CASE 107

Clustering Agriculture, Forestry, Biorefineries and Stranded Assets

Executive Summary:

Societies today are highly dependent on petroleum and it is a great challenge to shift towards more renewable and sustainable ingredients. Biorefineries are at the core of making this shift possible by using biomass, which does not compete with food as feedstock, and to create a portfolio of competitive products. Methods such as steam explosion enable industry to extract and separate biomass into valuable raw materials without the use of catalysts, offering a concrete example of zero emissions and waste converted into value at low cost. Research has shown that substances like the tobacco plant offer much more than a revenue from a deadly smoking habit. We are discovering more potential from agricultural and forestal products to create biochemicals, animal feed and useful enzymes. As we begin to make the shift towards a new type of sustainability known as "The Blue Economy", we must not forget to repurpose defunct factories and contaminated land that are stranded assets in order to boost a local and competitive economy and with a positive impact on the environment.

Keywords: biorefineries, petroleum, renewable and sustainable ingredients, agro-waste, petrochemicals, steam explosion, waste products, biochemicals, animal feed, local economic development, stranded assets, job creation

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Humble Beginnings: Dr. Aurelio Peccei

In 1986, the president of ENEA (the Italian alternative energy research institute) and vice-president of the Club of Rome, Dr. Umberto Colombo, accepted to write the foreword to my book "Aurelio Peccei: the Crusader for the Future, A Portrait of the Founder of the Club of Rome". Ever since that moment he offered a strong support for my work. Aurelio Peccei was a remarkable executive who had led major industrial enterprises such as FIAT and Olivetti, and whom I had the privilege of working with for four years (1980-1984). I became acquainted with Dr. Peccei when I had just been elected as a student leader in Belgium (AIESEC). He always encouraged me to remain independent and never take a job with a multinational or a leading consultancy. He argued that the world needs people with a creative mind, an appetite for calculated risks and the clarity on the way forward in spite of expert opposition. This is the role he encouraged me to play in society.

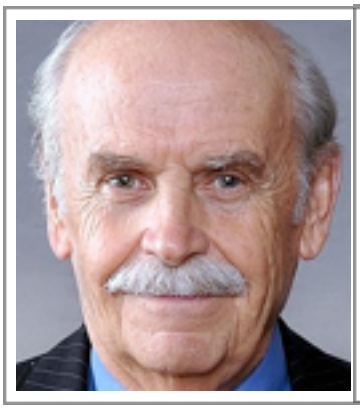
Aurelio Peccei | Umberto Colombo | Juan Rada | Hugo Thiemann

The leadership of the Club of Rome after the death of Aurelio Peccei in 1984 did not welcome my presence at their meetings, unlike Dr. Peccei who not only encouraged me to come and join them but also put me on the spot to share my opinion. I had joined the spheres of the Club together with Dr. Juan Rada, the Director of the International Management Institute (IMI) in Geneva and later Senior Vice President of Oracle Corporation. Although we were marginalized in a think tank that proposed to study the long-term effects of social and economic developments on a global scale, we benefited from a high level thought process delivered by a dedicated group of front line thinkers who were keen to see a new generation of disruptors to the status quo. Umberto Colombo, Hugo Thiemann (Director of the Battelle Memorial Institute), Bohdan Hawrylyshyn[1] (Director of the Centre d'études Industrielles CEI in Geneva), Maurice

[1] Bohdan Hawrylyshyn is author of the Report to the Club of Rome entitled: "Road Maps To The Future. Towards More Effective Societies" published in 1980.

Guernier[2] (Inspector of Finance with the French Government), Orio Giarini (Director of the Swiss-based insurance research institute) and Carl-Göran Hedén (Director of the Karolinska Institute in Stockholm) were happy to become occasional mentors after Dr. Peccei had passed away.

One of the core subjects that moved this select group of forward thinkers was the creation of biorefineries. The arguments put forward associated the difficulty to shift from a society that is highly dependent on petroleum to one that relies on renewable and sustainable ingredients. This comes with the hard reality that petroleum is cracked and then synthesized into thousands of man-made molecules, whereas agricultural produce and forest products are solely planted as a monoculture for a single product and everything else was wasted. These experts disregarded the prevailing logic that there is a need to replenish the soil with the agro-waste as plants do not provide the most efficient nutrition to the soil; the leftover material needs to be processed by animals, fungi and bacteria and their waste is an ideal nutrient for the soil. It is the waste of the waste that became a central logic in the cascading of matter, nutrition and energy which characterizes the principles of "zero emissions". The heated debate and the core proposals permitted to focus on the processing of any renewable biomass feedstock along the same logic as petrochemical refineries obtaining dozens of functional chemicals, food and feed. Dr. Colombo undertook an extensive research program at ENEA investing over the years over €100 million, and Maurice Guernier positioned it as a revolution that would ensure development in Africa influencing African heads of state. Prof. Hedén who worked on the subject in concrete terms, networking around the world. He encouraged me to pursue this pioneering economic development model as soon as I took up the role of senior advisor to the Rector of the UNU in 1994.



