.

In the final analysis autotrophic green organisms—green plants—form the foundation for the living system. The world as diverse as the mushrooms, the millions of animal species, humankind—cannot exist except as a consequence of their biochemical work. This work would not be possible except by the grace of the innate property of these organisms to transform the energy of solar radiation to chemical free energy.



wikimedia: Hermann Schachner

Cells of the moss Plagiomnium affine *showing numerous plastids per* cell.

It is clear that life is not a simple terrestrial phenomenon, but manifests itself as a cosmic phenomenon in the history of our planet, in so far as the principle of Redi corresponds to reality.

And furthermore it follows that the living system is not an assemblage of isolated individuals, an assemblage owing to chance, but exhibits a mechanism where the constituents have functions which influence and coordinate it.

8 Autotrophic green matter is able to perform its proper function in this mechanism thanks to its elaboration of a green substance with very specific and remarkable properties—*chlorophyll*. It is a complex compound which contains atoms of magnesium and has a molecular structure, containing carbon, oxygen, hydrogen, and nitrogen, that is quite similar to that of the red hemoglobin in our blood, where the magnesium is replaced by iron.

Chlorophyll, whose structure and chemical properties are beginning to become clear, is produced in plants within special tiny microscopic granules—the plastids—dispersed throughout the cells. These plastids only originate from the division of other plastids. The organism is unable to obtain them otherwise. This demonstrates a remarkable fact, which indicates a general phenomenon analogous to that expressed by F. Redi's principle. No matter how far we push back into the past—we see the formation of chlorophyllic plastids brought about exclusively by previously formed plastids.

Thanks to plastids of chlorophyll, the organism of green plants is able to pass down its life to other organisms.

If we only considered their nutrition—green plants would be able to exist alone on the surface of our planet.

9 The repercussion of the existence of autotrophic organisms with chlorophyllic function on the surface of the Earth is immense.

Not only is it they which give birth to all other organisms and humankind—but they regulate the chemistry of the terrestrial crust. One can get an idea of the magnitude of this phenomenon by recalling some numerical facts.

The verdure of our gardens, our fields, forests, and prairies surround us. Seen from another planet, from cosmic space, Earth would have a green tint. But that mass of chlorophyll represents but a part. The greatest portion of chlorophyll is invisible to us. It lies in the uppermost layers of the worldwide ocean at depths of up to approximately 400 meters. It is contained in innumerable myriads of unicellular, invisible algae each of which gives birth in the course of two or three daily rotations of our planet, to a new generation, which begins to reproduce itself. In this way, if they did not figure into the nutrition of other beings, their number would become prodigious

and fill the worldwide ocean.[5]

The existence of free oxygen in our atmosphere and in the waters is the expression of the chlorophyllic function. All the free oxygen of the globe is a product of green plants. If green plants no longer existed, in a few hundreds of years there would not remain a trace of free oxygen on the surface of the Earth, and in the end chemical transformations would capture it all.[6]

The mass of free oxygen of the surface of the Earth corresponds to 1.5 quadrillion ($1x10^{15}$) metric tons. That number gives only an idea of the geochemical importance of life.

The amount of chlorophyll produced in green plants necessary to keep free oxygen at this level corresponds to many billions of tons at least, existing at each moment in the bodies of autotrophic plants.

S. N. Winogradsky, the Ukrainian-Russion microbiologist and soil scientist (1856-1953).

10 It has been more than thirty years since the Russian biologist S. N. Winogradsky introduced into this situation a new and important attribute which demonstrates the already-great complexity of the living system.

He discovered the existence of autotrophic living beings without chlorophyll. These are invisible beings, bacteria which teem in the soils, in the superficial parts of the crust, and penetrate the floor of the worldwide ocean.

Notwithstanding their smallness, thanks to their prodigious reproduction, their importance in the economy of nature is huge. This enormous reproduction—comparable with that of the unicellular green algae—obliges us to consider their existence as a phenomenon on the order of that of green plants.

Certainly the number of species of autotrophic bacteria is small, not more than a hundred, while that of green plants is close to 180,000. But whereas in a day each bacterium is able to engender many trillions of individuals, one green unicellular alga, which of all the green plants reproduces the most rapidly, cannot produce in the same interval of time but a few, and generally much less—say one sole individual in two or three days.[7]

The bacteria discovered by S. Winogradsky are independent in their nutrition not only of other organisms, but of solar radiation. In the construction of their bodies they use chemical energy from terrestrial chemical compounds—the minerals—rich in oxygen.

