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The Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo)

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ABSTRACT

As part of the Mexican policies to foster the renewable energies in our country, the Secretary of Energy (SENER) and the National Council for Science and Technology (CONACYT) have decided to support academic-industry alliances in order to promote and accelerate the development of geothermal, solar, and wind energy. One of these alliances is the Mexican Center for Innovation in Geothermal Energy, CeMIE-Geo (as stands for its name in Spanish). CeMIE-Geo is a group of 23 institutions consisting of academic institutes and private companies leaded by CICESE, an institution funded by CONACYT 40 years ago and aimed for scientific research and higher education. CeMIE-Geo has been funded to conduct scientific research, technological development and to stimulate innovation in all the areas of geothermal industry. We will work in 30 strategic projects focused in different aspects of geothermal industry, from exploration to production, as well as in projects with high or low enthalpy. In addition we must coordinate the preparation of qualified specialists required by the Mexican industry at all levels, from continuous education courses to PhD graduate programs. We are also setting up a highly specialized laboratory system based in the infrastructure existent in the Mexican universities and research institutes, which will be substantially upgraded and integrated in a national system to support research and development as well as to offer world class analytical capabilities to geothermal industry in Mexico and abroad. In this paper we show the projects and programs of CeMIE-Geo and give a view of our general goals and specific objectives.

1. INTRODUCTION

By 2024 Mexico has set the target of producing 35% of its electrical energy from non-fossil sources. This goal started a number of government policies focused to promote the use of renewables and the creation of public funds dedicated to the development of science, technology and innovation projects. The Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo as stands for its name in Spanish) is one of this projects funded by the National Council for Science and Technology (CONACYT) and the Secretary of Energy (SENER). The project is leaded by CICESE, an institution funded by CONACYT 40 years ago aimed for scientific research and higher education. CeMIE-Geo is an academic-industry alliance comprising 23 institutions, 12 of them in the academic sector and 11 private and public companies.

The participant institutions in CeMIE-Geo are:

1. Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
2. Centro de Geociencias de la UNAM (CGEO)
3. Instituto de Energías Renovables UNAM
4. Instituto de Geología de la UNAM
5. Instituto de Geofísica de la UNAM
6. Instituto de Ingeniería de la UNAM
7. Instituto de Investigaciones Eléctricas (IIE)
8. Universidad Michoacana de San Nicolás de Hidalgo (UMSNH)
9. Universidad Politécnica de Baja California (UPBC)
10. Centro de Ingeniería y Desarrollo Industrial (CIDESI)
11. Centro de Tecnología Avanzada A. C. (CIATEQ)
12. Centro de Sismología y Volcanología de Occidente UdeG (SisVoc)
13. Gerencia de Proyectos Geotermoeléctricos (CFE)
14. Clúster de Energías Geotérmica y Renovables A.C (Clúster Geo)
15. Geoconsul S.A. de C.V.
16. Geotem Ingeniería S. A. de C. V.
17. Exploración perforación y Estudios del Subsuelo S. A. de C. V. (EPYESA)
18. Geología Minería y Consultoría S.A. de C.V.
19. Especialistas en Turbopartes S.A. de C.V.
20. Prados Camelinas S.A. de C.V.
21. GS Energía S.A. de C.V.
22. Generadores de Negocios en Energía Renovable y Ambientales S.C.
23. Baja Innova S.A.P.I. de C.V.

Most of the geothermal expertise in the country is grouped in the listed institutions. The idea is to use the existing physical and human infrastructure in the country, strengthen it, and promote its functioning in a coordinated manner, in such a way that efforts be focused to promote scientific research, technological development and innovation in the field of geothermal energy.

