ENCYCLOPAEDIA OF HYDROCARBONS

ISTITUTO DELLA
ENCICLOPEDIA ITALIANA
FONDATA DA GIOVANNI TRECCANI

Printed in Italy

Photolith and printing by
MARCHESI GRAFICHE EDITORIALI S.p.A.
Via Bomarzo, 32 - 00191 Roma

CHAIRMAN
Roberto Poli

CHIEF EXECUTIVE OFFICER
Paolo Scaroni

DIRECTORS
Alberto Clô, Renzo Costi, Dario Fruscio, Marco Pinto, Marco Reboa,
Mario Resca, Pierluigi Scibetta

ISTITUTO DELLA ENCICLOPEDIA ITALIANA

ENCYCLOPAEDIA OF HYDROCARBONS

ART DEPARTMENT

Art Director: Gerardo Casale

Graphics: Giuseppe De Gregori
Illustration sourcing: Daniele Piselli; Claudio Cigognetti; Alessandro Albanese, Anna Maria Ciai, Gilberto De Angelis
Drawings: Marina Paradisi; Giuseppina Elia, Massimo Montelli, Anna Olivieri, Francesca Ottaviano, Giuseppe Polegri, Paola Salvatori (cartography)
Graphics and layout: Giuseppe De Gregori; Giulia Romana Faggiani, Francesca Ottaviano
Quality control: Anna Rita De Nardis
Secretaries: Aurora Corvesi, Carla Proietti Checchi

LIBRARY

Gabriella Miggiano; Marina Battaglini, Massimo Menna, Giuliana Scudder
Secretary: Gabriella Michetti

PUBLISHING DEPARTMENT

Publishing administration: Luisa Fusé; Cecilia Rucci, Mirella Aiello
Planning: Luisa Cinquina; Tiziana Picconi
Quality control: Rosalba Lanza; Simonetta Paoluzzi
Industrial production: Maria Devrushian; Loreta Lucchetti
Secretary: Eliana Naddeo

PUBLISHING DIRECTOR

Massimo Bray

Presentations

In the twentieth century hydrocarbons were, and will continue to be in the coming decades, by far the most important energy source, the engine of economic and industrial development, a decisive factor in social organization, and a strategic raw material, whose destiny closely links alliances, conflicts, and geopolitical and security issues.

No other sector of the economy has comparable levels of complexity and uncertainty, and yet is able to play such an important role in the international arena. Knowledge of the world of hydrocarbons, their history, technical characteristics and prospects is crucial to understanding current international systems and their future development.

The aim of Eni's *Encyclopaedia of Hydrocarbons* is to offer readers, whether specialists or otherwise, a clear and detailed insight into this sector, addressing the aspects relating to historical events, scientific knowledge, the elements and the interrelations underlying the value of the oil and gas industry, the ongoing and foreseeable technological developments, and the economic and legal aspects that influence their prospects.

The first edition of this work was the brainchild of Enrico Mattei – founder and first chairman of Eni, then called E.N.I (Ente Nazionale Idrocarburi) – who, introducing in 1962 the *Encyclopaedia of Petroleum and Natural Gas*, stressed its features of technical and scientific innovation, strategic necessity and an urgency for ideas.

Scientific innovation refers to it being the first in-depth, systematic collection of monographs in the fields of study relating to research and to the use of hydrocarbons in various industrial sectors, as well as the technological knowledge forming the basis of the oil industry.

A strategic necessity for a country – Italy at the time was "the last to appear on the world oil scene" – signifies Eni's deeply rooted mission to contribute to the country's economic development, operating actively at the international level.

An urgency for ideas, lastly, relates to the need to illustrate the "enterprises and the characters of those who devoted their utmost energy to putting this resource to its best use", and to concretize the vocation to spread knowledge as an innate objective of industrial success.

In its fifty years of history, starting just after the end of the Second World War in a country poor in raw materials, Eni has become one of the major international oil and gas companies in the world. Today Eni is present in some seventy countries, where it operates responsibly towards its stakeholders, investing in people and their enhancement, participating in sustainable development by means of integrating social and environmental themes into its growth process.

Looking back at the starting phases of its activities, the extent of the road covered by Eni, and its

capacity to successfully tackle the many challenges that have strewn this road, appear in their real dimension. The technological, entrepreneurial and cultural assets achieved to date are an essential requisite for successfully facing up to the complex future prospects.

