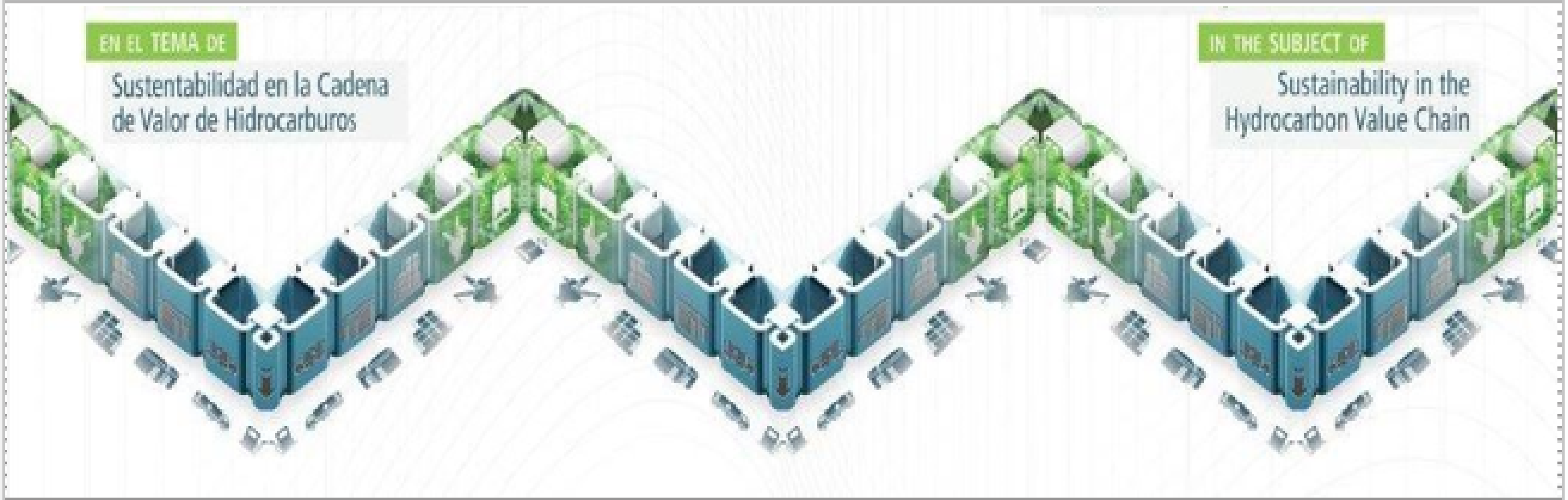
SENER
SECRETARÍA DE ENERGÍA

REPORTE DE
PRIORIDADES NACIONALES EN EL TEMA DE SUSTENTABILIDAD EN LA CADENA DE VALOR DE HIDROCARBUROS



2018

NATIONAL PRIORITIES REPORT

Versión: 1.0

SUSTAINABILITY
IN THE
HYDROCARBON VALUE CHAIN
IN MEXICO

Steering committee:

Moisés Magdaleno Molina (Leader)
Instituto Mexicano del Petróleo
Dr. Blas L. Pérez Henríquez (Co-Leader)
Stanford University

Technical support:

Jaqueline Salazar Montes de Oca
Luis Alberto Melgarejo Flores
María Esther Palmerín Ruiz
José Javier Vázquez Martínez
Juan Manuel Mondragón Bocanegra
Jesús Alberto Arenas Romero
Miguel Ángel Ramos Morga
Esteban Antonio Guerrero Jaimes
Joshua S. Dimon
Jens-Erik Lund Snee

JULY 2018

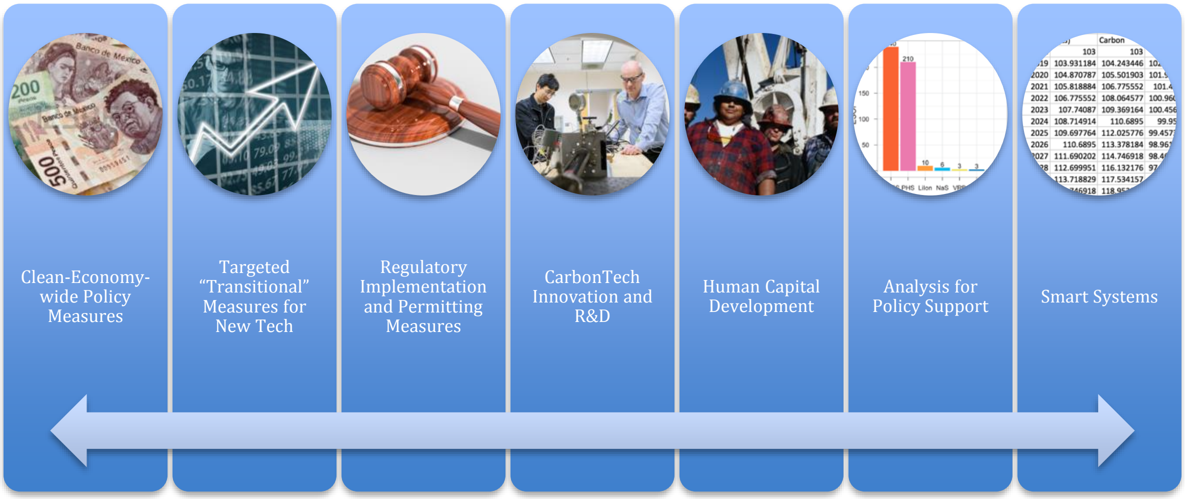
Nota: Las prioridades nacionales que contiene esta versión fueron concebidas considerando la opinión de expertos nacionales e internacionales, por lo que su contenido técnico no presentará cambios de fondo respecto a la versión y edición final de este documento.

Contents

EXECUTIVE SUMMARY

This document presents a holistic perspective on a series of policy recommendations to allow innovation as well as research and development (R&D) to support the emergence of a more sustainable hydrocarbon value chain (HCVC) in Mexico. It provides an investment plan for developing an integrated policy framework, as well as the necessary decision-making tools to enable and develop enhanced human and institutional capacities for Mexico to take advantage of the promise of cutting-edge emerging technologies, as well as innovative business models when maximizing efficiency, productivity, and risk management in this industrial sector. Moreover, it provides guidance on how to foster optimal use of hydrocarbon resources using economic incentives to spur technological and managerial innovation in the enhancement of co-benefits to society and minimization ofof negative externalities or impacts. It suggests clean innovation for more sustainable practices, frameworks, processes and products using carbon tech and digitalization and artificial intelligence approaches among other emerging technological solutions. This report suggestss the creation of a binational knowledge exchange platform and innovation implementation lab to support policy and technological innovation to enhance the sustainability of the hydrocarbon value chain in Mexico. Key elements of this program are as depicted in Figure 1:

Figure 1: Key Programmatic and Planning Elements for a Sustainable HCVC in Mexico