2. OBJECTIVES

Mexico has a long tradition as a geothermal country. The Federal Electricity Commission, via its Gerencia de Proyectos Geotermoeléctricos (GPG), has an extensive experience in the geothermal industry since 1959, when they start operating the first generation plant in America, in Pathé, Hidalgo area. Currently, GPG operate four geothermal fields in the country (Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes) and their work has led Mexico to the fourth or fifth site in the world ranking, in terms of installed capacity (Gutiérrez-Negrín, 2012). Mexico now moves toward opening up its energy sector, including electricity generation. At the time of writing this manuscript the Mexican Congress discusses an ambitious reform to the Laws on Energy and particularly a Geothermal Law allowing private investors to enter the emerging energy market in the country. This new reality imposes great challenges as well as opportunities never seen before. All geothermal experts from both industry and academia are called to close ranks with GPG in order to contribute to a better understanding of our resources and provide a solid support to the development of a national geothermal industry.

The creation of CeMIE-Geo responds to this necessity. Our mission is conform a group of institutions and individuals in order to have a unified knowledge in geothermal technology and capable of generate synergies that promote innovation, scientific research and technological development, contributing to strengthening the geothermal industry in the country. Some of the long-term general objectives are:

- To expand and strengthen the capability for scientific and technological research promoting its collaborative use.
- To develop specialized human resources for academy and industry
- To promote innovation encouraging technology-based companies and strengthening the capabilities for research and technological development in the geothermal sector companies

More specific and short-term goals are:

- To strengthen capabilities in geothermal energy so as to overcome existing technological barriers.
- To establish strategic projects which contribute to a better knowledge and use of geothermal energy.
- To promote technological conditions suitable for the development of Mexican geothermal industry.
- To offer training programs at different levels in geothermal energy.

In order to fulfill these objectives SENER-CONACYT provided a seed grant for about 75 million dls to cover operation during the first four years. It is expected that in this four-year period CeMIE-Geo shall consolidate a consortium able to look for its own future resources, providing scientific and technological support and specialized services to the geothermal industry in Mexico and abroad. The group has defined a basic organizational structure shown in Figure 1.

