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THE WORK OF ITALIAN SOLAR ENERGY PIONEER GIOVANNI FRANCIA (1911-1980)

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ABSTRACT

In technical and scientific literature, Giovanni Francia is known above all for his pioneering work, starting in the late 1950s, on honeycomb structures and on linear and point focus reflector systems.

The purpose of this paper is to serve as a reminder of his work in solar energy, and to call attention to his lesser-known activities, also in other fields, such as motor vehicles.

In the solar energy field, many of the theoretical analyses and technical solutions that brought Francia moments of international celebrity were later forgotten. Eventually, though, they proved to be again topical and to have great practical potential.

Other studies and research by Francia – little known because they were published only in French or Italian, or not published at all – give us a picture of Francia not only as a painstaking scientist, but also as a revolutionary thinker in addressing questions of a general nature, as in his 1971 "Project for a Solar City: Hypothesis for an Urban Structure," or his 1974 essay on "The Sun and the Limits of Energy on Earth."

1. INTRODUCTION

This paper is part of a study I began some years ago on the history of solar energy in Italy, and whose early results I presented at ISES 2003 (1). For ISES 2005, I decided to focus on the story of Professor Giovanni Francia, who was, without the shadow of a doubt, the most well known Italian in the national and international solar community for his pioneering work, starting in the late 1950s, on honeycomb structures and Fresnel concentrators (2, 3, and 4).

I quickly realized, at the beginning of my research, that it can take only a few decades for the traces of people and events to be lost. In fact, it proved difficult to find eyewitnesses who could tell me something more about Francia's work as well as to locate and consult the documentation I was discovering through my research. After more than a year of collecting technical and scientific documents that seemed at first sight sufficient for my study, in November of 2004 I decided it was time to visit the solar station at Sant'Ilario, where Giovanni Francia had tested the first solar tower system (sometimes called *central receiver* or *power tower*) in 1965.

The town of Sant'Ilario is located on a steep and densely populated stretch of the Ligurian coast, around 10 miles from the center of Genoa; it overlooks the sea and has a fine climate. As soon as I arrived, I found that the premonition I'd had was right: no one could tell me anything at all about the solar station that – as I'd read in a 1981 Ansaldo document – had been dedicated that year to Giovanni Francia (5).

My only hope was to find an elderly person who might recall the station and be able to tell me where it was located. It was my good fortune to come across a man named Ludovico Marzano, who in the 1960s had

Fig. 1 – Giovanni Francia and one of his honeycomb structures (Francia Archive)

been the gatekeeper of the solar station complex. He answered my questions with interest and emotion, and in a few simple words, gave me his recollection of Giovanni Francia: "As if he were one of us, he'd ride up on his motorcycle; he was an enthusiast, a fine person. As long as he was here, everything worked; with his death, everything ended."

The station (or the little that remains of it) is set on an area of less than 500 square meters (5382 sq. ft.) on the grounds of what is now the Sant'Ilario Agricultural Institute. The Institute itself originated from an idea likewise related to solar energy, but for agricultural uses. In 1882, a wealthy merchant named Bernardo Marzano created the Royal Practical School of Agriculture here in his home town; his idea was that the school would introduce the farming methods necessary to turn Ligurian land into vegetable fields and winter gardens by exploiting solar energy, thereby giving the local population a new opportunity for economic development. After a quarter-century of oblivion, all that survives at this historic school to commemorate Francia are a few broken mirrors and the rusty mechanisms of the last plant he designed. On the Institute wall facing these remains, though, is a marker recalling that Rodolfo Valentino, the famous star of silent films, attended the school from 1910 to 1912.

This account of my visit to the Sant'Ilario station is meant partly to underline the spirit in which I attempted to reconstruct the story of the pioneer Giovanni Francia: above all by describing the places where he lived, studied and worked, and through the accounts of people who knew him in his private life and in his profession, rather than by reviewing the technical literature, which is already well known.

The opportunity I had to consult Francia's archive, which is preserved by his heirs, was fundamental to my project. I went through it at the end of February 2005, shortly before the deadline for presenting this paper. [1]
The Francia Archive contains notes, letters, articles, patents, the proceedings of Italian and international conferences, journals, clarification notes exchanged with academics, companies and research centers. It also includes photographic documentation on experiments and prototypes, and some personal documents that give us a better idea of Giovanni Francia's personality. Most of the documents are in Italian, but there are also many letters and documents in French, referring chiefly to Francia's relations with Marcel Perrot of the Solar Energy Research Group at the University of Marseilles' science faculty, and with COMPLES (Coopération Méditerranée pour l'Energie Solaire).