They produce by means of this decomposition—and by virtue of the syntheses which are their consequence—an immense geochemical work. Their role is very great in the history of carbon, sulfur, nitrogen, iron, manganese, and probably many other elements of our globe.

It is certain that they belong to the same life group as the other organisms, because they get their nutrition from these last and use their waste. We are led to think that the connection is very close, that they belong in this genetic group.

One can consider them as very specialized derivatives of green plants, as is done for non-chlorophyllic plants in general, yet without excluding the possibility of seeing in them representatives of the ancestors of chlorophyll-producing beings.

In our present state of knowledge, the first hypothesis seems most likely. Nevertheless, one must always take into account that these organisms of S. Winogradsky play a preponderant role in phenomena of the superficial modification of terrestrial minerals. These modifications seem to be immutable over the course of the geological history of our planet. They have not changed since the Archaic Era.

11 Man is a heterotrophic social animal. He can only exist in the presence of other organisms, especially green plants.

His existence on our planet is clearly distinguished all the same, from that of all the other organized beings. Reason, which distinguishes man within the assemblage of living matter, gives living matter remarkable characteristics, profoundly changing its [living matter's] action on the environment.

The genesis of man was a singular event, unique in geological history, which had no analog in the preceding myriads of centuries.

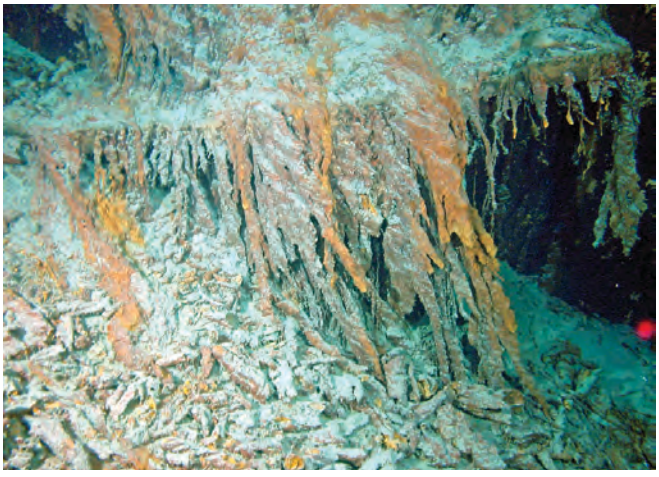
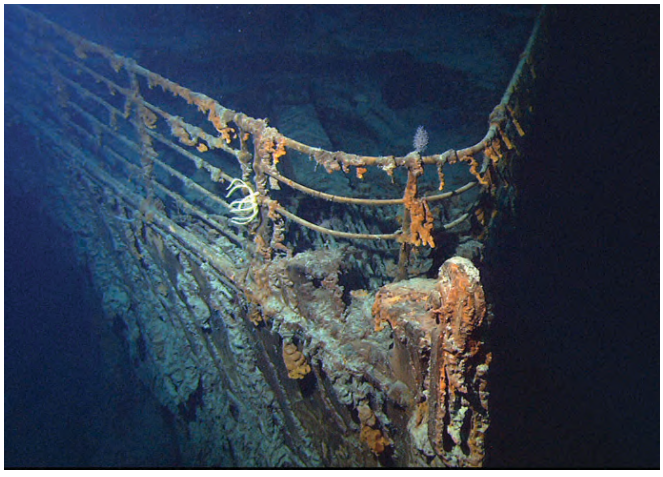
From the scientific standpoint, one must consider it as the consequence of a long natural process, of which the beginning is lost to us, but which has lasted without interruption over the course of all of geologic time. Until now, no scientific theory has been able to encompass the paleontological evolution of organized beings, of which the latest important expression has been the genesis of man.

---

5. Most, but certainly not all of these "invisible algae" would now be placed among the prokaryotes as cyanobacteria.

6. This was written in 1925, and shows a clear understanding of the primary role of photoautotrophic organisms in the generation of the present atmosphere of Earth, which he addresses again in his *Biosphere*, published a year later.

7. If the chemoautotrophic bacterium divided once every half-hour, in 24 hours it would produce about 281.5 trillion individuals. If the eukaryotic unicellular alga divided once every 24 hours it would produce two individuals.