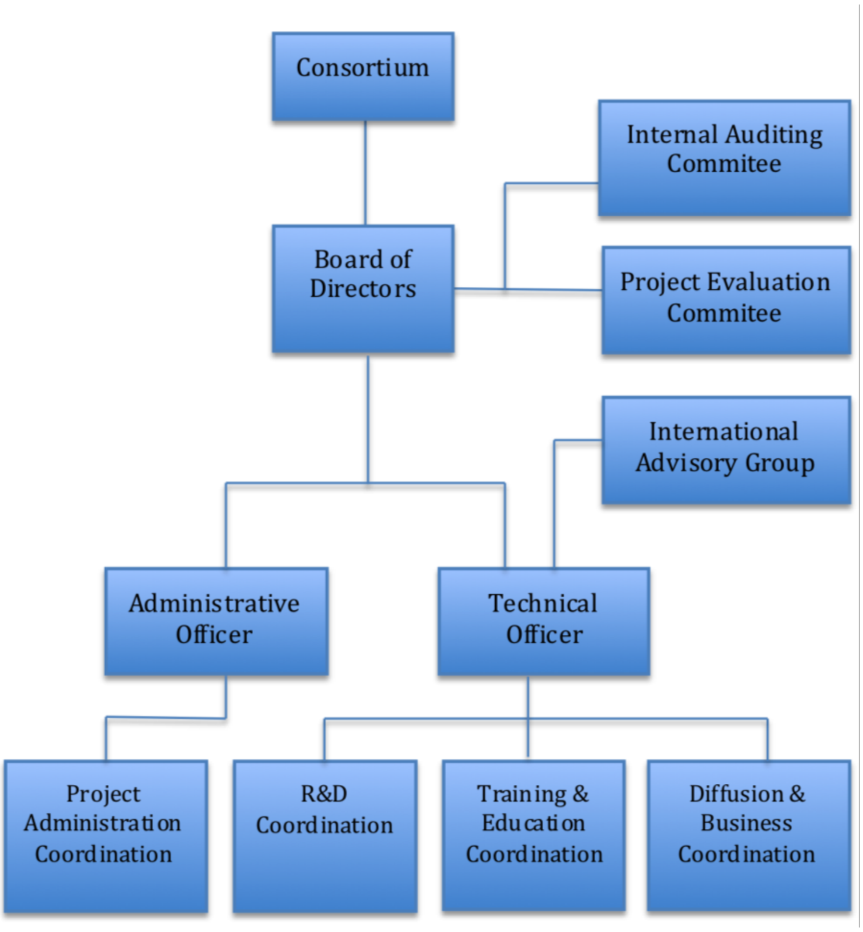

Figure 1: CeMIE-Geo organizational structure.

2. STRATEGIC PROJECTS

During the initial four-year stage CeMIE-Geo will be working on 30 strategic projects involving scientific research and technological development in different aspects of the geothermal industry. A group of projects will be devoted to resource mapping and estimation of the national geothermal potential. Another group is concerned with the evaluation and development of exploration techniques based on: geology, geochemistry and geophysics. We will also be working on technological developments, especially for the stages of energy production, such as models, prototypes, pilot plants, etc. Another group will do demonstrative projects on a subject very little developed in Mexico, i.e. the use of low temperature geothermal sources for direct applications in space conditioning, industrial and agro-industrial processes, etc. In addition we have two transversal projects involving most of the participating institutions: an Education and Training Program and a Specialized Laboratory System.

2.1 Resource assessment

The basic information about temperatures, heat flow and geothermal gradient that is currently available is sparse and incomplete. Data acquisition surveys and more comprehensive studies of heat flow, geothermal provinces, as well as a better census of thermal manifestations and aquifers are needed to have an updated estimate of the geothermal potential of the country, initially for hydrothermal and hot dry rock resources, and later for other types of geothermal reservoirs, including submarine vents. The specific projects in this issue are:

- Geothermal gradient and heat flow maps of Mexico. PI: Rosa Ma. Prol, UNAM
- Map of geothermal provinces in Mexico from fluid geochemistry and distribution of aquifers. PI: Ruth Villanueva, UNAM
- Assessment of the Enhanced Geothermal System (EGS) potential for power production in Mexico. PI: Eduardo Iglesias, IIE
- Assessing the potential and over-exploitation of the geothermal power capacity of Mexico using noble gas isotopes. PI: Aída López, UMSNH
- Testing probes for measuring shallow heat flow in geothermal zones. PI: Víctor Hugo Garduño, UMSNH

2.2 Exploration techniques

There are several recent protocols for geothermal resource exploration, however its implementation still leaves a substantial margin of uncertainty before the expenditure of significant financial resources to drill exploratory wells. It is necessary to develop technologies, applicable from the surface or by drilling shallow wells, to reduce the uncertainty in the location of the reservoir, and in the estimation of size, temperature and chemical characteristics. In this issue the proposed projects plan to experiment new geological, geophysical and geochemical techniques in known Mexican geothermal fields; but also to explore the unknown marine resources in the Gulf of California. The specific projects in this group are:

- Intensive survey of geothermal exploration in Wagner, Consag, Delfín, Guaymas and Alarcón basins in the Gulf of California rift system. PI: Antonio González, CICESE
- Spatial and temporal monitoring of geophysical variables in geothermal fields. PI: Marco Antonio Pérez, CICESE
- Integration of modern techniques for geothermal exploration using geological, geochemical and geophysical methods. PI: Gerardo Carrasco, UNAM
- Development, implementation and application of analytical methodologies of water/rock interaction processes in geothermal reservoirs of low and high enthalpy: Application to Mexican fields. PI: Eduardo González, UNAM
- Development and application of new advanced methods in fluid geochemistry and hydrothermal alteration for the exploration of geothermal systems. PI: Edgar Santoyo, UNAM
- Geothermal exploration of the volcanic complexes of Cerritos Colorados, Acoculco and El Aguajito-Reforma: Insights from volcanology, stratigraphy, geochemistry and experimental petrology. PI: José Luis Macías, UNAM
- Fracturing, faulting and current deformation field study, supported by seismic analysis and tomography in the geothermal fields of Cuitzeo, Mich., and Cerritos Colorados, Jal. PI: Víctor Hugo Garduño, UMSNH
- Passive seismic and magnetotelluric exploration in the Tulancingo-Acoculco and Ceboruco Volcano geothermal fields. PI: Francisco Núñez, SisVoc UG
- Sustainable development and minimization in the environmental impact of the geothermal reservoirs exploitation in Mexico. PI: Zayre Ivonne González, CICESE
- Development of a model for technical, financial, legal and regulatory feasibility assessment of high, medium and low enthalpy geothermal exploration and development projects. PI: Sergio Galván, UMSNH