In the following sections I shall try to illustrate primarily the life of the man, the scientist and the technologist Giovanni Francia, who, after his first experiments in the garden of his house in Nervi, at Via S. Ilario 17, in the mid 1950s, succeeded – step after step, often using homemade equipment and sometimes putting up his own money, and his wife's too – in explaining how to use solar energy and why the world should use solar alone.

Giovanni Francia lived and worked in northwestern Italy, at 44° latitude, between Turin (capital of Italy's auto industry), San Germano Chisone, Nervi, Sant'Ilario, Sestriere and Cesana Torinese, and Genoa, which at the time was the center of a major steel, electromechanical and nuclear industry pole.

2. THE MAN, THE SCIENTIST AND THE TECHNOLOGIST

An account of the history of Giovanni Francia's contribution to the development of solar energy applications cannot be separated from his human experience, which influenced his personality and his way of operating.

Francia, the first of four children, was born on July 15, 1911, to an educated, aristocratic-minded mother and a pharmacist father who had a passion for inventions. In 1904 his father created "Gastrol Francia," a natural medicinal product, but he did little to commercialize it. This was an experience that his son recalled when he was seeking patents for his own inventions. Upon his father's purchase of a pharmacy at San Germano Chisone, the young Francia moved to this town not far from Turin and attended school in Pinerolo, traveling back and forth by bicycle. It seems that the solar energy pioneer had no great aptitude for schoolwork; in his first year in junior high, he was graded 5 out of 10 in all the subjects except math (6/6), conduct (10/10) and religion (7/10). He flunked the year.

At 18, Francia lost his father and, with two sisters and a younger brother, had to take on some family responsibilities. At the same time, he was struck by tuberculosis, and was forced to spend four years in a

[1] It took me a good deal of time to locate Francia's archive, and I was able to do so only through a chance meeting at the Genoa Science Festival in 2004. Up till then I hadn't thought there was any such thing as a Francia archive, because the people who had worked with him just before his sudden death, on April 25, 1980, told me they assumed that the archive had been lost, and they didn't know whether he had any heirs, or if so where they lived. In my first perusal of the archive, my talks with Francia's widow, Anna Colli, with the widow of their son Paolo (who died in 2000) and with their three grandchildren were especially helpful.

mountain sanatorium. He had to give up his desire to study engineering at the university, and fell back on mathematics. He studied on his own, and despite the distance from the university he passed all his exams with excellent grades, except the last one in general math. He was interested in astronomy and studied the orbits of double stars. He also learned rock-climbing in the mountains. After earning his degree (probably in astronomy), from 1934 to 1936 he taught as a special assistant at the Royal Polytechnical Institute in Turin (6).

In 1937 Francia earned another degree, in math, with a final grade of 90/100. In 1940 he began to teach at Genoa University, living in Nervi at the Pensione Letizia, where he met Anna Colli, whom he married in 1944. Their marriage was a solid partnership both in life and in the professions until 1970. Colli worked in scientific publishing (Edizioni Scientifiche Genoa) and edited university textbooks, including geometry and math books, some written by Francia himself. Francia combined teaching at Genoa University and professional work. At the University he taught a variety of subjects (analytic and projective geometry, descriptive geometry, machine and project design) at different faculties (Science, Mathematics, Architecture, Engineering). It's worth noting that Francia never taught in some of the fields he was engaged in as a consultant (including motor vehicles, aircraft, space, textiles, electro mechanics and solar energy), where he obtained very important results, sometimes from an economic standpoint as well as a technical, thus confirming his versatility and his mastery of technical and scientific matters.

The documentation I consulted shows that Francia's work method was to observe a phenomenon, figure out its main physical aspects and its possible practical implications, work out a theoretical explanation, test it, and then develop a practical application, paying particular attention to the feasibility of integrating the proposed solution in existing reality, to its simplicity and to its likely costs.
When Francia learned of a problem, instead of studying how others had tried to solve it he turned his mind to how he might solve it himself, exploiting his great capacity for synthesis and his thorough understanding of technical and scientific subjects, from physics to mathematics and geometry. His brilliant mind would come up with the simplest solution; then he would test it, often using whatever equipment, sites and contacts were available at the moment.
For his first patent, obtained in 1955, on better building blocks for gravity dams, Francia did the tests on a scale model erected in the garden of his home in Nervi.
The Sant'Ilario station, where Francia tested his solar systems, was not far from his home, and he continued to use it until shortly before his death, in the framework of collaboration with the Ansaldo Company, which began in 1973. For high-altitude tests, at Sestriere and Cesana Torinese, he relied on the collaboration of Lillo Colli (not related to Francia’s wife, Anna Colli), owner of the *Rifugio Gran Pace sulle Montagne della Luna*; Francia and his wife had met him in 1948, during a vacation in the mountains, and established a long-lasting friendship.