The workshop followed the methodology established by the "basic research needs workshops" of the United States Department of Energy (DOE). Adapted to the Mexican context, this workshop brought together a number of distinguished national and international experts in the field from countries and institutions with robust research portfolios in energy policy and innovation. Delegates were divided in five working groups or expert panels based on the following thematic tracks. Below is the list of key national priorities divided by panel and identified by the group of experts during the workshop:

Panel 1: Optimal use of oil and gas resources in the age of decarbonization

1. Develop and emphasize a culture of continuous improvement throughout the entire hydrocarbon value chain, focusing on improved efficiency and reduced emissions.
2. Optimize utilization and processes in existing and new refineries and petrochemical plants to ensure increased efficiency and a cleaner production of fuels and petrochemicals.
3. Develop advanced petrochemical processes and enhanced refining.
4. Adopt carbon capture technologies for enhanced utilization of CO_2 (i.e., enhanced oil recovery - EOR).
5. Foster the transformation of CO_2 into useful products.
6. Develop technologies for cleaner and more efficient combustion.
7. Establish an Unconventional Research Center to focus on the optimization of development in an environmentally responsible manner.
8. Develop a regional planning process for unconventional development (i.e., land use planning).

Panel 2: Analysis of Life Cycle and Eco-efficiency in the hydrocarbon value chain

1. Create an institute or entity that directs and compiles data for the life cycle analysis (LCA) of the hydrocarbon value chain, LCI (life cycle inventory) and atmospheric emissions assessment.
2. Develop methodologies, models, and tools in these areas.
3. Build human capacities in science, analysis and operations for LCA.
4. Analyze opportunities for new technological and future sector needs by means of developing new equipment, processes, models and methods adapted to the evolution of the hydrocarbon value chain.

Panel 3: Efficient use of water

1. Characterize and model deep aquifers and watersheds in unconventional shale fields.
2. Water quality assessment across the hydrocarbon value chain.
3. Integrated, efficient and sustainable water management (e.g., water-energy nexus) in the Hydrocarbon value chain.

Panel 4: Social Impact and co-benefits in the oil and gas industry.

1. Develop approaches and instruments (e.g., civic tech) for participation across the life cycle of the industry.
2. Build capacities in these fields among communities, government institutions, and the private sector.
3. Support holistic socio-environmental regulatory frameworks for the energy sector.
4. Integrate the social dimension of sustainability throughout the life cycle of hydrocarbon programs and projects.
5. Develop effective co-benefits approaches for local communities.

Panel 5: Policy options to support the transition to a more sustainable oil and gas industry

1. Develop clean-economy wide policies to decarbonize in the hydrocarbon value chain.
2. Support the implementation of economic incentives such as carbon pricing and emissions trading to support clean innovation and investment.
3. Develop decision-making tools (e.g. tecno-economic analysis) for the development of new carbon technologies (i.e., carbon tech).
4. Create frameworks for the development of digital systems to monitor and manage key sustainability indicators of the entire operation of the hydrocarbon value chain including baselining to measure impacts in time (e.g., digital, smart hydrocarbon systems through deeply embedded data analytics).
5. Develop shared-resource systems research and analytical capacities for innovative, integrated and holistic policy and technological solutions to enhance sustainability of the hydrocarbon value chain.

1 INTRODUCTION

Following the Energy Reforms of 2013 and 2014, one of the most important challenges that Mexico will face in the coming decades is to make optimal and efficient use of its vast energy resources. The Mexican government is faced with the challenge of promoting economic growth, while minimizing the environmental and social impacts of the activities of the oil and gas industry.

The objective of this document is to reflect this workshop's structure, proceedings and recommendations derived from its development. This international workshop, which took place in Mexico City in May 2018, brought together business leaders, government officials, as well as academics and researchers in order to:

1. Discuss the latest institutional designs, corporate frameworks and technologies for improving sustainability in the hydrocarbon value chain;
2. Identify needs for research and development, talent training, development of institutions and improving knowledge and technological capabilities in Mexico; and
3. Recommend areas for the investment of SENER – National Council of Science and Technology (CONACYT) Sectorial Funds for energy innovation according to the greatest impact and need.

This document aims to be a guide of National Priorities for the Government of Mexico in general, and in particular for investments under the purview of the energy innovation sectoral funds managed by SENER and CONACYT for scientific research, technological development and training for the development of human resources to enhance the sustainability of the hydrocarbon value chain in Mexico.

1.1 WORKSHOP SUMMARY

The workshop followed the methodology established by the "basic research needs workshops" of the United States Department of Energy (DOE).[1] Adapted to the Mexican context, this workshop brought together a number of distinguished national and international experts in the field from countries and institutions with robust research portfolios in energy policy and innovation. The participants were tasked with identifying and discussing the basic research needs of high priority or other opportunities in technical areas that are ripe for future research and investment to enhance the sustainability of the hydrocarbon value chain in Mexico. The workshop also identifies prospects for bilateral or multilateral research and development collaborations that would benefit from cooperation on high-impact scientific research to this end. The three-day discussions were structured in three plenary sessions and multiple focused well-structured roundtable discussions divided into five working groups by thematic track.

Panel 1 and Panel 5 served as "bookends" for the thematic areas that were discussed. These opening and closing panels established a set of framing parameters for our workshop discussions. These sessions contained and outlined the discussion themes to identify a series of recommendations within each thematic track. The discussions ultimately resulted in a set of national priorities in which the Hydrocarbons Sectoral Fund SENER – CONACYT can invest in order to advance key strategic technological and policy decarbonization paths for the oil and gas industry in Mexico. Investment in innovation, R&D and capacity building

---

[1] See: https://science.energy.gov/~/media/bes/pdf/reports/files/brn_workshops.pdf

to support the low carbon transformation of this industry will aim at maximizing the business opportunities that will emerge as the entire value chain evolves towards a low carbon future. To jumpstart the discussions the thematic tracks and panels were introduced conceptually to delegates as follows:

Panel 1: Optimal use of oil and gas resources in the age of decarbonization

Mexico has abundant oil and gas resources that provide an important resource for economic development. Additionally, the availability of new technology for producing abundant unconventional oil and natural gas resources through horizontal drilling and multi-stage hydraulic fracturing creates new opportunities and challenges. It is now well established that compared to coal, natural gas for the generation of electricity and for industrial applications has beneficial effects on air pollution, greenhouse gas emissions and energy security. In this context, shale gas resources represent a critically important transition fuel on the way to a decarbonized energy future.

For these benefits to be realized, as well as those of "uneconomic" oil reserves, it is imperative that these resources be developed in a sustainable manner, with effective environmental safeguards to reduce their impact on land use, water resources, water quality, air and the nearby communities.

Panel 2: Analysis of Life Cycle and Eco-efficiency in the hydrocarbon value chain

Life Cycle Analysis (LCA) is a methodological tool that allows establishing environmental, social and economic indicators during the entire production cycle of a product or process (from the cradle to the grave or from the well to the wheel). It allows the identification, calculation and evaluation of emissions and impacts throughout the entire production chain and identifies the areas where they are concentrated.