Bohdan Hawrylyshyn

Hugo Thiemann

Maurice Guernier's Report

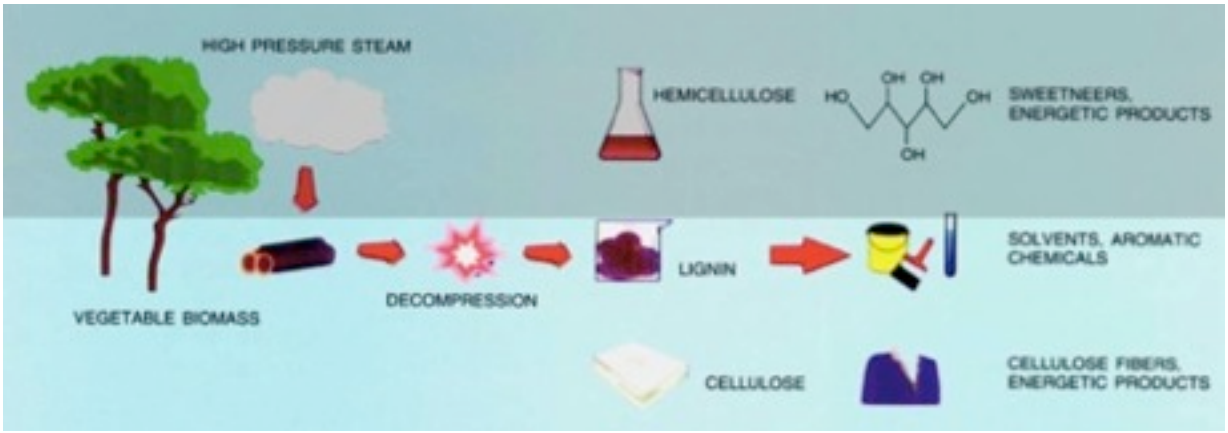
Carl-Göran Hedén

[2] Maurice Guernier is author of the report to the Club entitled “Third World: Three Quarters of the World” with a picture of the original French edition "Le Tiers Monde - Trois Quarts du Monde" published in 1980.

Tobacco Plant Industry: More Than a Cigarette

Prof. Hedén is a medical doctor who developed great interest in biology and headed this department for years at the Karolinska Institute, which is the renowned medical research institute and hospital in Stockholm, Sweden. When the tobacco industry was put under increased scrutiny in the 1970's by the public at large and the Scandinavian policy makers in particular, the national Swedish tobacco company decided to embark on a research programme to study the content of the tobacco plant. They designed a complete facility that would separate the biomass and derive some 2000 distinct molecules from the plant. The desk research demonstrated that the tobacco plant contains a wealth of components over and beyond nicotine that constitutes a much greater value than the revenue that could be generated from the production of a cigarette. This research, followed in great detail by Prof. Hedén, lead to a debate among engineers about how to design the refinery for tobacco and which ingredients to derive first.

The research programme spanned several years until the pressure from the Swedish Government reached a new high in the 1980's and the spending for research on tobacco was further curtailed. The Swedish tobacco company felt it was on the brink of a fundamental rediscovery, which prompted it to speed up the search for a new livelihood for its business by diversifying into the potential of the plant instead of selling the toxicity of the tobacco. The move to North Carolina (USA) provided a great openness and flexibility on the costs and introduced the tobacco researchers to a set of process technologies that have not been explored in Sweden. At the centre of the separation and isolation technique stood the process known as steam explosion. I learned to know about the steam explosion in the beginning of 1994 when I had just started the ZERI activities in Japan and was amazed that as an active anti-smoke campaigner, I had to recognize that a few people inside the world of cigarettes were designing very sustainable industrial processes from which we could learn a lot.



Graphic presentation of steam explosion by Environment Canada

The logic of establishing the research facility in North Carolina (USA) was inspired by the fact that 80% of crop residues in this state are located in the coastal area which renders the transport cheap and easy. The total volume of corn stover and wheat straw could be used to produce 200 million litres of ethanol per year. Considering that one would limit the delivery to only forty kilometres around the production plant, the coastal region of North Carolina could then establish four ethanol plants driven by the availability of biomass in the region. This decentralized production model base determined the size of operations and the energy balance of production.