This was the practical and essential approach with which Francia developed and registered 21 patents in Italy and other countries from 1955 to 1980, some of them of major technical, scientific, industrial and economic importance. Ten of his patents were in the field of solar energy, to which Francia gave primary attention throughout his life and until his death, on April 25, 1980.

His paramount interest in solar energy is attested to by all the people who knew him and with whom I've spoken. It's also plain to see in a letter he received in 1966 from an industrial promoter. The writer scolds Francia for neglecting to exploit so many of his important inventions, preferring to devote his efforts to solar energy: "The complete study of the desalinator, the patent for the braking stabilizer, the one for the power brake and others are all left by the wayside while you're working single-mindedly on the solar engine" (7).

3. STUDIES, INVENTIONS, EXPERIMENTS AND PROTOTYPES (1955-1980)

In the rest of this paper I shall describe in chronological order, starting from 1955, several of Francia's numerous activities, stressing some aspects, which, though known, seem useful to recall here.

3.1 Vehicle stabilization while braking (1955)

Around 1955 Francia revolutionized motor vehicle stability during braking with a universally applicable invention that interested auto- and tire-makers such as Fiat and Dunlop, and earned Francia flattering results, including economic.
It is hardly an exaggeration to say that if we ride safely today in ABS-fitted cars, we owe it in good part to the decisive contribution of Francia's patents (8, 9).
As in other sectors, here too Francia had the merit of rethinking the whole problem, framing it in absolutely rigorous terms and working out a complete theory that takes account of all the forces that the road transmits through each of a car's wheels. He invented a practical system capable of controlling the car's dynamic equilibrium at every instant; in other words, a system that varies the braking forces on all the wheels and keeps the car's adherence to the road under control whatever the

driving conditions. He also studied the application of his braking system to aircraft, particularly military planes, with the aim of shortening runways.
Francia also developed a theory on temperature distribution in brakes and its implications for their design. The results of this study enabled him to start collaboration with the Ferrari auto manufacturer and close relations with its founder, Enzo Ferrari.

3.2 The honeycomb and the solar engine (1960)

Francia's interest in solar energy started to appear in the late 1950s, after a business trip to the United States, on braking systems.
He began with the idea of collecting solar heat, which is abundant at low density and temperature, in order to obtain the high temperatures used in modern industries, such as to run large turbines at power plants. He argued that solar energy would be competitive only when solar boilers were capable of supplying steam at pressures higher than 150 atmospheres and temperatures above 500°C. This was the solar-energy research field in which Francia was to work for the rest of his life, though not exclusively.

His first step toward raising the solar energy collection temperature was to invent the honeycomb structure, an array consisting of a large number of long, thin, parallel tubes made of glass, quartz or plastic. Being transparent to solar radiation but opaque to the heat rays emitted by the hot surface, the array reduces the collector's losses from re-irradiation and convection.

Figure 2 shows the design for the first honeycomb system that Francia built, in early 1960, for the sole purpose of testing the theory he was working out. In this case, the honeycomb was made up of hexagonal tubes 8mm in diameter and 160 mm long. The device produced temperatures of 230-240°C, as against the 500°C expected theoretically.

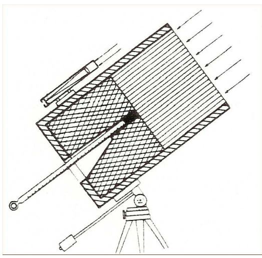

Fig. 2 – The first honeycomb absorber (Francia Archive)

When his friend Lillo Colli pointed out, in August 1960, the existence of motionless concentration systems, Francia replied that he was "studying the American work, that glass is obviously well known but there's nothing about the absolute black body or any of the other results I've obtained by combining the one and the other" (10).

Between 1960 and 1961, Francia built the first experimental station at Cesana Torinese. Here he tested the first boiler coupled with a concentrator and protected by a honeycomb structure made up of 2000 thin glass tubes. It reached the temperature of 600°C. Francia then translated his honeycomb structure, theory and experimental results into the first solar patent (11) and presented them at the United Nations Conference on New Energy Sources (solar, wind, geothermal), held in Rome at the headquarters of FAO, the U.N. Food and Agriculture Organization (2).