2.3 Technological developments

Although the technology associated with thermodynamic cycles and power generation equipment is well advanced, there is still some room for innovations. In this issue we want to promote a domestic geothermal engineering and motivate the creation of technology-based enterprises. The projects are:

- Development of computer tool based on the best available equation of state, for the calculation of thermodynamic properties of H2O and CO2 mixtures in a wide range of pressure, temperature and composition. PI: David Nieva, IIE
- Technological developments for the use of low enthalpy geothermal energy. PI: Martín Salinas, UNAM
- GeoSteam.Net: A vapor transport simulator to optimize the design of steam-pipeline networks and generation of electrical energy in a geothermal field. PI: Mahendra Pal, IIE
- Integration of a poly-generation plant using geothermal energy through a cascade concept. PI: Carlos Rubio, UMSNH
- Monitoring the structural integrity of pipes by ultrasonic guided wave tomography. PI: Alberto Ruíz, UMSNH
- Development of super-alloys and special titanium based alloys for applications in turbines for geothermal power generation. PI: Arnoldo Bedolla, UMSNH

- Geothermal power generation using CO_2 captured from fossil-fired power plants. PI: Alicia Aguilar, UMSNH
- Design and construction of a low enthalpy turbo-generator with capacity of 300 kW. PI: Juan Felipe Soriano, UMSNH
- Evaluation of technologies to maximize the extraction of geothermal energy deposits of medium and low enthalpy. PI: Jesús Pacheco, UMSNH
- Design of a comprehensive methodology for the perforation of geothermal sites of medium and low enthalpy, with technology innovation and definition of risk parameters. PI: Hugo Gutiérrez, UMSNH

2.4 Direct uses of geothermal heat

Technologies for thermal conditioning of spaces and direct industrial applications with heat from geothermal sources have been used for decades in other countries, and will surely be economically viable in areas with inhospitable climates in our country. However these proven technologies are basically unknown by Mexican entrepreneurs and by the general public, so this lack of knowledge should be considered a non-technical barrier that must be addressed. It is necessary to disclose the technology conducting technical and economic studies and developing demonstration projects that result in reliable information showing the feasibility of the use of resources of low and medium enthalpy. The projects in this issue are:

- Feasibility analysis and development of a prototype demonstrating the use geothermal energy for heating of greenhouses. PI: Abelardo Mercado, UPBC
- Feasibility analysis, comparison of technologies, market research, and development of a Geothermal Heat Pump (GHP) demonstration project for air conditioning of residential and commercial spaces in Mexicali, Baja California and Cuernavaca, Morelos, Mexico. PI: Alfonso García, IIE
- Modular design system for residential air conditioning through the use of geothermal energy. PI: Héctor J. González, UMSNH
- Design, development and detailed characterization of a food drying geothermal heat system with the quality required by the food industry. PI: Julio Vargas, UMSNH
- Development of a system for the generation of controlled-climate from the exchange of heat with the subsoil and the utilization of the thermal inertia of the earth's crust, with applications to industrial, commercial, public and household spaces. PI: Crisanto Mendoza, UMSNH