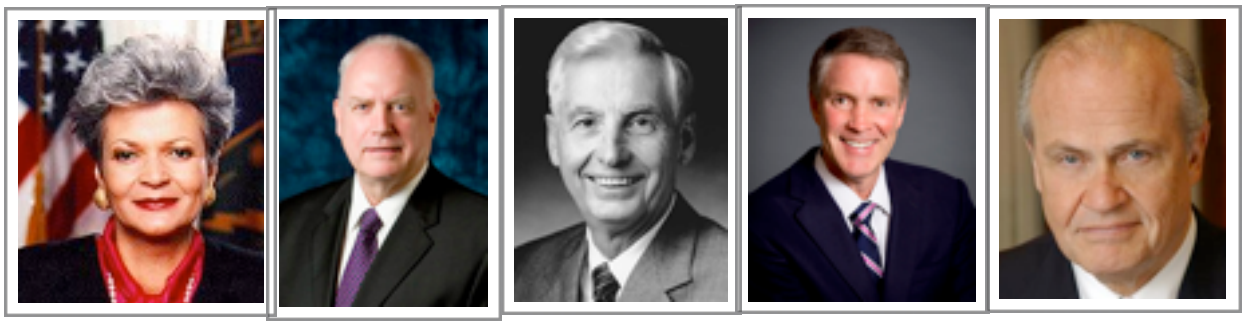
The Steam Explosion Effect

Steam explosion is a separation and extraction technique for plant material that requires nearly no chemicals or catalysts. It operates with saturated steam (180 to 230 °C) under high pressure (15 to 30kg/cm²) exposing shredded biomass. These physical conditions break up the chemical bonds between lignin, cellulose and hemicellulose which are the three major components of a plant. When this biomass is forced through a narrow nozzle, the matter loses its physical structure which makes it more soluble in water. This was one of the first industrial innovations that clarified that physics should precede chemistry. The steam explosion has the potential to replace chemical pulping and black liquor (waste) while generating a rich portfolio of new revenues. The products obtained include lignin which can be used to produce carbon fibers, vanillin and asphalt. The hemicellulose is a polymer consisting of five or six carbon sugars to produce natural sweeteners like xylitol or natural solvents. The cellulose is a glucose polymer used to make paper and textile or to manufacture alcohol. As I was in search for concrete examples of zero emissions and zero waste to present to the meeting where the Kyoto Protocol would be decided in 1997, this pilot biomass refinery funded by the tobacco companies at a rate of US$ 7 million offer a fine demonstration that this process was not only technically viable, but also financially sound.

Walter Truett Anderson Gunnel Dahlhammer Sam Nilsson David Crocket Jacky Foo

The pressure on the tobacco companies was raised even further and a stop on research imposed by the government in 1990's led to the demise of this investigation

programme. Fortunately, Prof. Hedén succeeded in maintaining contact with the defunct research team through the Biofocus Foundation and received the commitment that this facility could be used for non-tobacco research purposes. The Biofocus Foundation, headed by Tommy Jonsson, brought together a group of pioneering thinkers such as Walter Truett Anderson, the President of the World Academy of Arts and Sciences; Gunnel Dalhammar from the Royal Technical University in Stockholm (KTH); and Sam Nilsson of the Nobel Foundation. This effort was further supported by MIRCEN (Microbiology Resource Center of UNESCO) which was later directed by Jacky Foo, who was a team member from the early days at the UNU in Tokyo. A team of experts from Europe visited the operations in the USA in 1995. I joined the group accompanied by David Crockett, the Chattanooga (Tennessee) City Councilor who was interested in bringing this facility to his city as part of his efforts to reindustrialize the region.



Hazel O'leary | Craven Crowell | Edgar Woolard | Bill Frist | Fred Thompson

Chattanooga was aiming to become the leading sustainable city of America and based on a dozen visits between 1993 and 1995, I contributed to the design of a new concept of an industrial development model that included electric bus transport which was the first of its kind in the USA and is still pioneering. The second UNU World Congress on Zero Emissions was held in 1996 in Chattanooga in the presence of US Secretary of Energy Hazel R. O'Leary, and the keynote was delivered by Edgar Woolard, CEO of DuPont, Craven Crowell, Chairman of Tennessee Valley Authority, and a few emerging politicians who are still very influential Senators like the US Senators Bill Frist and Fred Thompson. One of the core subjects of the conference was "Material Separation Technologies" as the basis of biorefineries. The subject was not sustainability, the world congress highlighted innovations that could steer business towards competitiveness and sustainability.

The Tigney Process and Stake Technology

I was impressed with simple design of the North Carolina plant and the ease with which this equipment could separate plant matter into fractions. It was a good example of zero emissions and the cascading of nutrients, energy and matter at low cost while generating higher value. However, the disintegration of the original research team due to the restrictions imposed on tobacco prompted Prof. Hedén to scan the world for

comparable initiatives around the world. The key scientific debate was whether the biorefinery could be a batch or a continuous process. A group of engineers debated in favour of the batch process since it allowed better control of the temperature, pressure and the energy recovery. This group was known as the Tigney Process and was invented by Edward DeLong. This technology was adopted by the Swedish scientists who paid around one million dollars to access the patents. The second process, known as Stake Technology, was a continuous separation and extraction method.