This information is used to establish opportunities to improve production and determine strategies for reducing environmental impacts, which in turn may require redesigning of the production process; installation of equipment to control emissions to the air, water, or soil; and establishment of best environmental practices.

Separate from LCA, eco-efficiency is a tool that enhances the efficient use of resources, minimization of negative impacts, and optimization of environmental, technical and economic benefits. In accordance with this approach, sustainability of industrial operations must be continually improved, with an emphasis on operational eco-efficiency and energy efficiency in this sector.

Panel 3: Efficient use of water

Renewable water resources are defined as being resources that can be used by a specific population in a sustainable manner. Mexico has 447.26 billion cubic meters of freshwater renewable resources that are available annually. Their distribution in time and space represents a challenge for development. The southeastern regions represent two thirds of the country’s renewable water resources and one fifth of the population, contributing a fifth of the national GDP. The northern, central and northwestern regions have one third of the country's renewable water resources but four fifths of the population and contribution to the national GDP. Considering the renewable water resources per capita, the southeast regions have seven times higher resources than those available in the rest of Mexico.

However, inefficient and wasteful consumption of water, lack of payment for water services, contamination of the water resources, inadequate use and poor administration, and

demographic pressure have rendered Mexico one of the countries with the least availability of water, occupying the 92nd position in the world.

In this context, it is of concern that the water consumption of the oil and gas industry increases every year. Since freshwater is becoming a scarce and valuable resource, several places have undertaken programs to recover and reuse wastewater for oil extraction and the refining process. Management of water coproduced with oil and gas depends mainly on economic factors that are directly influenced by the volume and quality of the water produced, state and federal regulations, the available infrastructure and the characteristics of the specific work. Reuse of the coproduced water for drilling operations and enhanced oil recovery (EOR) operations is on the rise**.** Much more needs to be understood with respect to water composition and its role on oil recovery and formation damage, however.

Panel 4: Social Impact and co-benefits in the oil and gas industry

At the global level, and for the fossil fuel sector specifically, social impact analysis is trending toward the use of cumulative impact assessment (often integrated with environmental impact assessment). To minimize effectively harmful social impacts of the fossil fuel sector, social considerations must be integrated throughout the hierarchy of the decision-making process for the industry. Social impacts must be considered from the early stages of modeling, planning and zoning, to the final stages of the fuel consumption life cycle and waste management.

The components of social impact analysis that are applied here for the purpose of defining national priorities are:

- Establishing the current status of the interaction between the interest groups and the developers of the different stages of the hydrocarbon value chain
- Defining the challenges and opportunities associated with social vulnerability
- Specifying the potential for socially responsible community relations and planning for a low carbon economy
- Applying cumulative impact analysis to characterize effectively the long-term effects for public health.

Panel 5: Policy options to support the transition to a more sustainable oil and gas industry

There is growing and irrefutable evidence that the accumulation of atmospheric greenhouse gases from the burning of fossil fuels is changing our climate. The pressure to respond to the threat of climate change is increasing. The only solution to limit the increase in the average global temperature to less than 2° C is to reduce systematically CO_2 emissions through the deep decarbonization of our energy system. From now on, we must reduce CO_2 emissions by 4% per year and maintain that for the next 50 years. This would result in a global emissions reduction of 75% in 2050 compared to today.

The main options for rapidly decarbonizing the global economy are divided into four categories:

- Reduce energy use through conservation efforts.
- Reduce energy use by improving efficiency.
- Switch to fuels and energy sources that emit low or no carbon in their lifecycle
- Capture, storage and utilization CO_2**.**
- Clean innovation for oil & gas decarbonization (i.e., Carbon Tech).

In the short term, the oil and gas industry can contribute to decarbonization by providing natural gas as a cleaner substitute for coal. Transitioning from coal to natural gas can reduce CO_2 emissions from power plants by more than 50%. Driven by economic considerations and potential regulations, this change began in the United States and has already contributed to lower emissions there. For deeper decarbonization, the industry could agree to "recover" the CO_2 produced by burning natural gas for electricity or industrial applications and then to sequester CO_2 in its oil and gas fields. The estimated 1,000 GT of CO_2 storage capacity in oil and gas fields could accommodate emissions from the burning of natural gas well into the century. However, investing in tools such as techno-economic analysis and creating cost-effective policy drivers to induce innovation and low carbon transformation of the industry such as carbon pricing is key. As the Mexican government plans to invest in supporting applied research development to decarbonize the hydrocarbon value chain in Mexico well integrated policy strategies need to be developed in such a complex systems context. Clean innovation will no doubt generate technological solutions for decarbonization as well as opportunities for economic development for Mexico if leadership in this sector is established. The energy reform process offers a great opportunity to do so.

This is Mexico's opportunity to begin the long but urgent decarbonization process of its energy system. The industry must not only reduce its own emissions, but it should also sell products that yield emissions reductions from customers. In short, become more sustainable.

1.2 PLENARY SESSIONS

In addition to the work of the five panels described above, representatives of academia, government and industry held plenary sessions focused on aligning the work to be done during the panels. The plenary sessions identified challenges, opportunities and barriers to addressing the problems, and they highlighted relevant national priorities and potential strategies to achieve the priorities.

Below is a summary of the key information presented in the plenary sessions by the national government-level decision makers who participated.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)

The energy sector is committed to the national sustainability agenda, and therefore to the goals of the 2030 Agenda for sustainable development related to:

- Social lag;
- Economic issues; and
- Environmental issues.

Mexico has taken a global leadership role on issues including climate change and biodiversity. The country has a long-term vision and has made global environmental commitments that are now established in clear targets, adhering to precise metrics rather than aspirational goals.

Following Norway’s lead in committing to a goal of zero emissions, PEMEX and IMP adopted this paradigm for the oil and gas sector in 2006–2007. The goal of zero emissions is especially complex in the oil and gas sector because it incorporates emissions throughout the entire lifecycle, meaning that the emissions from all hydrocarbon raw materials (oil, gas, coal) must be accounted for and must remain within the system. Those tasked with implementing the emissions reductions face challenges that include operating within and developing new organizational structure|, and navigating international agreements and commitments including a goal of reducing greenhouse gas (GHG) emissions by 25%.

Secretaría de Energía (SENER)

One of the SENER’s objectives is to manage technology funds and human resources training. The funds were created in 2007, and they became operational in 2009, evolving over time to generate better impact results in the energy sector. In 2009, a call was made to identify funding needs based on the concerns of the scientific community. Unfortunately, a portfolio of projects was developed that suffered from a disconnection between the financed objectives and the identified national challenges.

Based on this experience, a binding model was sought, which led to the development of the Mexican Energy Innovation Centers. These Centers are consortiums of public or private research centers, higher education institutions, companies and government entities that have the objective of working together on projects dedicated to developing technologies, products and services that allow our country to take advantage of its enormous potential in renewable energies. In addition, invitations were extended to members of the scientific and academic communities to help identify barriers and opportunities for developing these technologies.