This presentation made Francia known internationally and prompted interest in the study of honeycomb structures, which continue to be the subject of a great deal of research because they hold the prospect of wide application: for instance, research on transparent insulating materials, which have been studied, especially in Germany and other countries, since the early 1980s.

Studies of honeycomb structures that can be considered in a way precursors of Francia's invention had been conducted in the 1930's in Russia, Germany and in the United States (12, 13, 14 and 15).

3.3 Fresnel linear and point focus reflectors (1960)

Francia was the first person ever to apply the Fresnel reflector technology principle in real systems, both linear and point focus (in a Fresnel reflector a smooth optical surface is broken into many segmented optical surfaces).

To raise the collection temperature of solar energy, Francia combined two different methods: the already-known concentration method and the honeycomb-cell method in order to reduce losses. The latter's performance was limited by thermal resistance and by the stability of the materials used for the cells.

The first plant, a linear Fresnel reflector system (38 kg/h of steam at 100 atm and 450°C), was built in Genoa in 1963 and assembled in Marseilles University at the Helios Technology Faculty in 1964 with support from the French CNRS and NATO.

In 1964, the S. Ilario solar station was founded with the support of the Italian National Research Council (CNR) and NATO, in cooperation with the Engineering Faculty of the University of Genoa led by Agostino Capocaccia. Between 1964 and 1965, Francia built the first point focus Fresnel reflector system at Sant'Ilario with the support of

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CNR and NATO (121 cinematic systems, each of them bearing a mirror for a total area of 30 square meters; it supplied up to 21 kg/h of steam at 150 atm and 500°C). This first plant was followed by several other plants through 1979. Here Francia tested various components of boilers and mirror fields (4).

For Francia, economic competitiveness was a key factor in a plant's design. The process he followed for the first point focus plant at Sant'Ilario was the reverse of the traditional one. He asked himself what the plant would have to cost to be competitive, and what industry had to offer for the most expensive part, the field of mirrors. He came up with a brilliant solution: a single mechanism that could be mass-produced would turn a whole row of mirrors to focus each one on the boiler (16).

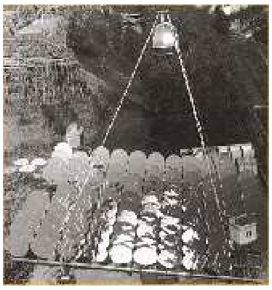

Fig. 3 – Point focus Fresnel reflector first system, Sant'Ilario Station, 1965 (Francia Archive)

In 1973 his work was noted by major industrial concerns that requested his advice for the construction of industrial-size demonstration plants that started operation in 1977 in the United States (the 400 kWth Solar Thermal Facility at the Georgia Technology Institute, 1977) and in 1980 in Italy (the 1 MW Eurelios power plant at Adrano, Sicily, 1980). In his last years Francia was busy at Sant'Ilario developing the solar gas boiler described in section 3.6 (17).

For a short time after his death, Francia's work at Sant'Ilario was still of some interest. For instance Ansaldo and ENEA built a central tower test facility at the Casaccia Research Center in 1982, which, however, was practically never used.

From May 1981 to December 1985 ENEL, the Italian Electricity Board, demonstrated the capacity to operate Eurelios in parallel with an electricity grid on an experimental basis. However, ENEL judged the results of Eurelios decidedly negative and concluded that "tower and mirror-field solar plants will not have significant applications even in the medium and long term." This conclusion contributed to silence Francia's legacy, at least in Italy (18).

But that legacy seems to be resurfacing, forcefully. For the first time in its history, solar thermal power has a chance to become cost-competitive according to a proposal of a low cost Compact Linear Fresnel Reflector (CLFR) array system by Mills and others. A proposal based also on concepts that were pioneered by Francia more than forty years ago in Marseille (19).

3.4 The Solar City Project (1971)

At the end of the sixties, upon meeting two young architects named Karim Amirfeiz and Bruna Moresco, Francia seized the opportunity to design a solar city. He had the ability to marshal their enthusiasm and suggestions, and to guide them, together with other collaborators, including R. Morozzo, P. Bertalatti, M. Lusetti and C. Pagano, in working out the "Solar City Project – Hypothesis for an Urban Structure" (20).
The design team coordinated by Francia invented a wholly new kind of urban complex for a population of around 100,000, closely linked to the exploitation of solar energy and constituting a repeatable, independent and energetically autonomous unit. The team produced drawings, calculations, detail studies, scale models and various experiments (the scale models are apparently still preserved at Genoa University).