2.5 Training Programs

It should be noted that the current strength of geothermal energy in Mexico dues to the existence of trained personnel in all phases of development of geothermal projects, working in GPG as well as in other solid institutions. However, an important part of this human resource is close to retirement, so there is an urgent necessity to train new technicians, engineers and scientists, by creating new geothermal training programs at all levels. The academic staff and education programs offered by some of the academic institutions forming CeMIE-Geo have a national and international recognition. We will use these capabilities and our academic infrastructure to improve and create new programs at several levels:

- Short courses for technical training.
- Technical specialization programs (Diploma).
- Graduate programs (PhD and MSc) offered by UNAM, CICESE, UMSNH, UPBC and UG.

The first level should focus on staff training to provide companies with a staff of mid-level employees that can efficiently perform in different chores, from exploration to marketing through geothermal resource exploitation. This training can be carried out efficiently through the development of short courses on specific topics, which may be part of more specialized programs, such as graduate and postgraduate programs.

In the second level is the preparation of highly specialized personnel in some of the phases of the geothermal process and must be made through graduates in specific topics: exploration, exploitation and marketing. These graduates have common themes: as all specialists they must have general knowledge about geothermal (basics geothermal course). The geothermal basics course should include the concepts of Earth Sciences, explanation of the basis of exploitation and utilization of the resource and the basis of calculation of finance and economic benefits of geothermal energy.

The third level will be directed to train experts who will be able to develop scientific and technological innovations applied to the exploration, exploitation and sustainable development of geothermal energy. This objective can only be achieved through the establishment of master's and doctoral programs in geothermal. Particularly interesting schemes may be proposed as professional master's degrees aimed at professionals who are currently working on geothermal exploration tasks, whether in public (GPG) or private companies. This will promote a comprehensive range of high quality training that would enable updating of concepts, and use of modern and innovative techniques that can be applied in real cases once they resume full time work in their assigned areas.

The academic members of CeMIE-Geo have graduate programs that can be tailored and supplemented for this purpose promoting the integration of the specialties in our institutions and taking advantage of courses already offered, aside from creating new courses to prepare high-level specialists in different branches of geothermal energy utilization. This will require the creation of virtual classrooms to share distance-courses at all venues and expand academic mobility programs, in addition to using the existing ones.

In addition CeMIE-Geo will strength links with leading international universities and institutions offering high quality geothermal educational programs.

2.6 Highly Specialized Laboratory System

A fundamental component of CeMIE-Geo will be a Highly Specialized Lab System comprising seven labs distributed throughout Mexico at four institutions: UNAM, UMSNH, CICESE and IIE. The intention is having world-class installations providing the analytical capability for our projects, but also to offer analytical services to the whole geothermal industry. Figure 2 shows the structure of CeMIE-Geo's lab system.