The North American scientists (Canadian and American) were keen to develop a portfolio of processes that would give value to wood beyond its incineration or its use for ethanol only. The core logic had been established: separate the lignin from the cellulose and hemicellulose so that the biomass is ready for hydrolysis and the residues, including pentose sugars, can be used for other purposes than merely fermenting ethanol. Half a dozen technology companies emerged in North America which cracked the opportunity to generate chemicals and fuel. These include enterprises such as Iogen (Ottowa www.iogen.ca) who use steam explosion to process straw with proprietary enzymes; Bionol Corp., later renamed as BC International (Dedham Massachusetts www.bcintlcorp.com) who convert corn stover, bagasse and wood chips into biochemicals but focus on ethanol; Arkenol (Sacramento, California) who work with concentrated hydrolysis; Paszner ACOS (Vancouver, Canada); as well as Stake Technology and Tigney already mentioned.

Janis Gravitis Jeremy Kendall Steven Bromley Tarcisio Della Senta Motoyumi Suzuki Raul Gardini Catia Bastioli

Stake Technology was the only group that already realized back in the 1990's that the key was more than the creation of the biorefinery and the extraction of multiple revenues from biomass. The entrepreneurs who invested years into the technology looked for ways to generate more value by moving closer to the consumer which lead to the merger of Stake Technology Ltd., with Pro Organics who supply the most complete range of certified organic produce, organic bulk foods and natural products. The merger was originally dismissed as a misfit along the logic of the core business and core competence promoted by the traditional business strategists. However, Jeremy Kendall, the then Chairman and CEO of SunOpta (the name of the newly merged company) saw an opportunity to offer integrated business models as early as 2003 (www.sunopta.com) bringing a cluster of innovative production processes together with competitive and healthy consumer products. Steven Bromley has been leading the company ever since and listed on the NASDAQ with total worldwide sales in 2013 excess of US$ 1.2 billion.

Dr. Janis Gravitis: Scientist Extraordinaire

When Prof. Hedén visited the Baltic States Latvia, Lithuania and Estonia, that had gained their independence in the early 1990's with the breakup of the Soviet Union, he realized that many of their research institutes, which were cut off from their funding through Moscow, were now struggling to survive even though their scientific base was exceptionally strong. He came to know Prof. Dr. Chem, Dr. Habil Janis Gravitis, head of the Laboratory of Biomass Eco-Efficient Conversion at the Latvian State Institute of Wood Chemistry (LSIWC). Dr. Gravitis earned his doctorate at the USSR Academy of Sciences and worked on strategic research that was mainly destined for military applications. Under the Soviet era, their research outfit was not known and any correspondence had to be addressed to Factory 127 in Moscow. This research institute was instrumental in the design of the Soviet space programme. The Soviet and Russian spacecrafts re-enter the atmosphere and land instead of plunging into the sea, thanks to an exceptional heat shield that was at one point in time derived from wood.

When Prof. Hedén discovered that the LSIWC designed and operated its own version of steam explosion, he urged me to establish a direct contact. The meeting with Dr. Gravitis in 1995 in Riga (Latvia) was truly enlightening. This unassuming scientist who was flanked by a very smart group of academics not only mastered wood chemistry, but also created and built their own equipment. I had seldom sensed so much wisdom in a room. While their language was often too technical for an economist with an MBA, the team comprising of Valery Ozols-Kalnins, Bruno Andersons, Janis Zandersons and Arnis Kokorevics, took the time to explain and clarify their complex insights. One meeting was sufficient to convince me that this team had the know-how to create a 21st Century biomass refinery that would become a cornerstone of the zero emissions research initiative (ZERI) which was to offer a fresh look at how business would be competitive after an agreement would be reached known as The Kyoto Protocol. After consulting with Tarcisio Della Senta, Vice-Rector of the United Nations University and obtaining the support of Dr. Motoyuki Suzuki, Director of the Institute of Industrial Science of Tokyo University and one of the key scientists for the zero emissions research programme of the Japanese Government, I made a bold move and invited Dr. Gravitis live and work with his family in Tokyo; he accepted the offer.

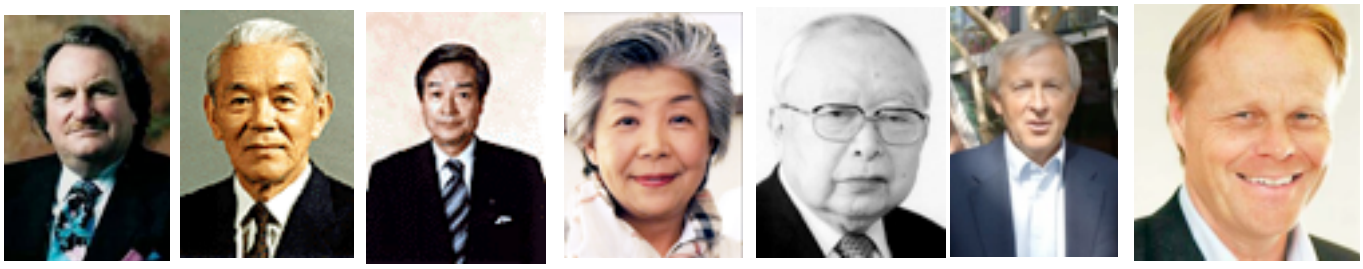
Dr. Colombo's Vision: Biofuels and Biochemicals