Subsequently, Mexico determined that a binding model is appropriate based on its membership in the Mission Innovation Initiative, which consists of 22 countries and the European Union. The Initiative aims to reinvigorate and accelerate innovation in clean energies with the aim of making them widely available. Mexico established 6 workshops, which sought to bring the best of national and international intellectual knowledge for the identification of national research priorities, technological development and human resources training. This strategy was determined to offer maximum value for Mexico, in terms of developing the energy sector in a clean and sustainable manner, while promoting dialogue with academia, government and industry. The results of each workshop are provided in the form of a published report, which is intended to provide all of the sectors involved with a consensus guide on the areas for which investment is required. The reports also represent a useful mechanism by which SENER may launch calls and initiatives to address the national challenges.

In the realm of public policy, the areas within the energy sector that present the greatest opportunity for reducing GHG emissions include mobile sources, power generation, and oil and gas production and refining. It is a national objective that new markets be opened for low-emissions natural resource production that aim for long-term sustainability.

Mexico gained membership in the International Energy Agency in February 2018, joining an elite group of national actors. Based on an evaluation of the country's energy sector conducted by SENER, in 2040, 3 million barrels of oil can be produced annually, ¼ of which will be deep water and ¼ from conventional onshore fields. Achieving this goal would entail an investment of approximately 640 MMUSD in the next 12 years, so it is imperative that it be carried out in a thoughtful manner.

Reconciling development policy with sustainability policy is a major challenge and objective. This Workshop was conducted to address this important tension, with a goal of developing a new business model for the hydrocarbon sector, rather than proceeding with business as usual. Development of new technologies and talent will be necessary for providing additional options for simultaneously advancing development and sustainability in the energy sector.

Mexico hosts enormous natural resource reserves, which are drawing international operators eager to exploit the resources for economic gain. In this context, the foundation must be laid for a future of low emissions and sustainable use. Laying this foundation will require optimizing technologies and investment instruments in order to develop the resources with the lowest impacts possible. Technology advancement is especially relevant for developing unconventional oil and gas resources, which is an area where Mexico has very little experience. Mexico has much more experience with conventional oil and gas operations, both onshore and offshore; the country recently invested about 2,500 million pesos in a new Center for Deepwater Technology (CTAP) to advance technologies and simulations for the development of offshore conventional resources.

National investments that complement the capabilities of the private sector can advance technological development and innovation. If designed appropriately, these investments can contribute to both sustainable and economic development. The scale of the opportunity and challenge in this realm emphasizes the need to develop national talent.

To this end, it is important to understand processes along the value chain, to create an interdisciplinary and inter-institutional group that is empowered to develop technology that will aid in fighting climate change. Through such a national–international partnership that brought together state, business, and academic leaders, Mexico has been developing

combined cycle natural gas power plants. A remaining challenge is to capture CO_2 from such plants and others in order to store it underground and prevent it from reaching the atmosphere.

It is also necessary to quantify the contributions of the various parts of the value chain to overall emissions. One promising technology is the injection of captured CO_2 to improve oil and gas recovery, which is referred to as carbon capture, utilization and storage (CCUS). Developing this technology requires analysis of its potential within specific parts of the value chain in order to guide the thoughtful allocation of resources. Feasibility studies will be required to investigate costs, implications, and benefits of CCUS. If deemed feasible, substantial work will be needed to allocate the enormous amount of resources required to deploy CCUS on depleted and producing oil and gas fields.

The sustainable energy model that Mexico has adopted, which is described above, requires meeting ambitious goals. This will be feasible only through the development and deployment of technologies intended to reduce financial risk and asset valuation losses due to climate policy, and which provide opportunity to academic and scientific sectors to provide technological solutions.

Agencia de Seguridad, Energía y Ambiente (ASEA)

ASEA was born as a result of the Energy Reform as a decentralized body of the Ministry of the Environment and Natural Resources (SEMARNAT). ASEA is a specialized regulator for the hydrocarbon sector that is focused on operational safety and environmental protection. The agency is tasked with ensuring that industry carries out its operations in a safe and environmentally responsible manner, throughout the entire value chain. In practice, this involves verifying the regulatory compliance of 300 offshore platforms, more than 9,000 onshore wells, over 60,000 km of pipelines, 18,000 service stations, 6 refineries and several storage terminals. Because ASEA employs only 465 staff, this is achieved only through an intelligent regulation model, which focuses on managing the risk of operations given the complexity of this type of industry. This model is based on international best practices, recommendations from international organizations, and experience built by regulatory counterparts in countries.

ASEA has established administrative subdivisions similar to international entities. ASEA's offshore regulatory activities operate in a similar manner to the United States Bureau of Safety and Environmental Enforcement (BSEE), which has implemented its regulations in a mandatory fashion following the Macondo accident. ASEA has engaged in dialogue with the BSEE about the lessons learned from that accident, and its accordingly carried out audits and adjusted its own model, accounting also for the specific conditions of the upstream sector in Mexico.

The focus for ASEA is on managing risk, recognizing that although zero risk is not possible it is still an appropriate aspiration. It is important to recognize that accidents are possible, which is why financial guarantees are requested from operators to address any eventuality, including coverage well control. In practice, vary by the type of regulated subsector, and other considerations.

In addition, ASEA has learned from the experience of other regulators that it is vital to avoid being over prescriptive when designing regulations for an industrial sector. Instead, ASEA develops regulations based on performance, focusing on yielding technological improvements that enhance safety and environmental protection.

Finally, correction is prioritized over punishment for companies that are not in compliance with ASEA regulations, as the primary focus is on achieving real improvements in company operations. Sanctions are still applied to noncompliant operators if necessary, but ASEA’s primary aims in its interactions with operators are to build trust and dialogue, with the aim of achieving real actions to reduce the degree of noncompliance that has been observed, rather than pursuing punitive actions that might not produce the desired results in a timely manner.

2 OPTIMAL UTILIZATION OF OIL AND GAS RESOURCES IN THE ERA OF DECARBONIZATION

2.1 Priority 1. Develop and emphasize a culture of continuous improvement throughout the entire hydrocarbon value chain, focusing on improved efficiency and reduced emissions

2.1.1 Challenges and Opportunities

- Launch a global benchmarking study for all aspects of the hydrocarbon value chain to focus on improvements in efficiency and reduced emissions.
- A broad campaign should be undertaken to identify needs, educate the work force and systematically implement improved efficiency and reduced environmental impacts across the entire hydrocarbon value chain.
- Utilize and implement new Artificial Intelligence (AI) and Machine Learning (ML) technologies to identify inefficiencies and improve process reliability in refineries.
- Reduce the flaring of associated gas through the improved capture of natural gas (and other volatile organic compounds (VOC's) and improve the efficiency of flaring when it is needed.
- Improve monitoring to identify methane leaks and to understand methane source characteristics from production to end use.
- Create appropriate regulations and procedures/best practices focused on quickly fixing major sources of leakage.
- Advance and implement combined-cycle natural gas facilities for electrical power generation.
- Take leadership role at Oil and Gas Climate Initiative (OGCI) to accelerate adoption of ISO 50001 standards and to meet the requirements of the Paris Agreement.
- Establish a campaign to utilize more efficient and cleaner engines, compressors, and other process equipment.
- Develop and implement a university-based training programs for efficient and environmentally friendly operations across the entire hydrocarbon value chain.
- Establish a program to train industry personnel in national and international companies to emphasize energy efficiency and environmentally sound practices
- Launch a program to investigate "valorization" of wastes produced from various stages of the hydrocarbon value chain.
- Develop recycling technologies for chemicals, plastics, and other value chain waste
- Establish a research program to develop useful products from waste products generated by the hydrocarbon industry.