At the start of the new millennium, the energy system seems to be oscillating between two extremes. On the one hand, there is an emergence of innovative themes and new protagonists, foreshadowing radically different solutions with respect to the past; and, on the other hand, the recurrence of unsolved problems which have periodically accompanied the history of hydrocarbons.

Looking at the new phenomena, the scenario looming in the evolution of the economic system appears to be characterized by a constant growth in energy demand, with rates of increase and geographical origins profoundly different from those of the past. In the forthcoming decades the strategy of the oil and gas industry will be dominated by two elements: the first, traditional one is the supply of increasing quantities of hydrocarbons on the market; the second, new one is operating in line with the strong demand for environmental quality.

Converging on this objective are various factors: the radical progress of science and rapid technological innovation, the spread of computer and communication technology, and alternative energy sources coming onto the scene, above all because of the need and urgency to achieve a high level of environmental compatibility.

Alongside these strongly innovative elements, the international energy scenario is witnessing the re-emergence of fears and unresolved problems that have accompanied the entire history of the oil industry. Such fears and unresolved problems generate attitudes and reactions of pure conservation, which can obscure both our understanding of what is new and the development of such opportunities. This is the case of fears that resources will become exhausted; of the return by some States to the search for energy self-sufficiency; of the crucial role played by oil, regarding both the aspirations and the instability in vast regions of our planet.

In the cultural debate, public policies and company choices, the overlapping of old and new runs the risk of hampering a clear assessment of opportunities. This can slow down the capacity to provide positive responses to the demand for energy, as occurs in this century in terms of geographical origin, quantity and quality.

The companies, in particular, find themselves facing a situation in which several factors co-exist and influence each other: the scarcity of sound investment opportunities in the upstream, the uncertain nature of the scenarios, strong competitiveness in every sector of the oil and gas industry, market deregulation processes and increasing environmental regulation.

To meet these challenges, it is necessary to rethink strategies and new ways of generating value in a sector in which – more than in any other business – the traditional dilemma between growth and profitability is made more critical and greater today than in the century that has just ended, by the intensity of capital required for new investments and by the duration of the projects.

It is equally important that these strategic themes and dilemmas should be the primary reflections of public decision-makers, financial institutions and social organizations on the basis of a shared culture, an ensemble of updated, serious and exhaustive elements of information, taking into account the new interrelations that are emerging between energy, development and environment. For this reason Eni has promoted this new *Encyclopaedia of Hydrocarbons*, to offer to a wide-ranging international public all the elements of knowledge essential for understanding the potential and challenges of a sector that is decisive for the balanced development of our economies and of our societies.

With this cultural initiative Eni has taken up a position both of continuity, with the intuition and the publishing work promoted by Enrico Mattei, and of renewed perspectives.

In line with the past, Eni's priority today is to stay in touch with all external institutions and people,

that derive services, products and wealth from Eni's work, but also opinions, stimuli and reactions in their capacity as citizens and communities.

At the same time, the objective of providing a transparent model of operating on the scientific, technological and market fronts, continues to be part and parcel of Eni's business style. Presenting its wealth of knowledge linked with hydrocarbons and energy in an articulate, rigorous manner is a further manifestation of Eni's policy of disseminating culture and knowledge bound up with its economic success. While, on the one hand, research and innovation pervade and sustain all industrial activities, on the other hand, coaching and training to maximize its internal and external human resources are indispensable elements for the company to fully accomplish its mission.

The inevitable evolution of Eni's approach and method in writing this work is observed in the fact that, at the beginning of the new millennium, the conception of an encyclopaedia project, albeit of a sectoral nature, entails taking on the challenge of systemizing contents and prospects that are in a state of very rapid change, trusting that its objective of completeness is achieved.

The project, surely an ambitious one, has been tackled not simply by putting together – as in the past – an accumulation of ideas and concepts, but rather by mapping out the transversal nature and interlinking of complex themes, within which great conceptual syntheses and organically connected subjects can find their own specific declination.

The most innovative feature of the *Encyclopaedia of Hydrocarbons* is the pervasive presence, in all the volumes and chapters, of the issue of environmental sustainability. Far from being considered as a separate, additional problem, the safeguarding of health, safety and the environment is regarded and treated as an intrinsic way of understanding and operating in this sector by Eni.

The aim is to compile a body of up-to-date knowledge fully representative of the manifold nature – technological, industrial, economic and geopolitical – of hydrocarbons within the context of the new global themes in which energy and the environment are interwoven, and which are bound to influence ever more radically the development of the sector, the systems of production, the economies and societies in various areas of the world.