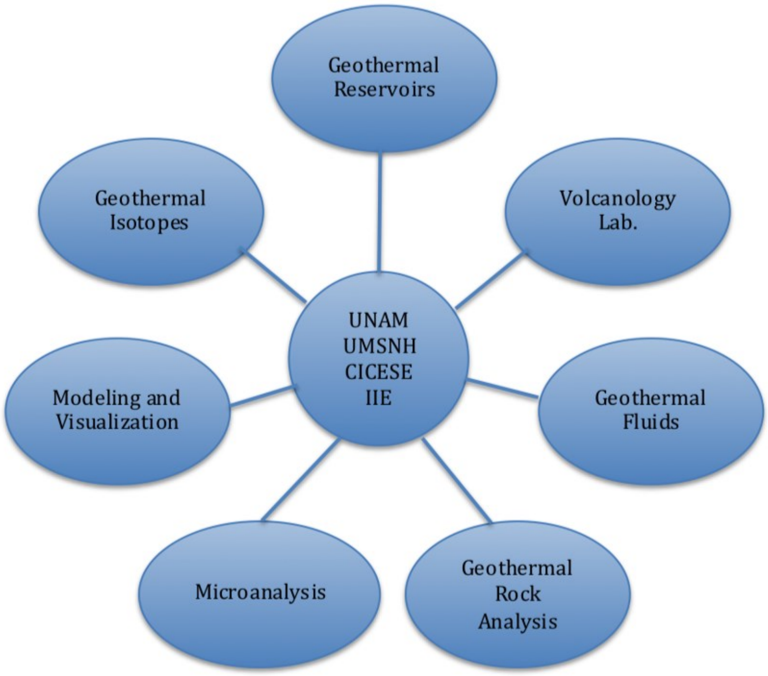

Figure 2: Specialized Lab System structure

2.6.1. Geothermal Reservoirs Lab

This laboratory shall carry out experimental studies for multiphase flow and heat transfer in a deformable porous medium to understand the behavior of geothermal fluids under HP-HT conditions. It will allow the development of efficient and environmentally sustainable techniques for fluid injection and extraction in the context of geothermal energy. Some specific issues that shall be addressed include:

- Permeability enhancement:
- Clogging due to depositional and diagenetic issues:
- Fracture development & Seismicity:
- Quantification of the signature of changes in pressure and temperature on acoustic fields: develop the criteria for time lapse monitoring of fluid fronts in geothermal reservoir.
- Stability of gas/fluid front under HT-HP conditions
- Movement and stabilization of injected fluid front under HT-HP conditions

2.6.2. Volcanology Lab

This facility will be set by UNAM and will be aimed for high quality sample preparation for geochemical and petrologic analysis as well as for radiometric dating. It will be equipped with rock precision cutter, magnetic separator, portable XRF analyzer and petrographic microscopes. Some of its capabilities include:

- Preparation of polished thin sections
- Crushing and grinding of rocks for chemical and isotopic analysis.
- Mineral separation and preparation of rocks for dating radiometric and mineralogical analysis
- Polished crystals for FTIR analysis and electron microprobe.
- Preparation of samples for granulometric analysis, components, density-vesicularities.
- Petrographic and mineragraphic analyzes.

2.6.3. Geothermal Fluids Lab.

The chemical composition of fluid phases within a geothermal reservoir is extremely important as it determines reactive processes that can influence the physical behavior of the system as a whole, and definitively exert a strong influence on the type of technology that can be used for exploitation of these systems, in particular due to the corrosive effects that some of these fluids may have. Consequently, it is necessary to have a laboratory especially equipped for the chemical determination of fluid collected both directly from geothermal fields as well as in relation to the experiments made in our geothermal projects and/or in other labs of the System. The lab will be setup at three institutions CICESE, UNAM and IIE, and will equipped with a double focusing magnetic sector field ICP-MS with lase ablation and multi-element analysis capability, besides other complementary equipment as liquid and gas chromatography, mass spectrometers, etc.

2.6.4. Geothermal Rock Analysis Lab.

This laboratory aims to provide analytical support for characterization of the chemical composition of various materials, as well as for the identification of crystalline components in a variety of materials, among which are metals, alloys, ceramics, cements, products of corrosion, scale, rock, etc. It will be setup at IIE and CICESE with X-Ray spectrometer, diffractometer, fluorescence and micro-computed tomography equipment, it will also have a drilling equipment for core sampling at shallow depth.

2.6.4. Microanalysis Lab.

This laboratory will have as main facilities a micro-computed tomography (CT) x-ray system, an Electron Microprobe (EPMA), a portable scanning electron microscope with fast energy-dispersive X-ray spectroscopy (EDS), infrared spectroscopy equipment (FTIR), a Raman spectrometer, and micro-thermometry analysis capabilities. The lab will provide infrastructure to investigate the internal structure of a rock material in 3D, the geometry of its components and their interrelationships, its porosity, sizes and shapes, thus understand the processes and conditions that impact the geothermal system operation, such as permeability, fluid flow, chemical evolution, fluid inclusions, minerals produced by geothermal alteration, etc. The lab will be set by UNAM, UMSNH and IIE.