2.1.2 Barriers

- Lack of information about flaring volumes in oil and gas facilities.
- Lack of technology for detection and monitoring of hydrocarbon leaks and insufficient knowledge of emitters.
- Insufficient use of natural gas for electrical power generation.
- Poor maintenance of equipment along the hydrocarbon value chain.
- Lack of systematic analysis of the main sources of leaks and spills.
- Excessive flaring and venting of methane and VOC's along the hydrocarbon value chain due to antiquated equipment and lack of maintenance.

- Proper technology is not being used for product and waste management.
- Lack of technology for processing, storage, treatment and removal of wastes.
- Lack of systematic accounting for the generation and disposal of chemical, plastics and other waste products generated along the hydrocarbon value chain.

2.1.3 Strategies

- Establishment of an unconventional oil and gas research center to focus optimization of development as well as minimizing the environmental impacts of development. The research center should address issues along on the entire hydrocarbon value chain and include specific training for clean, safe and efficient operations. This center will train new and existing workers to update knowledge about best operational practices, energy efficiency and state-of-the-art processes.
- Launch an integral strategy for controlling methane leaks and understanding of methane sources from well-to-wheel. This strategy will utilize both top-down and bottom-up measurement techniques developed and implemented in collaboration with international experts. One long-term component will be the installation of vapor recovery systems for methane detection in existing facilities.
- Launch a global benchmarking study for all aspects of the hydrocarbon value chain to focus on improvements in efficiency and emissions.
- Launch a study to recommend options for accelerating the adoption of the ISO 50001 standard along the hydrocarbon value chain.
- Make guidelines for operators and regulators to design and best practices for control of the main sources of leaks.
- Establish university training programs for energy systems with a focus on energy efficiency and environmental protection.
- Conduct a study to investigate how to educate and integrate trained oil and gas employees who are not currently employed in the sector as development expands.

2.1.4 Impacts on Research

- Identification for modernization of equipment, improved operations and practices that can have immediate economic benefit and reduced environmental impacts.
- Developments of methods for reduced and improved efficiency of flaring through development and adoption of best equipment for mitigation of air pollutants and GHG will have immediate economic and environmental benefits.
- Utilization of methodologies for identification and reduction of methane leaks along the hydrocarbon value chain will identify main emitters and limit the main sources of leaks – again immediate economic and environmental benefits.

2.1.5 Impacts on Technological Development

- Innovation will emerge for new procedures, equipment, and accessories for minimization of environmental impacts and maximization of energy efficiency.

2.1.6 Impacts on Human Resources Formation

- Develop specialized human resources with an emphasis on energy efficiency and clean processes with a priority in the short-term program. Specialized programs for mechanical, electrical, and environmental engineers must be developed in order to evaluate equipment operating conditions, maintenance, and instrumentation.

2.2 Priority 2. More fully utilize refineries and petrochemical plants, increasing their complexity, to ensure increased efficiency and better production of fuels and petrochemicals.

2.2.1 Challenges and Opportunities

There is an urgent need to upgrade and more fully utilize existing refineries and improve their efficiency, produce more fuels, enhance production of petrochemicals, and reduce waste streams. To this end, we also recommend a focus on “refineries of the future” to address Mexico’s energy and petrochemical needs and to improve overall efficiency. The following questions must be answered:

- How will new production from unconventional reservoirs change the crude oil composition that reaches refineries?
- How will refineries need to be modified to accommodate the different types of crude oil that will be available as unconventional development occurs?
- How can AI/ML and use of distributed sensing technology be integrated into refinery operations to improve efficiency and reduce emissions?

2.2.2 Barriers

- Technology is needed for processing heavy fuel oil in existing refineries or in new investment projects. For new technologies, new technical and professional capabilities must be developed.
- In Mexico, new technology must be generated to operate efficiently the petrochemical and refining facilities in order to attain environmental standards and optimize water and resources use.
- Cogeneration technology and carbon capture require considerable investment resources and extensive Human Resources Formation, because of new technology.
- Maintenance and safe operations must be improved in refining and petrochemistry. Inertia must be overcome to train people with the technical capabilities for this challenge.
- Non-programmed stops in plants. These stops must be minimized or eliminated in order to attain an efficient and clean operation.

2.2.3 Strategies

- Identify facilities with priority to install or update power generation using high efficiency processes including cogeneration.
- Launch joint programs between government, academia and manufacturers of combustion engines, compressors, power generation and related equipment for developing and using high efficiency processes and devices.
- Launch an effort to implement Petrochemicals 4.0 and other state of art processes:
  - Launch immediately an exhaustive study in downstream facilities to identify problems and to propose specific solutions. Measurement and control equipment must be included to identify opportunities for improving safety, efficiency and clean operation.
  - Formulate recommendations to implement Petrochemicals 4.0 in new and existing facilities.
  - Include the participation of international regulators, research centers and manufacturers, to transfer knowledge and identify commercial partners.
  - Establish a research program to study how ML/AI can be integrated into refining and petrochemical processes to improve efficiency, detect leaks, and reduce waste streams.
- Expand disruptive research on downstream technologies to improve efficiency. As an important part of this effort, launch a research program on nanotechnologies and catalyzers for improving efficiency.
- Develop a technical and economic model to establish the ideal configurations of future refineries in Mexico in order to satisfy its energetic needs. This model should include non-conventional sources and changes in crude composition.

2.2.4 Impacts on Research

- Establish a research program on nanotechnologies and catalysts for the purpose of improving efficiency in refinery operations
- Develop technologies for biorefineries
- Develop an economic model to determine ideal refinery configurations for future national energy needs
- Update knowledge in IA/ML for downstream processes.

2.2.5 Impacts on Technological Development

Development and use of new technologies for improving fuel production, minimization of fuel imports and clean downstream facilities.

2.2.6 Impacts on Human Resources Formation

New Human resources must be formed with wide and solid knowledge in coking and hydrodisintegration, chemical, mechanical and environmental engineering and heavy crude oil composition and its implications in downstream processes.

New capabilities in IA/ML must be generated. Basic research specialists for disruptive research must be generated.