In 1995, Dr. Umberto Colombo learned about this progress, and became even more keenly interested in this steam explosion development. We had regular conversations about the way forward. He was convinced that petrochemical installations would soon become white elephants and to move forward would require the insights on how to convert these sunken investments into productive units substituting the feedstock of petroleum with a biomass. He introduced me to Dr. Catia Bastioli who directed the conversion of the Montedison bioplastics research laboratory into an independent company named Novamont. Umberto Colombo was very much in line with the strategic

thinking of Raul Gardini—the flamboyant Italian entrepreneur who was convinced that the future lay in the clustering of strategic activities instead of the blind focus on a core business with a core competence. Gardini's vision was to first cluster chemicals and energy, and then merge food production (especially sugar) into this super cluster to create a conglomerate based on biofuels and biochemicals, strengthening agriculture through the creation of more products and more value. This was an early version of the Blue Economy. Gardini's logic was developed from the perspective of long-term competitiveness of a region, and coincided with the logic that the members of the Club of Rome had developed theoretically in the early 70's. After Raul Gardini lost control of his emerging conglomerate, the new management quickly undid his progress and it took the courage of Dr. Catia Bastioli to ensure that the bioplastics component, with polymers derived from wasted biomass, would have a future.

Bioplastics from Renewables

The world of bioplastics was not new to me. As Chairman of Ecover, I had discussed the opportunities to work together with ICI Chemicals in 1991 and 1992. The British group, under the leadership of John Harvey-Jones, had developed a bacterial plastic under the brand name Biopol, but it was struggling to get into the market. It was remarkable that this traditional chemical group, driven by a chairman who was not a chemist, laid one of the European bases of bioplastics. Even when these Biopol containers were more expensive than the traditional petrochemical ones, I was very keen on proceeding with the introduction of these containers for my biodegradable detergents. Unfortunately these plastics were not stable enough for our liquid soaps and failed to meet the quality standards, prompting further research. Little did I know that as soon as I gave up control of the detergent group, that project would be scrapped. Nevertheless, the hot discussion about bioplastics made from food had already begun in 1992, so the opportunity to source packaging derived from bacteria that had fattened themselves on sugar seemed a great alternative.



John Harvey Jones H. Fujimura M. Taniguchi Masako Unoura Jiro Kondo Göran Carstedt Per Carstedt

Biorefineries: Generating Income and Competitive Products

I finally met Dr. Catia Bastioli for a longer series of meetings in 1999 at the ENI sponsored international congress on "Towards Zero Emissions: The Challenge for Hydrocarbons" where she presented her vision for Novamont. Dr. Gravitis also joined on

paper with a provoking title, "A Way to Produce Value Added Products and Base for Agricultural Zero Emissions". The Japanese contribution from Hiroyuki Fujimura, the Chairman of EBARA, set the stage for a remarkable setting where the 8th largest petroleum company (ENI) and the largest petrochemical concern (Versalis) of Italy provoked a debate under the aegis of Umberto Colombo, their current chairman, to create a new paradigm for energy and chemistry. The emphasis was on how to evolve towards a world of chemistry where the biorefineries provide additional income for farmers while generating products that compete in performance and price with the traditional petrochemicals. While the meeting itself remained a unique event that was never repeated at that scale under the auspices of a leading petroleum group, it catalyzed a broader interest in the subject among academia, policy makers and business.

Over the years Dr. Gravitis created a strong nucleus in Tokyo with the support of Masako Unoura who for years was my personal assistant in Japan. It was Mitsubishi Heavy Industries that took the lead under the guidance of the team that I had assembled at the UNU Institute for Advance Studies. A wealth of subjects were studied and curated into articles with biorefineries as the common denominator[3]. The processing of agricultural produce emerged as a source of multiple incomes, which is a core characteristic of zero emissions and The Blue Economy. The subjects varied from the separation of non-wood forest products, the environmental management of plantations in the tropics (especially palm) through to the generation of additional income, the production of cross-linked polymers from biomass, the production of glucose and water-soluble polysaccharides from cellulose, and the use of sugar cane bagasse as a wood source for charcoal. The research has resulted in new biomass treatment techniques for the production of chemicals, biofuels and composite materials. One of the first commercial products was the production of a self-binding particle and fibreboard.