2.6.6. Modeling and Visualization Lab.

The modeling of geothermal systems is a multi-physics problem in which, besides temperature, it is necessary to simultaneously model other physical fields and phases. Furthermore, geothermal systems are multi-scale and it is therefore necessary to discretize the models with a fine resolution given the natural complexity that characterizes them. A finer discretization leads to models closer to reality and this can be translated into a better understanding of the geothermal systems and better management and development decisions in the exploitation stage. This facility will be at CICESE and it is based in a computer cluster with 48 nodes, 32 cores, 64 GB of memory each, to conform a total of 1536 cores and 3072 GB of memory. It will be complemented with peripheral equipment such as workstations and software for different applications. An additional a GIS laboratory will be setup at UNAM dedicated to handling databases and cartographic information. Some specific issues to be addressed in the modeling lab include:

- Numerical modeling of multiphase and multicomponent flow in porous, heterogeneous and fractured media.
- Static or dynamic modeling of geothermal systems using the mass and heat transport coupled equations.
- Geophysical data inversion to determine the distribution of the physical properties in the subsurface in geothermal systems.
- Basin evolution modeling using numerical methods such as finite elements or finite differences.
- Geochemical modeling of geothermal flows (reactive transport).

2.6.7. Geothermal Isotopes Lab.

The main objective of this lab is the isotopic characterization of aqueous fluids from geothermal reservoirs. The analysis results can be used in modeling of hydrothermal systems, temperature estimations, studies of waste fluid injection and evaluation of physicochemical processes in the reservoir. The applications of hydrological studies are mainly focused on the isotopic characterization of aquifers to evaluate interconnection, charging zone location and the detection of possible sources of pollution. It will be setup at CICESE and IIE, equipped with isotope analyzers for water, methane, and CO2, as well as mass spectrometer.

CONCLUSIONS AND EXPECTED IMPACTS

Fostering renewables against fossil fuels in Mexico will certainly have key impacts on environmental, scientific, technological, economic and social aspects.

We expect that CEMIE-Geo will have a high impact on the scientific and academic fields in the country, and internationally, not only in geothermal areas. The commissioning of the laboratory system and the implementation of projects led by national experts as well as the frequent collaboration of international specialists, will encourage the participation of different scientific disciplines demanded by the geothermal industry.

The technological impact of CEMIE-Geo could also be foreseen as very high, considering that projects in its initial portfolio will be focused precisely in technological innovation. The main technological impacts expected from the projects to be developed, and from the laboratories that will be constructed are in the better exploitation of fields with low and intermediate temperatures, both for possible use in generating electricity as direct uses of heat.

The implementation of CEMIE-Geo's portfolio of projects will contribute to improve exploration techniques in order to increase the success rate in drilling of exploration wells, consequently in some extent will help to reduce initial costs, usually elevated, of geothermal projects, both electric as those for direct uses.

On the social side, the CEMIE-Geo will help investors interested in developing geothermal resources both, high and low enthalpy systems, which will undoubtedly have a positive effect on job creation. CeMIE-Geo's training programs will contribute to develop more and better-qualified specialists as well as to improve their professional competence, opening the access to better jobs.

An increased use of geothermal resources, both to generate electricity and for direct use of the heat, will contribute to mitigate the emission of greenhouse gases reducing the environmental impacts of energy use. As this is the main objective of CEMIE-Geo, its creation and operation will also contribute importantly to this purpose.

It is worth mentioning that it is widely recognized and extensively documented that the hydrocarbon era is in decline, most of the producing countries, including Mexico, reached their maximum production peak a couple of decades ago. The hydrocarbons left underground are increasingly difficult to extract and have lower quality. Unfortunately, it seems that renewables alone will not be enough to replace fossil fuels; we will require further substantial changes in energy consumption habits of the countries and their societies.

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