This knowledge is offered to all those who are interested, both in the specific field and in society at large, so that they may glean information, knowledge, and ideas for reflection and added awareness.

Roberto Poli
Chairman of Eni

Paolo Scaroni
Chief Executive Officer of Eni

Istituto della Enciclopedia Italiana

The Istituto della Enciclopedia Italiana and Eni present a new edition of the *Encyclopaedia of Hydrocarbons*, which was proposed and introduced in 1962 with the title of *Encyclopaedia of Petroleum and Natural Gas* by Enrico Mattei, founder and first chairman of the Ente Nazionale Idrocarburi.

In the meantime, the importance has increased for a thematic work about this crucial sector in the contemporary world. The entire, complex apparatus of industrial production, transport, communications, and technologies omnipresent in the day-to-day existence of populations living on every continent, particularly in affluent societies, runs on the energy, summed up in the hendiadys of oil and gas.

The well-being and the extraordinary scientific and material progress enjoyed by humanity today are, however, under threat from more than one source of concern. The first one is preserving the quality of the environment against the polluting effects of the processes of production and use of hydrocarbons. The second one stems from the predicted exhaustion of the oil-bearing strata. The third one deals with the geopolitical equilibria of the areas containing these resources. The fourth one regards the need to secure alternative energy sources.

Science, politics and economics, therefore, come into the picture. But neither the groups that invest financial resources in production processes – and one fails to imagine any more globalized than those pertaining to oil and gas – nor the political parties governing the States and the international organizations of the States, nor the scientific communities and industrial decision-makers are able to draw up an adequate strategy to tackle these real causes of collective worry. Such issues are brought to the attention of the best informed public opinions in this new millennium.

We have therefore decided to respond to the many questions forming part of the series of concerns outlined, using scientifically rigorous information and rational assessment.

We feel confident that Eni and Enciclopedia Italiana will receive the gratitude of all those who, by profession or institutional responsibility, have to reach choices on energy issues, so decisive for our immediate future and for that of forthcoming generations.

Francesco Paolo Casavola
President of the Istituto della Enciclopedia Italiana

Preface

On the occasion of the 50th anniversary of its foundation, Eni has taken the initiative of producing the *Encyclopaedia of Hydrocarbons*, in collaboration with the Istituto della Enciclopedia Italiana Treccani.

The basic reason for this choice is an awareness of the central role of hydrocarbons in economic development, in international relations and in technological prospects.

The need to explain the pivotal position of the petroleum industry, regarded as a mainly strategic activity, definitely inspires this encyclopaedia and is clearly reflected in its approach and organization.

Hydrocarbons have been the engine and symbol of progress, but the latter cannot be separated from the quality of hydrocarbons production and transformation processes, and hence from the analysis and problem solving connected with health, safety and the environment. The very close connection between sustainable development and technological innovation can be clearly observed in the structure of the work.

Taking the potential readers into account has also helped to clarify the correct approach towards the subjects to be dealt with in the new encyclopaedia.

Defining the potential public enables the technical and scientific level to be calibrated. The main requirement to be satisfied has been to create a high quality product intended for the world of economics, finance, politics and science, of high technical and scientific quality, while possessing special characteristics as an instrument for the diffusion of culture.

The organization chosen for the *Encyclopaedia of Hydrocarbons* is thematic. This approach does away with the inevitable fragmentary nature of an alphabetical system and also makes it possible, in keeping with the aim of the work, to present subjects of a more general nature, for example, those that are typically economic or which deal with international regulations and types of contracts, alongside the technical-scientific themes.

The work also describes matters not directly connected with the oil and gas industry, but which can find a form of integration with it. Precisely with this in view, the most debated issues (e.g. nuclear energy and renewable resources) have been addressed, comparing various opinions and obviously relying on the prestige and authority of the positions expressed.

The *Encyclopaedia of Hydrocarbons* comprises five volumes, each with approximately 800 pages of illustrated text. The work is published in two original language versions, Italian and English.

The first four volumes are organized on a thematic basis and contain a systematic outline of the knowledge relating to the hydrocarbons industry. The contributions, assigned to the most authoritative specialists from every part of the world, have a strong interdisciplinary slant, to underscore their educational and critical aspect, as well as that of providing information. They are also enhanced with interesting illustrations, and an ample specific bibliography with, in many cases, references to general literature necessary to study the subjects in greater depth.