The ZERI Pavilion at the World Expo 2000 in Hanover with the first ever bamboo/cement fiberboard roofing © 2000, Pauli

[3] The annex contains dozens of articles published on the subject

This new type of fibreboard was prominently used as the roof for the ZERI Pavilion at the World Expo in the year 2000 in Hanover. It was supplied by Taiheiyo Cement thanks to the leadership provided by Masatsugu Taniguchi, Senior Vice-President and member of the Board, and his colleague, Noriaki Hayama in charge of innovations. Taiheiyo Cement was keen on developing a board that would be carbon neutral. After the worldwide prohibition of asbestos, the search was open for ecologically sound fibers until the work we had launched in the field of biorefineries and bamboo struck a chord with the Japanese research team that went ahead and planted 2000 hectares of bamboo in Indonesia. This green bamboo was continuously harvested and crushed, cut into small fibers that are a maximum of 2.5 millimetres long, causing a self-hydrolisis and then pressed into boards that contain 50% cement and 50% bamboo (75% of the weight is cement and only 25% is bamboo). Taiheiyo was very successful with the introduction of this board in the construction industry. Its raw form has a distinguished pastel green shade, it is carbon neutral and it absorbs noise—a highly valued characteristic for the high-speed train stations (Shinkansen) in Japan which all adopted this board as the new standard. The success of this initiative based on the deeper understanding of auto-hydrolysis of bamboo (and other wood) led to the decision of the CEO at Taiheiyo Cement to donate the roof of the ZERI Pavilion at the Expo as a token of appreciation for our contribution to this new business.

The rapid translation of the research relating to the biorefinery concept and the arrival of a few commercial products gained traction as the diversity of the academic interest strengthened the programme. While the UNU and the Institute of Industrial Science kick-started the international effort on the back of Latvia and Sweden, it reached the attention of the Science Council of Japan, then chaired by Prof. Jiro Kondo, the American Chemical Society, the Japanese Wood Research Society, the International Lignin Institute and the International Research Centre for Sustainable Materials. By 2004, the status of the research had matured to the point that the European Union confirmed its strategic interest in the subject and started funding programmes. Even though the research can clearly be considered a success, I had great difficulty and began to lose my patience with the fact that due to excessive bureaucracy and funding difficulties the North Carolina facility was never started up again, and that the few US$ 500,000 machines produced by Mitsubishi Heavy Industry hardly confirmed the advent of an industrial scale that we sought. By 2005 I had concluded that I was trying to be the wave and the time had come to take a step back and attempt to be the surfer.

Clustering Forests with Mobility

At an intellectual and strategic dialogue between Peter Senge (author of the book “The Fifth Dimension”) and myself, organized by the Director of SOL (System Organization Learning) Göran Carstedt, I had the opportunity to meet the entrepreneurs behind the first wood chemistry biorefinery that I could see in operation. It was created in Önsköldsvik (Northern Sweden) and considered wood as a multiple source of biochemicals and fuels, especially ethanol. Per Carstedt was Göran’s brother who

owned a Ford car dealership, had made the blunt decision to purchase 1000 ethanol powered Ford cars in the US and sell them through the region of Umeå in the north of Sweden, as such creating the demand for a biofuel. This would trigger demand and lead to the conversion of wood pulping into a first stage of the biorefinery, pulping and ethanol production. His strategy worked and the plant was operational with a guaranteed local purchase of ethanol by 1000 vehicles. The integrated cash flow of selling the cars and then the fuel created conditions which demonstrate the viability of strengthening local economies. Soon SAAB, the car maker realized that there was a demand for a more ecological fuel and introduced the first 100% ethanol car. SKANDIA, the truck maker followed with the design and assembly of ethanol-powered trucks. Never underestimate the power of an initiative undertaken by a private citizen in the periphery of the world (Northern Sweden is not the center of renewable energy).

This transformation of the market driven by demand urged local entrepreneurs to take the initiative and create the first biorefinery. It was implemented by SEKAB AB at their Domsjö factory. They produced traditional cellulose for paper products and then opted to generate lignin and ethanol as additional revenue streams. The dry lignin capacity of SEKAB increased in 2012 to 120,000 tons. This represents a major shift away from the age-old chemical pulping which considers lignin as waste, and at best to use it as a fuel (as part of the black liquor). The by-products manufactured from these biochemical derivatives include windscreen washer fluid, vinegar, water-based paints, pharmaceutical ingredients, perfumes, cleaning products, varnishes and inks. The fuel is an ethanol adapted for diesel engines that is 95% pure ethanol. The research network strengthened to include Science Partners Technical Research Institute headed by CEO Maria Khorsand and the Processum Biorefinery Initiative AB with Peter Blomqvist as Chairman, Clas Engström and John Rune as shareholders, that develops further products and processes for 21 companies located on the Northern Swedish Baltic Coast with 1300 researchers and experts. This is converting into a powerhouse of know-how that is found nowhere else. Chalmers and Lund University joined the wave and institutionalized the research.