Left: Lori Johnston, RMS Titanic Expedition 2003, NOAA-OE, Right: Courtesy of NOAA/Institute for Exploration/University of Rhode Island (NOAA/IFE/URI)

"Rusticles" feasting on the largesse of the noösphere. These are consortia of bacteria and fungi enjoying a 100-year feast on the iron parts of the sunken Titanic 3.8 km beneath the ocean surface. Chemoautotrophs present in this living community are capable of deriving energy from oxidizing the iron deposited on the deep, dark, and oxygen-poor terrain of the ocean bottom after the RMS Titanic *sank.*

We are unable to represent the genetic change of the living system—the extinction and generation of innumerable species—except under an empirical generalization—that of the evolution of species.

For a man of science, the empirical generalization is the foundation of all knowledge, its form the most certain. But, to connect it to other facts and empirical generalizations, the learned man must avail himself of theories, axioms, models, hypotheses, abstractions. We have but an imperfect sketch in this domain.

It is clear that there exists a determined direction in the paleontological evolution of organized beings, and that the appearance of understanding, of reason, of coordinated will on the terrestrial surface—this manifestation of man—cannot be a game of chance. But it is impossible for us at present to give an explanation of this phenomenon, that is to say of the logical connection with our abstract scientific construct of the world—based on these models and these axioms.

12 Man is profoundly distinguished from the other organisms by his action on the environment. This distinction, which was great from the beginning, has become immense with the passage of time.

The action of other organisms is almost exclusively determined by their nutrition and their growth and increase. The sole fact of the formation of free oxygen is sufficient to appreciate the planetary importance of their nutrition. And it is one fact among thousands of others. The formation of coal, petroleum, iron-bearing minerals, humus, calcites, coral islands, are isolated cases—among thousands of others—of the manifestation of their increase.

Mankind certainly acts in the same way as all of these organisms. But his mass is completely negligible in comparison with the totality of living matter and the direct manifestations in living nature of his nutrition and his increase are almost nothing. The wise Austrian economist L. Brentano has given a very clear representation of the scale of humanity within the environment. If one assigns to each human individual a square meter, and if one brings together all the humans existing on the terrestrial surface—the surface that they would occupy would not exceed that of Lake Constance.[8]

It is clear that the manifestation of such a living mass considered on the scale of geological phenomena would be negligible.

Reason changes all. Through it, man utilizes material in the environment—inanimate or living—not only for the building of his body, but also for social life. And this usage has become a great geological force.

Thought, by its existence, introduces into the crustal mechanisms a powerful process having no analog before the appearance of man.

13 Man is the *Homo faber* of M. H. Bergson. He changes the aspect, the chemical and mineralogical composition of his living environment. His living environment is the whole of the surface of Earth.

His action becomes stronger and more coordinated with each passing century. The naturalist must acknowledge a natural process of the same order as all of the other geological manifestations. This process is necessarily regulated by the principle of inertia—it will follow its

8. Lake Constance, 571 km^2 in size, lies between Germany (Bavaria) and Switzerland at the foot of the Alps, and is fed by the Rhine River.

NASA Earth Observatory, Jesse Allen

A patchwork of farmland in northwest Minnesota along the Buffalo River

course regardless, if forces don't exist which oppose it or which take it to a potential state.

The discovery of agriculture, made over 600 generations before us, decided the path of humanity. By controlling the life of the autotrophic green organisms on the terrestrial surface man gained leverage, with immense consequences for the history of the planet. Man has become by this fact master of all living matter, and not just green plants, since the existence of all beings is controlled by the green plants. Little by little he changed living matter by the decisions—the goals—of his reason.

Through agriculture, he was liberated—in his nutrition—from the natural living environment, of which all the other organized beings are naught in this respect but impotent processes.

14 Relying on this great conquest, man has annihilated "virgin nature." He has introduced immense quantities of new, unknown chemical compounds and new forms of life—races of animal and plants.

He has changed the course of all of geochemical reactions. The face of the planet became new and found itself in a state of continual upheaval.

But man has not yet succeeded in gaining, in this new environment, the security necessary for his life.

In his social organization, existence itself, for the majority is precarious, the distribution of wealth does not give to the great mass of humanity the means of a life conforming to moral and religious ideals.