2.3 Priority 3. Develop advanced petrochemical processes and enhanced refining

2.3.1 Challenges and Opportunities

Mexico has the opportunity to gain by implementing improved methods for obtaining petrochemical end products. This effort should be focused on achieving substantial energy savings and reductions to the waste stream. This program will include adoption of the Petrochemicals 4.0 framework in an interdisciplinary approach.

2.3.2 Barriers

Several petrochemical plants are out of operation.

Outdated polyethylene petrochemical plants (high and low density).

PEMEX is the only provider of ethylene oxide and one of the two providers of glycols.

2.3.3 Strategies

- Launch a research program to develop new pre-cracking and separation processes.
    - Establish a research center for sulfur chemistry to make use of sulfur byproducts and to improve SO_2 separation methods.
    - Study N_2 separation methods
    - Investigate ways that the Petrochemicals 4.0 framework can be integrated in the Mexican petrochemicals industry.
- Establish a research program to study how ML/AI can be integrated into refining and petrochemical processes to improve efficiency, detect leaks, and reduce waste streams.
- Launch a program to conduct basic research into petroleum chemistry and petrochemical processes.
- Launch research programs to develop technologies for producing electricity from produced gas and to convert gas to liquids
- Launch a research program to develop techniques for “valorization” of wastes produced from various stages of the hydrocarbon value chain
- Compile existing research on recycling technologies for chemicals, plastics, and other value chain waste. Create new research programs to develop specific new technologies relevant for Mexican hydrocarbon value chain waste.
- Establish research program to develop green products for hydrocarbon industry.
- Develop technologies for biorefineries.

- Ensure that all of the above studies associated with refining and petrochemical processes make use of existing findings from international and domestic research.

2.3.4 Impacts on Research

Development of a new approach in Mexico for Refining and Petrochemical processes, research in chemistry, separation processes and development of green processes.

2.3.5 Impacts on Technological Development

- Development of new technologies for separation processes, refining, biorefineries and petrochemical processes.
- Innovation on approaches for Refining and Petrochemicals with the concepts of IA/ML.

2.3.6 Impacts on Human Resources Formation

Human Resources Formation associated with the strategies. Especially in new technologies for separation processes, refining, biorefineries and petrochemical processes.

A new set of engineers, specialists and researchers on IA/ML must evolve from this effort.

2.4 Priority 4. Adopt carbon capture technologies for enhanced utilization of CO_2 (for EOR)

Mexican O&G production is mostly conventional, and EOR production is in its early stages. There are many depleted or sharply declining fields where EOR techniques will increase production. This makes this action line a high priority subject.

2.4.1 Challenges and Opportunities

- Advanced EOR techniques research for cost-effectiveness analysis and environmental and social impacts is required for exploiting oil resources in mature fields.
- A CO_2 Quality Atlas to supplement the existing Atlas on CO_2 is required.

- Special materials research that can be used for CO_2 processing, transport, and injection including corrosion-resistant tubulars.
- Understanding the role on oil recovery and oil reservoir formations of trace amounts of H_2S, and other gases, typically present in CO_2 captured from combustion sources.
- Human resources formation for carbon capture and EOR is needed.

2.4.2 Barriers

In many conventional oil reserves in Mexico, less oil is produced because production is mature. Nevertheless, remaining oil needs to be extracted and many reservoirs are amenable to gas injection processes. Economical, technical, and human resource barriers emerge because of the lack of economic resources, technical capabilities and specialists in this area.

2.4.3 Strategies

- Launch an initiative for advanced EOR techniques research. This initative will include research on cost-effectiveness analysis and environmental and social impacts
- As described above, create a CO_2 Quality Atlas to supplement the existing Atlas on CO_2 Availability, including costs for implementing CO_2 EOR depending on distance and quality of the CO_2 source to the fields.
- Launch a research program to develop special materials that can be used for CO_2 processing, transport and injection, including corrosion-resistant tubulars
- Conduct a study to determine the amount of oil that could be produced with EOR in addition to conventionally produced oil in the short, medium and long terms. The study will identify the cost-effectiveness and scope of the application of CO_2 EOR to the Mexican O&G industry compared to other EOR techniques. It will also investigate the environmental and social impacts of applying this EOR technique in Mexican O&G operations. The report will provide the status of technology and human resources related to the application of EOR.
- Development and assimilation of new post- combustion processes and materials to reduce capture, operation and maintenance costs.
- Development of less energy intensity processes for oxygen production from air for oxy-combustion and pre-combustion.
- Development of clean and efficient pre-combustion processes.
- Development of new and more efficient materials and processes for CO_2 capture by adsorption.
- Development of new processes for syngas purification.
- Development of new processes and polymeric membranes for carbon capture.
- Development of new cryogenic processes to separate CO_2 low concentration streams.
- Development of reservoir characterization, including special core analysis, and simulation methodologies for modelling geological storage of CO_2 in the contexts of both cooptimized EOR with storage as well as aquifer storage.
- Formation of human resources at technical and professional levels for EOR and carbon capture and CO_2 storage.

2.4.4 Impacts on Research

Development of new processes for EOR and carbon capture and CO_2 storage, with emphasis to local surface and subsurface conditions. Study of environmental and social implications of new technologies and processes.

2.4.5 Impacts on Technological Development

Innovation in new technologies and methodologies for EOR, carbon capture, and CO_2 storage

2.4.6 Impacts on Human Resources Formation

Human Resources Formation must be focused on training in new processes and technologies for EOR, carbon capture and CO_2 storage. Capabilities for impacts on fields of EOR methods will be required. Environmental and social impact experts will also be needed.

2.5 Priority 5. Transformation of CO_2 into useful products

This priority will focus on research of technological paths for transformation of waste CO_2 to final products for commercial applications in an energetically favorable manner. This a long-term priority.

2.5.1 Challenges and Opportunities

In the long term, mitigation of GHG will be achieved only if new paths for transformation of CO_2 are found. Among the possible paths the following can be mentioned:

- New catalyzers and heterogeneous catalysis;
- Chemical and biological transformation paths;
- Conversion of CO_2 from wastes to other useful products;
- Chemical building blocks;
- Synthetic fuels; and
- Polymers.

2.5.2 Barriers

Most of the known transformation paths are incipient and efficiency, cost or energy use are not attractive in order to be developed commercially.

2.5.3 Strategies

Launch a long-term research program for developing and adopting technologies to convert CO_2 into useful products. The study will investigate the most viable technological routes for developing products from CO_2, and to scale them for commercial applications. It considers other techniques that could create synergy with CO_2 transformation technologies. Types of products may include:

- New catalysts and heterogeneous catalysis;
- Chemical and biological transformation paths;
- CO_2 from waste to raw materials;
- Chemical building blocks;
- Synthetic fuels; and
- Polymers.

2.5.4 Impacts on Research

Research on transformation of CO_2 into useful products will permit to find innovative paths and minimize GHG.

2.5.5 Impacts on Technological Development

New products and technologies will be developed in long term and innovative, less energy intensive and low pollution paths need to be found for succeeding in this task

2.5.6 Impacts on Human Resources Formation

New generation of chemical and material engineers and specialists in transformation of CO_2 into useful products must be trained. New technologies also will need technical and professional experts in control, chemical and materials areas.