Maria Khorsand

Clas Engström, John Rune and Peter Blomqvist

Jorge Alberto Vieira

Photo-Biorefinery: Harnessing the Power of the Sun

On the other side of the Atlantic Ocean, things had quietly progressed with the concept of a photo-biorefinery—a refinery that is powered by the sun. It is the brainchild of Prof.

Lucio Brusch, founder of ZERI Brasil Foundation, and his friend and colleague Prof. Jorge Alberto Vieira Costa from the School of Chemistry and Nutrition of the University of Rio Grande based in the city of Rio Grande. Their view on the photo-biorefinery began from an effort to convert a rice paddy field into a production unit for rice, fish and Spirulina. The goal was to produce more with the existing facilities rather than extract more from the existing raw materials. As we learned in this case, the principle of "do more with what you have" can be applied in different contexts. The South of Brazil, often described as the rich region of Brazil, has pockets of poverty. The elimination of subsidies for fertilizers imposed by the World Bank and the IMF resulted in the early 1990's a major crisis among the rice farmers. While we introduced mushroom farming on rice straw, we then focused on creating more revenue with micro-algae. It was clear that this part of the world with the richest biodiversity of micro-algae could and should convert the paddies into bioreactors.

The production of micro-algae was a resounding success. The doubling of biomass every 24 hours encouraged the researchers who had been exposed to the logic of the biorefinery through visits by Janis Gravitis and Carl-Göran Hedén to Brazil on how to apply it to micro-algae. Nearly all micro-algae research at the time focused on the production of biofuels. Since lipids and oils are only a minor component, the research team set out to identify all other possible output from algae. CNPq (the National Research Council for Scientific and Technological Development of Brazil) agreed to fund the research and the output was remarkable. If one were to produce micro-algae for the sole purpose of fuels, then it is not competitive. If one were to focus on the production of nutrition and biochemicals for polymers, oils and lipids, then the photo-biorefinery would be highly profitable. The Seival Thermoelectric Plant outside of Porto Alegre (Brazil) turned into the ideal partner for this programme. They operate one of the few carbon-powered electric generation stations in Brazil and the insights gained by farming Spirulina in rice beds was now applied at an industrial scale. The concept of the photo-biorefinery in Brazil has evolved into a major pool of know-how, considered to be one of the five most important in the world with nearly 50 graduates at the master and doctoral levels.

Italy Takes the Lead in Biorefineries

The latest breakthrough in the design and the implementation of biorefineries has been achieved in Italy. The groundwork was laid by Raul Gardini three decades ago with the strategic industrial vision, the commitment of Prof. Umberto Colombo, who after his pioneering work at ENEA became the Minister of Science and Higher Education, and indeed the drive towards implementation by Dr. Catia Bastioli. What started as a research lab producing bioplastics under the brand name of “Mater-Bi”, emerged twenty years later as the pioneering company that promotes local economic development, converting by-products from agriculture, extracting polymers, elastomers, herbicides and lubricants, and forms the building blocks of dozens of products based on azelaic acids, pelargonic acids and esters. This in turn produces a new portfolio of building

blocks for new generations of (bio) chemicals. The waste can be converted to animal feed and the natural enzymes from the thistle flowers are key in the production of cheese.

Repurposing Defunct Factories

While the biorefinery concept is coming into the modern age based on the vision of a sustainable system of production and consumption, it is key to point out that the capacity to implement the transformation of biomass into multiple revenues is only part of the breakthrough. The second shift Novamont achieved is the reuse of the existing capital investment in the infrastructure for petrochemicals. The grand contribution of Catia Bastioli and her team is not only in the design of the biochemistry and the process innovations, it is of equal importance to find a new use for existing facilities which are described in the industrial jargon as “stranded capital”. The infrastructure and the culture of health and safety known as "responsible care" of a petrochemical plant represents a considerable capital investment which should not have to be a write-off because of over investment in the Middle East and China caused by over capacity.

Areal view of the ENI/Versalis facilities in Porto Torres, Sardinia

The Matrica biorefinery, joint venture Versalis & Novamont ©2014 Nova

In addition, the clean-up cost due to the unintended consequences of inadvertent use of catalysts or construction materials (like asbestos) weighs heavy on the profit and loss statement. As soon as a chemical plant and any other production unit that was constructed three or four decades ago is up for a shut-down, the owners will have to establish a provision for the closure and clean-up cost. The bill could easily run into the hundreds of millions, sometimes even billions of dollars. Now we have to ask what would generate more revenue and grow the economy: the clean-up or the re-investment in providing a new life to the site to ensure it becomes an ongoing business concern for

a few additional decades with an innovative business model. The Blue Economy approach wishes to make the operations sustainable and to ensure that we use what is locally available, including the sunken capital investments and the reorientation of the remediation expenditures.