The encyclopaedia is completed by a fifth volume intended to provide a guideline for readers in studying the four other volumes which have a thematic content.

Very succinctly, the plan of the work is as follows.

The first volume, after an introductory part on petroleum geology (origin and formation of hydrocarbons, geological characteristics of the accumulations and further information), describes the activities of prospecting, well drilling and development, the study and development of deposits, the production and transport of hydrocarbons and natural gas storage.

The second volume is devoted to an analysis of the structure of refineries, to describing the main derived products and refining operations (distilling processes, processes to improve the quality of fuels, thermal and catalytic conversion processes, etc.), obtaining the basic products (*building blocks* from natural gas, olefins, aromatics), to the production of intermediates for petrochemicals, and to polymeric materials. Problems of safeguarding the environment, and of health and safety, connected with downstream activities are studied. The volume highlights both the high degree of integration among the various sectors, and the great innovations in products and processes that have taken place in the production cycles in the last few decades.

The third volume illustrates evolving technologies and possible scenarios, providing a wide-ranging, in-depth panorama of development activities targeted on a multiplicity of objectives: the production of hydrocarbons from non-conventional oil sources (heavy crudes, bituminous sands and schists, hydrated gases), the production of hydrocarbons from alternative fossil sources (from the liquefaction of coal to the conversion of natural gas into liquid fractions), optimizing the field recovery factor, management of sulphur and water co-produced with crude, energy vectors and use of hydrogen, the use of advanced technologies for generating electricity (industrial cogeneration, distributed and highly efficient generation, energy from fuel cells, energy from renewable sources, etc.), the development prospects of sustainable motorized transport (production of more eco-friendly fuels, the use of electrical or hybrid traction), the separation, confinement and biofixing of CO_2, and the development of environmental monitoring techniques.

The fourth volume first analyses the amount and the geographic location of reserves and resources. Next, comes an examination – also in terms of the geopolitical context and of expected scenarios – of the main economic aspects connected with the hydrocarbons industry: the economic foundations of oil and natural gas, public policies, the types of market and pricing policies, the key figures (the oil companies, the producer and consumer States, international bodies, etc.), company strategies, the macroeconomic background, the transformation of the gas industry from monopoly to competition, risk management and environmental issues. Following this, international legislation connected with oil and gas exploration and exploitation is analysed, also taking into account the aspects related to the prevention of pollution, as well as the main national regulations. Complementing the volume is an appendix dedicated to a number of aspects of particular significance for the development of the hydrocarbons industry (files on the most important countries from the oil standpoint; analysis of the finds that have given substantial boosts to progress in the sciences and technologies of hydrocarbons; chronology of the main historical events that have influenced the oil world).

The fifth volume is subdivided into two parts. The first part has a thematic structure and provides the chemical and physical facts on which the science of hydrocarbons is based: the nature and characteristics of hydrocarbons, physical and chemical equilibria, surfaces and dispersed systems, flow of fluids, kinetics and catalysis, heat exchange, separation processes, chemical reactors, rudiments of the polymerization processes, automation and control, combustion, detonation and explosions, analysis of systems and mathematical models, properties of materials. The second part is arranged alphabetically, in the manner of an encyclopaedic dictionary, and contains the items intended to give readers the necessary tools to understand the rich technical terminology used in the petroleum industry.

Mario Beccari Ugo Romano
Project Directors of the Encyclopaedia of Hydrocarbons

PLAN OF THE WORK

VOLUME I
EXPLORATION, PRODUCTION AND TRANSPORT

1 – Geosciences
2 – Petroleum exploration
3 – Drilling and completion of wells
4 – Oil field characteristics and relevant studies
5 – Development phase of hydrocarbon fields
6 – Field production phase
7 – Hydrocarbon transport and gas storage

VOLUME II
REFINING AND PETROCHEMICALS

1 – Oil refining industry: general aspects
2 – Distillation processes
3 – Processes related to environmental issues
4 – Processes to improve the qualities of distillates
5 – Thermal conversion processes
6 – Catalytic conversion processes
7 – Deep conversion of residues
8 – Lubricating oil manufacture
9 – Safety and environmental protection in the refining industry
10 – Bulk products and production lines in the petrochemical industry
11 – Synthesis of intermediates for the petrochemical industry
12 – Polymeric materials