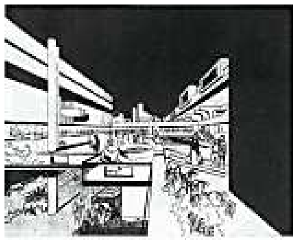

Fig. 4 – Model of a solar city, built in 1971 by Karim Amirfeiz and Bruna Moresco under Francia's guidance (Francia Archive)

Underlying the project was Francia's and his collaborators' conviction that it was possible to create an "urban unit in which the essential services – lighting, heating, electricity – were supplied independently by solar energy." Daytime lighting, in this farsighted project, would be supplied entirely by solar radiation, via 100,000 square meters of openings that would allow the sun's "guided light" to penetrate into the living and working spaces. Winter heat would come from surplus summertime solar energy stored in the earth underneath the city, and the small amount of electricity needed to run household appliances could be supplied by solar thermoelectric plants designed on the basis of prototypes built by Francia at Sant'Ilario.

3.5 The Sun and the Limits of Energy on the Earth (1974)

In 1974 Francia made a detailed physical-mathematical analysis of the Earth's thermal balance, and published a short summary of it in French (21). To my knowledge, the entire study (written in Italian), with all the physical and mathematical analyses, has never been published.

In this study, Francia focused on the temperature of the Earth's surface: the temperature of equilibrium between energy radiated from the Earth into space and the energy received from the sun.
The kinds of energy that reach the Earth's surface are solar (around $65,000x10^9$ TOE/year, with fluctuations that cause variations on the Earth in the amount of $2.9x10^9$ TOE/year every eleven years), tidal ($2x10^9$ TOE/year), geothermal ($24x10^9$ TOE/year) and energy produced by humans from fossil and (since the 20th century) fissile fuels (estimated in 1974 at $8x10^9$ TOE/year).

Since the amount of solar thermal energy that reaches the Earth is thousands of times greater than the total of non solar energies, Francia reasoned that at first sight, the modest amount of thermal energy produced artificially by humans might lead one to think that it has no effect on the Earth's thermal balance. But with a series of arguments relating to the way that the Earth's surfaces – water, snow, soil – absorb and reflect solar radiation in the different seasons, Francia demonstrated that this is not the case. To the contrary, if the modest amount of thermal energy produced by humans was in the course of a century to reach values fifty or a hundred times higher than in 1974, it might well induce phenomena of thermal instability, setting off a chain of events that would bring our planet into a new balance, very far from the original one, at speeds much faster than living beings can adapt to. Accordingly, Francia argued that it is urgent to turn to solar energy, the only kind that does not lead to thermal pollution of the Earth.

3.6 Air cooled solar receivers for temperatures up to 800-1000°C (1978)

In 1978 Francia started a project for a prototype of an air-cooled solar receiver, partially funded by CNR. The purpose of this project was the development of high temperature air-cooled receivers to be connected to a Brayton cycle for producing electric power in desert areas where good solar radiation is plentiful, but water for cooling, as needed for a steam cycle, is not.

Moreover, an air-cooled solar receiver would make it possible to set up many small electricity-generating units, all connected to a single grid (22, 23).

Francia's first solar receiver, rated 50 kW, was installed at the Sant'Ilario station in August of 1979 and subjected to 190 hours of testing. On September 8 of that year, with solar radiation intensity at 650 W per square meter, the unit reached the temperature of 670°C, and in subsequent tests it reached 880°C.

In his January 1980 report, written a few months before his death, the tireless pioneer Giovanni Francia complained that the work was limited because he had not received the expected financing from the CNR, and that it had been possible only thanks to his collaborators' selflessness and to the trust placed in him by industrial concerns and suppliers.

Fig. 5 – The first 50 kW air-cooled solar receiver designed by Giovanni Francia, installed for testing at the Sant'Ilario station in August 1979 (Francia Archive)

4. CONCLUSIONS

Giovanni Francia was not a conventional scientist. Both as a student of mathematics and as a professor at the University of Genoa, he succeeded for his talent and determination. After his first experiments in the late 1950s on anti-radiating structures or honeycombs made up of thousands of thin glass tubes, he developed a solar career during which he not only showed how solar energy should be collected at high temperatures, but also explained why we should use only solar energy so as not to alter our planet's thermal balance.

Though Francia focused most of his work on Fresnel type reflector plants, he was also interested in other aspects of solar energy, as can be clearly seen from his solar city project, where he suggests using solar energy for lighting, and from low to high temperature for heating household water, for space heating and cooling, and for meeting electricity needs.
Francia died just as his work was starting to receive international recognition and solar experts were coming from all over the world to visit the Sant'Ilario station.

6. ACKNOWLEDGEMENTS

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