Novamont never constructed a facility from scratch; it always took an existing operation and converted it into a production unit with new life thanks to new cash flows. The headquarters and research facilities in Novara are the old research operations of Montedison, the bankrupt facilities of Ajinomoto in Bottrighe (Italy) were converted into modern fermentation units, the old PET bottle plant of Mossi & Ghisolfi located in Patrica (Italy), are also transformed and so the list goes on. The largest and the most profound plant conversion was implemented in 2014 when the Novamont research and engineering team successfully reoriented the first petrochemical cracker of Italy, located in Porto Torres, Sardinia, into the world's largest biorefinery by the name of Matrica. It is a 50/50 joint-venture between ENI/Versalis and Novamont. This production plant set a new benchmark for processing 2.5 million tons of crude oil into 700,000 tons of chemicals with an installation that processes a weed.

The success of any biorefinery relies on the availability of a renewable feedstock. An estimated 70,000 hectares of Sardinian farmland has been taken out of production over the years as the European Union tried to reduce the supply of costly produce it had committed to purchase at a fixed price. The logic was that it was cheaper to pay the farmer not to farm, than to have to buy the produce. However, weeds invade and dominate when land is not tilled and planted for years. The prevalent weed in Sardinia, and the rest of the Mediterranean is known as “thistles” or “cardoon” (*Silybum marianum*). While there was clarity on the opportunity to use the capital lay-out for biochemistry, it was the insight into cardoon chemistry that provided a new logic for this latest biorefinery.

First imagine a defunct petrochemical facility and now imagine cardoon chemistry that provides four chemical products (polymers, elastomers, lubricants and herbicides) where the waste is used as animal feed. Local farmers rely on soy imports from Brazil for feed as is the standard around the world. Today the waste of the plant, after producing the building blocks of four major chemical products, is valued as animal feed. To everyone's surprise, the local population wondered if we had the "dust" from the thistle flowers which turned out to be bacterial enzymes required to make traditional goat cheese. When one starts to convert a petrochemical facility, then cheese production does not pop up naturally as an opportunity for economic development. However, when one applies the logic of The Blue Economy, then one embarks on a process that evolves over time and offers opportunities that no one has imagined. It is here that science meets business, one has the certainty of the law of physics and the predictability of chemistry, the other has the appetite to convert an idea into reality.

Capital Follows Innovations

To date, the amount of investments have been driven by the programmes in Sweden with over €250 million, and Italy that is surpassing €500 million capital lay-out from seven facilities across the country and at least €200 for research and development. The Brazilian research has mobilized approximately €15 million over the years, nearly all from the Government. Mitsubishi Heavy Industries and the Industrial Research Institute have also committed over €20 million with the ongoing manufacturing of laboratory equipment. Now if we include the investments by the Tigney and Stake technologies, then we have to add an additional €120 million. While there is considerable additional capital spending, it is with organizations and corporations with which we have had no relation; neither do we include the research facilities of ENEA which run into over one hundred million of euros for equipment and fundamental research.

The job-creation factor is also critical. Biorefineries generate more jobs than a regular paper and pulp plant or a standard petrochemical factory. This contributes to local economic growth. On the other hand, the direct jobs remain limited and the clusters of initiatives created approximately 45,000 jobs. However, the number of indirect jobs is in excess of 100,000 mainly thanks to the additional stimulus to agriculture and forestry. The numbers of Porto Torres are very indicative. ENI required 2.5 million tons of crude oil to manufacture 700,000 of chemicals, and its production facility was not competitive. At its peak Matrica may be producing only half of that output, but will be competitive globally and generate a comparable number of direct jobs, while it stimulates local agriculture, instead of financing governments on the other side of the Mediterranean.

Sweden, Italy, Brazil and Canada are not the most dominant economies in the world but their research capability is strong and their patent portfolios in these areas number in the thousands. It is clear that biorefinery has come a long way since Prof. Hedén talked to Swedish members of parliament about the marvels of biotechnology and microbiology. His message was not an endorsement of genetic modification but rather a call for the generation of more value from the renewable resources as a strategy to preserve the competitiveness of Sweden. In reality, he was arguing for The Blue Economy long before the concept even existed. It is therefore no surprise that when he was invited by Heitor Gurgulino de Souza, the Rector of the UNU to lead the team that would undertake the feasibility study of the UNU Zero Emissions Initiative that he concluded, "Zero emissions as proposed by Gunter Pauli is not only technically, scientifically and economically viable, it is necessary if we want to attain our goal of sustainable societies."

Translation into Gunter's Fables

The business of mushrooms has inspired me from early on to write two fables: fable # 41 "Fuel from the Tree" dedicated to Paolo Lugari. He inspired the creation of this cluster already back in 1987 with my discussions on the biorefineries from the regenerated rainforest in Colombia. The fable #5 "Why don't they like me?" is partly inspired by the bamboo fiber board produced by Taiheiyo Cement in Indonesia.

For more information

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Some Relevant Scientific Publications by the ZERI Team of Scientists on the Subject

Representative publications on wood ultrastructure research:

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