VOLUME III
NEW DEVELOPMENTS: ENERGY, TRANSPORT, SUSTAINABILITY

1 – From primary sources to the market
2 – Hydrocarbons from non-conventional and alternative fossil resources
3 – New upstream technologies
4 – Energy carriers
5 – Power generation from fossil resources

VOLUME IV
HYDROCARBONS: ECONOMICS, POLICIES AND LEGISLATION

VOLUME V
INSTRUMENTS

ENCYCLOPAEDIA OF HYDROCARBONS

VOLUME I

EXPLORATION, PRODUCTION AND TRANSPORT

SCIENTIFIC CO-ORDINATION
Pier Federico Barnaba, Giovanni Brighenti, Renzo Mazzei

INDEX OF VOLUME I

EXPLORATION, PRODUCTION AND TRANSPORT

2 – PETROLEUM EXPLORATION

3 – DRILLING AND COMPLETION OF WELLS

4 – OIL FIELD CHARACTERISTICS AND RELEVANT STUDIES

5 – DEVELOPMENT PHASE OF HYDROCARBON FIELDS

6 – FIELD PRODUCTION PHASE

7 – HYDROCARBON TRANSPORT AND GAS STORAGE

NOTES

UNITS OF MEASUREMENT

The units of measurement generally adopted are those of the Système International (SI), with corresponding multiples and submultiples. Only in particular contexts, typically connected with the petroleum industry, certain non-SI units of current use have been maintained.

Main units of measurement adopted

ampere	A	henry	H	pascal	Pa
angstrom	Å	hertz	Hz	poise	P
atomic mass unit	u	horse-power	hp	pound	lb
bar	bar	hour	h	pounds per square inch	psi
barrel	bbl	inch	" (in)	radian	rad
becquerel	Bq	joule	J	second (angle)	″
British thermal unit	Btu	kelvin	K	second (time)	s
calorie	cal	kilogram	kg	siemens	S
candela	cd	kilowatt-hour	kWh	sievert	Sv
coulomb	C	litre	l	standard cubic foot	scf or SCF or sft^3
darcy	D	lumen	lm	steradian	sr
day	d	lux	lx	stock tank barrel	stb
decibel	dB	metre	m	stokes	St
degree Celsius	°C	square metre	m^2	tesla	T
degree Fahrenheit	°F	cubic metre	m^3	tonne	t
degree (sexagesimal)	°	minute (angle)	′	tonnes of oil equivalent	toe
electron volt	eV	minute (time)	min	volt	V
farad	F	mole	mol	watt	W
foot	' (ft)	newton	N	weber	Wb
gram	g	nit	nt	yard	yd
gray	Gy	ohm	Ω	year	yr
hectare	ha	parts per million	ppm		

TERMINOLOGY AND SPELLING

In the sectors of petroleum engineering and chemistry, of the petrochemical industry and of the earth sciences, specific terms, acronyms and expressions are frequently used. The criterion adopted in this work is based on their frequency of use, i.e. given two possible terms, the more common one has been used.
British spelling, according to the most authoritative reference works, has been adopted.

CHEMICAL NOMENCLATURE

In the nomenclature of simple compounds, the rules of IUPAC (International Union of Pure and Applied Chemistry) have been adopted as far as possible, traditional names being limited to the cases admitted by IUPAC. When there are two or more names admitted, the commonest one is adopted.
Two principal exceptions to the above rule have been applied in this work:

- For organic compounds used in the petrochemical industry, the name adopted is that listed in: WELLS G.M. (1999) *Handbook of petrochemicals and processes*, Aldershot, Ashgate; Brookfield (VT), Gower.
- The British English spelling of sulphur and sulphur containing compounds is adopted.

TRANSLITERATIONS

In writing names belonging to other languages with an alphabet other than the Latin alphabet, the *Romanization Tables* compiled by the Library of Congress of Washington have been applied, introducing however certain modifications intended to reduce to a minimum the number of diacritical marks, and – in particular in the case of Arabic and Persian – adopting a number of transliterations by now accepted in local and international usage.

Opposite page:
Kazakhstan, the Caspian Sea, artificial island for the perforation and production in Kashagan, the world's biggest reservoir discovered in the last thirty years. The activity is carried out in a joint venture, where Eni partecipates acting as the sole operator. The reservoir is situated in the north of the Caspian Sea, 80 km from Atyrau. Its development represents one of the biggest challenges in the world petroleum industry.