2.6 Priority 6. Develop technologies for cleaner and more efficient combustion

Research on factors affecting combustion behavior and efficiency is the main purpose of this priority. Emphasis must be put on adoption and development of best, efficient and clean technologies.

2.6.1 Challenges and Opportunities

Most of the fossil fuels for combustion in Mexico are imported. Adoption and development of new and clean technologies is a key factor for a low emissions development. Construction of new refineries must consider improved and clean combustion processes.

2.6.2 Barriers

Obsolete equipment in refineries and petrochemicals.

2.6.3 Strategies

- Develop an economic model to determine the operational, cost, and environmental impacts of the use of various combustion fuels in petrochemical plants and refineries.
- Establish a research program on the factors that influence combustion behavior and efficiency, with emphasis on developing and adopting cleaner and more efficient combustion technologies and practices.

2.6.4 Impacts on Research

Research in combustion areas with emphasis in cleaner and efficient production will be promoted.

2.6.5 Impacts on Technological Development

Development and adoption of cleaner technologies

2.6.6 Impacts on Human Resources Formation

Human resources training in chemical, mechanical, process, control and environmental engineering will be needed for adoption and development of new technologies.

2.7 Priority 7. Establish an Unconventional Research Center to focus on the optimization of development in an environmentally responsible manner

2.7.1 Challenges and Opportunities

Hydraulic fracturing of shale gas and tight oil reservoirs is going to be carried out in Mexico at a commercial level in 2019. Technical and methodological challenges will emerge, as they have in U.S., Canada, China and Argentina – the other countries around the world where unconventional oil and gas resources are being developed. Among others, geological and geophysics interpretation of seismic data, characterization of unconventional reservoirs, identification of optimal drilling and hydraulic fracturing methods and implementation of technologies to minimize and environmental and community impacts.

2.7.2 Barriers

- There is currently limited direct experience using horizontal drilling and multi-stage hydraulic fracturing In Mexico in unconventional reservoirs.
- New procedures and regulations must be developed to optimize development and reduce environmental and community impacts associated with drilling and hydraulic fracturing in thousands of wells.
- Special attention needs to be paid to efficient utilization and protection of water resources and minimizing community impacts.
- There is an immediate need to identify pro-active strategies to engage affected communities in the development of environmentally and socially responsible development.
- Technology transfer must be achieved in order to assure safe, efficient and clean operations.

2.7.3 Strategies

- Immediately identify collaborative actions among existing institutions including IMP and universities in Mexico and abroad to engage the wide range of issues associated with development, environmental and social challenges of unconventional development. This Collaborative will serve a wide range of current and future needs for optimizing development and minimizing environment and social impacts. The Collaborative will take advantage of existing capabilities in multiple institutions including international institutions (such as Stanford, University of Texas/Texas Bureau of Economic Geology, University of Michigan,

Pennsylvania State University, MIT) in new research collaborations for the new Unconventional Research Center.

- Begin the process of building a new Unconventional Oil and Gas Resource Center in Mexico research center to be completed in 3–5 years.
- Via both the Collaborative and new Research Center immediately begin the process to identify and apply international best practices and identify research needs to optimize development of Mexico’s unconventional resource. It is especially important for Mexican participants to attend international conferences on unconventional development (e.g., URTeC, SPE, SEG, AAPG, etc.).
- Launch an effort to diversify funding sources from government, corporate, and nonprofit including private funding and more flexible government funding.
- Create procedures and databases to facilitate data collection and timely sharing with appropriate institutions in an open and transparent manner.
- Consolidate existing research and launch new research efforts to characterize unconventional reservoirs in terms of their composition, physical properties, organic content and maturity.
- Launch new research efforts to characterize the geomechanical setting of unconventional reservoirs in terms of the state of stress and pore pressure.
- Start new research programs to study drilling and completion practices based on reservoir type. This will initially require compilation and integration of data from existing vertical wells and begin evaluation of completion practices used in analogous reservoirs found in elsewhere in the world.
- Expand existing IMP and university research on use of CO_2 for EOR that simultaneously optimizes oil recovery and the stored volume of CO_2.
- Launch feasibility studies for use of CO_2 as a fluid for hydraulic fracturing
- Evaluate and develop green technologies for use in unconventional resource extraction (for example, non-toxic drilling and fracturing fluids, low-emission equipment, etc.).
- Undertake a new research program for oil and gas waste “valorization” technologies and practices.

2.8 Impacts on Research

Identification of optimal methodologies and technologies for unconventional resource exploration and production (both adapted from international practices and developed in Mexico) is needed and could generate immediate economic and environmental benefit.

2.8.1 Impacts on Technological Development

Efficient and cleaner technologies and innovation is needed in order to exploit unconventional resources. The cluster of existing institutions and the new research center will facilitate these tasks.

2.8.2 Impacts on Human Resources Formation

Human resources formation is required in many scientific, engineering, environmental and social science disciplines to facilitate the transfer of knowledge and technology. The creation of cluster and a research center will facilitate the training of professionals, researchers and specialist.

2.9 Priority 8. Develop a regional planning process for unconventional development (land use planning)

2.9.1 Challenges and Opportunities

One of the principal differences with conventional oil and gas development is the need for tremendous numbers of wells associated with unconventional development. There is an opportunity for Mexico to undertake unconventional development using a holistic approach, learning from experiences in USA and Canada.

There is an opportunity for sustainable development through the creation of the new national research center for unconventional resources and the institutional collaborative.

A comprehensive planning process will facilitate the sustainable development, exploration and exploitation of non-conventional resources.

2.9.2 Barriers

- The regional planning process needs participation and consensus among all the stakeholders.
- There is a lack of information available to the public about development activities.
- Some regulatory practices limit optimization of exploitation of unconventional resources.
- Social component must be considered in order to avoid potential conflict. Unless there are incentives in place that benefit affected communities, there will be appreciable pushback to development.

2.9.3 Strategies

- Establish a holistic national research program on planning for unconventional resource development and organize existing research programs.
- Develop a regional planning process for unconventional development (land use planning) for roads, traffic, pipelines and infrastructure.
- Development of regional water management strategies involving the use of non-potable (brackish and saline) water resources as much as possible.
- Develop mechanisms to improve transparency of information regarding development of unconventional resources. This should involve land use planning, water resources (water use and contaminated water treatment and disposal).
- Develop regional information centers in the areas where development will occur to serve as a resource for communities, companies and government entities.
- Establish mechanisms for community engagement and identification of incentives and benefits that can be provided to affected communities.
- Continue to work to build regulations that are both practical and flexible, adapting examples from areas around the world.
- Must appropriately integrate national, state, and local levels of government, as well as academia and IMP, in order to ensure that local societal, infrastructure, environmental, and geologic factors are considered.
- Infrastructure planning efforts should begin immediately to identify short-term infrastructure needs. These efforts should continue in the long term to ensure planned infrastructure development and to identify gaps and environmental/social impacts of infrastructure.
- Begin making models for long-term infrastructure needs and development plans. These models should include specialized focus on economic, transportation, urban planning, ecological, oil and gas, water, and social sector.
- Create procedures for providing technical advice to the appropriate regulatory agencies to assist with establishing guidelines for unconventional development
- Conduct regional assessments and baseline measurements in areas of unconventional development to understand environmental and social sensitivity factors by region/basin that capture seasonal behavior (water, noise, potential for induced seismicity, land use, etc.).
- Design and make recommendations for best practices for chemical use during unconventional operations based on toxicity and ecotoxicity.
- Support and/or host efforts proposed in other tracks to map and characterize groundwater resources in unconventional development areas

- Develop a long-term vision for IMP as a consolidated national center for all conventional and unconventional oil and gas research needs that interacts with regulators, companies, and academia.