New, troubling events, which relate to the bases of his existence, are let loose in these recent times.

The reserves of natural resources decrease visibly. If their usage grows with the same force, the situation will become grave. In two generations one would detect a scarcity of iron; petroleum would also quickly become scarce; in a few generations, the question of coal would become tragic. It is the same for most of the other natural resources. The dearth of coal would be particularly grave, because it is coal which procures for man the energy necessary for society in its present form.

This is an inevitable phenomenon, because man uses the stores of natural resources which were formed throughout myriads of centuries and which could not be replenished except in the same length of time. These reserves are necessarily restricted. Similarly if one found other unknown sources, or if one used the less rich or deeper concentrations—one would only push back the date of the critical period—but the troubling problems would remain unresolved.

For generations, profound thinkers have perceived the necessity of radical social means, of scientific acquisitions of a new order to rein in the imminent danger. At the beginning of the last century, the imminent scarcity of natural resources was not yet perceived, because the energy at man's disposal in this era was still largely connected to ancient material forms of existence—to the life and works of men, of plants, and of animals. Nevertheless already the founders of socialism—particularly Count H. de Saint-Simon, W. Godwin, and R. Owen—understood the primary importance of science, the impossibility of resolving the social question while using only the resources which existed in their day, without augmenting, by science, the means of human power.

It was truly a scientific socialism in a sense which has since been forgotten.

The problem which is posed at this moment before humanity clearly goes beyond the social ideology, which has since been elaborated by the socialists and communists of all schools, who in their constructs have allowed the vivifying spirit of science—its social role—to elude them. Our generation has been victim of an application of this ideology in the course of tragic events in my country—one of the richest in natural resources—of which the results were death and famine for the multitude and economic failure of the communist system which seems undeniable. But the failure of socialism seems more profound. It presents in general the social problem from a too-restricted viewpoint, which does not correspond with reality; it remains superficial.

15 To resolve the social question it is necessary to plumb the foundations of human power—to change the form of nourishment and the sources of energy which man uses.

Precisely on these two points, little by little the thoughts of researchers are engaged. Here one is on solid ground. Not only can there be no doubt of the possibility of solving these two problems, but it is also clear that they will inevitably be solved in a very short time, even in comparison with the human lifespan.

The solution to these problems is taking shape as a result of scientific progress outside of all social preoccupation. After generations, science, in its quest for truth, is forced to discover new forms of energy in the world and great organic chemical syntheses. It labors with very insufficient means, the only ones available in human society today, where the situation is in striking contradiction with its [science's] real role as producer of wealth and of human power.

This scientific movement can be accelerated by creating new methods of research; it can't be stopped. Because there is not a force in the world which can shackle human understanding in its march, once it has understood, as in the present case, the scope of the truths which are opened before it.

16 Until now, the power of fire in its multiple forms was almost the sole source of energy for society. Man obtained it by the combustion of other organisms or their fossil remains.

Some decades ago, he began systematically to replace it by other sources of energy, independent of life—first by hydropower. The quantity of hydropower—the motive force of water—existing on the terrestrial surface was measured. And it was seen that, large as it seems, it is not sufficient by itself for societal requirements.

But the reserves of energy which are at the disposal of reason are inexhaustible. The force of the tides and ocean waves, radioactive atomic energy, solar heat are able to give us all the power needed.

The introduction of these forms of energy into life is a matter of time. It depends on problems whose solutions present nothing impossible.

The energy thus obtained will not have practical limits.

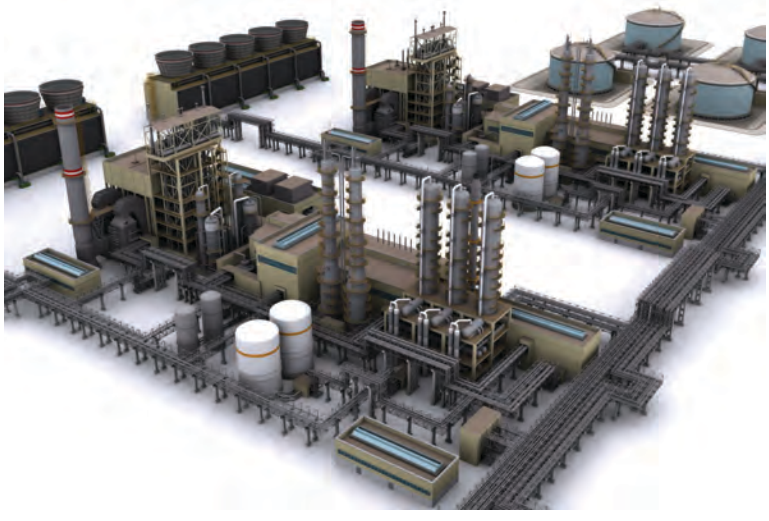
In directly utilizing the energy of the sun, man is made master of the source of energy of the green plant, of the form that he now uses through the intermediary of the latter in his nourishment and as fuel.

17 The synthesis of foodstuffs, freed from the intermediary of organized beings, when accomplished, will change human prospects.

It grips the imagination of the learned after the great successes of organic chemistry; in fact it presents a hidden but always vibrant aspiration of laboratories. It is never lost from view. If the great chemists only express it from time to time, like the able M. Berthelot, it is because they know that the problem will not be resolved before the undertaking of a long preliminary work. The work is carried out systematically, but must be the labor of many generations, considering the great poverty of science within our social structure.

One generation has already disappeared since the death of M. Berthelot. We are much closer to this supreme goal than we were during his lifetime. We can follow its slow but incessant progress. After the brilliant work of the German chemist E. Fischer and his school on the structure of albumin and of the carbohydrates, there can be no doubt of its eventual success.

During the Great War, the problem was often envisaged in various countries in its practical aspect and



Deviantart user Shefu-de-combinat

Ammonia processing by the Haber-Bosch process was one of the most significant steps toward human autotrophy in modern history. It can be argued that the synthesis of ammonia from atmospheric nitrogen and hydrogen without the required intervention of microorganisms, can be credited with enabling half of our 7 billion earthlings to be alive today. Furthermore, half the nitrogen present in the average human body today, came from Haber-Bosch ammonia, not from life-derived nitrogen-fixing processes. The green revolutions were fueled by Haber-Bosch nitrogen fixation, which is today fueled mainly by natural gas, but could be integrated into nuplexes using fourth-generation nuclear technology to boost this technology to the next level.

faith in its imminent solution took deep root among the learned.

Certainly it often happens that a scientific discovery is lost or doesn't find its practical application, its introduction into life, until long after it was first made. But we can be confident that the synthesis of food will not meet such a fate.

We await the discovery of this synthesis, and its great consequences to life will immediately be manifested.

18 What would be the significance of the synthetic production of nutriments to human life and to the life of the biosphere?

By its accomplishment man would free himself from living matter. From a social heterotrophic being, he would become an *autotroph*.

The repercussion of this phenomenon within the biosphere would be immense. It would signify the schism of the block of life, the creation of a third branch independent of living matter. By this feat there would appear on the terrestrial surface, and for the first time in the geological history of the globe, an *autotrophic animal*.

Today, it is difficult, perhaps impossible, for us to grasp the geological consequences of this event—but it is clear that it would be the culmination of a long paleontological evolution, which would represent, not an action of the free will of humanity, but the manifestation of a natural process.

By this achievement, human understanding would produce not only a great social effect, but a great geological phenomenon.

19 The repercussion of this synthesis in human society shall certainly touch us with ever-greater force. Will it bring good or will it bring new desolations to the human species? We don't know. But the course of phenomena—the future—will be perhaps controlled by our will and by our reason. We must prepare to understand the consequences of the actions of this inevitable discovery.

Only isolated thinkers sense the approach of this new age. They see these consequences differently.

One finds the expression of these intuitions in works of fiction. The future seems troubled and tragic for some (*Histoire de quatre ans*, by D. Halévy), at the same time that others see it as great and beautiful (*Auf zwei planeten*, from the profound German thinker and historian of ideas, K. Lasswitz).

The naturalist can only contemplate this discovery with a great tranquility.

He sees in its accomplishment the outcome of a grand natural process which has endured for millions of years and which gives no sign of dissipating. It is a creative process, and not anarchic.

Indeed, man's path is always formed in great part by man himself. The creation of a new autotrophic being will give him possibilities which have been lacking for the accomplishment of his secular moral aspirations; it will open for him the path to a better life.

V. Vernadsky
Member of the Russian Academy of Sciences
General Review of Pure and Applied Sciences, 1925.