2.9.4 Impacts on Research

- Sustainable models for infrastructure integrating regional planning will be developed.
- Development of methods that address Life Cycle Analysis for non-conventional resources from the perspectives of both resource development and environmental and community protection.
- New planning and research for dealing with abandoned wells will be developed.

2.9.5 Impacts on Technological Development

- New methodologies for baseline and regional planning will be developed in order to minimize environmental and social impacts.

2.9.6 Impacts on Human Resources Formation

Human Resources Formation will benefit from collaboration between national, state, and local levels of government, as well as academia and IMP.

3 LIFE CYCLE ANALYSIS & ECO- EFFICIENCY IN THE HYDROCARBON VALUE CHAIN

The concept of cleaner production was established by the United Nations Environment Program (UNEP) Office of Industry and Environment in 1989. Cleaner production was defined as "the continuous application of an integrated preventive environmental strategy and applied to processes, products, and services to improve eco-efficiency and reduce risks to humans and the environment "(UNEP, 1999). The applications of this concept, as has been performed so far, are mostly in the industrial sector. The most prominent application of this philosophy of cleaner production is the field of life cycle analysis (LCA). Life cycle analysis is a method to quantify rigorously environmental impacts across the value chain or “product life cycle”, from primary material extraction, manufacturing, use, and disposal.

Life cycle analysis can be used to develop greater efficiency in the use of energy resources or raw materials in order to prevent or reduce environmental impacts and guide industrial processes towards sustainable development. In the ideal case, life cycle analysis can be used to support simultaneous increases in productivity and competitiveness, as wasted materials and emissions to the environment often present opportunities for improved operations. The main objective of the industry is to transform the raw material into a product, good or marketable service and the generation of waste and emissions during the process are generally due to loss and misuse of the raw material. Such misuse often causes additional costs as well, due to the costs of waste treatment and disposal. Additionally, wastes and emissions add to the social and physical-biotic impacts which can degrade communities quality of life (Arroyave, & Garcés, 2006; Chapman & Gant, 2007; Cote, Tansey & Dale, 2006; McHarry, Strachan, Ayre & Callway, 2005; Parto & Herbert-Copley, 2007)

The hydrocarbons value chain is complex. Many different types of facilities exist across Mexico, performing a wide variety of functions from primary extraction, transport, and refining of hydrocarbons. Across this value chain the impacts are currently poorly understood and must be delimited and identified. The identification of where the emissions come along the value chain will be a very useful input to formulate public policies on the path towards a low carbon society.

The emissions quantification and evaluation of impacts that occur along the hydrocarbon value chain must be carried out, reported, analyzed and discussed using the life cycle analysis framework.

3.1 Priority 1: Create an Institution that directs and compiles data for the life cycle analysis (LCA) of the hydrocarbon value chain, LCI (life cycle inventory) and atmospheric emissions assessment.

At present, information on materials, energy and emissions flows in the hydrocarbon industry in Mexico is limited. This lack of information hinders the development of inventories and makes it challenging to prioritize improvements or investments in pollution reduction.

3.1.1 Challenges and Opportunities

There are data gaps on quality and integrity of data on material consumption, air emissions, water emissions, soil impacts, and waste flows. Generally, companies only submit these kinds of data to the authority to avoid being fined. [What is the current level of practice in Mexico? What is required to be reported and what is not required to be reported? Who collects each data type, if it is collected?]

This lack of information makes performing the LCI (life cycle inventory) difficult. The LCI is the foundational result of an LCA and includes all mass flows into and out of a set of processes or value chain. Without an LCI, it is impossible to move to the “analysis” or “assessment” stage where the emissions listed in an LCI are interpreted, analyzed, and compared.

In order to enable LCI generation, the current data collection system must first be studied. After this, the development of information collection, validation and public disclosure standards must be performed. This should be performed by an institution that collects this data, creating a reliable Information Management System with regular periodic updates.

The lack of good-quality data is evident in the hydrocarbon sector. With the energy reform and new companies participating in Mexico’s hydrocarbon sector, this is an excellent time to establish best practices around data reports and their validation, and to establish standards for high quality data reporting. The main challenges are:

1) **Baseline assessment**: Prepare a hydrocarbon value chain baseline assessment with current emissions, discharges and waste. This will require a comprehensive effort to formulate this baseline, but this baseline will serve as a reference for future decision making.
2) **Data collection and management**: Conduct data collection and management, with formal reporting requirements and an Information Management System. These data are currently scattered in different agencies or companies.
   a) A complete database is required for hydrocarbon industry emissions, energy use and process flows. Currently, there are no data to verify the reported inventories.
   b) Current LCA tools lack adequate factors specific to Mexico that take into account the particularities of our ecosystems: for example emission or discharge into the air, water or soil intensity, impact factors on human health, environmental quality or local ecosystems.
3) **Data verification and validation**: Systems to verify reported data with periodic field surveys or measurements are needed.
   - The baseline study should consider field measurements, for example, aerial measurements to quantify emissions at important sites that are difficult to access and without a high cost.
   - Monitoring, verification and regulation application in the construction of new facilities.
   - Field studies are needed to verify data, as they are not enough by themselves.

3.1.2 Barriers

Industries, especially those with excess and emissions high rates, often do not want such data to be public. This is because they are concerned about other companies' judgment or data misused against them. Demanding policies must be created to require public disclosure of data on materials consumption, air, water, and soil emissions or waste. Such disclosure should be required of all operators so that no one operator feels compelled to release data while others are not required to release such data.

3.1.3 Strategies

Create an ethical and professional culture in both large and small companies about the necessity of reporting raw materials consumption, emissions and waste, for environmental conservation and well-being of people.

Promote green industry certifications in order to motivate industries to submit their emissions and reduce their pollution levels by maintenance programs and equipment repair and evaluation.

As a reference, in other countries producing hydrocarbons (such as Canada and Norway) data publication is a rule and even industries receive benefits for reporting such data.

1) Develop a baseline study of hydrocarbons sector current emissions. Possible partners: PEMEX, SEMARNAT, INEGI

   As part of the study, LCI database must include air quality measurement ((NO_X, PM), air toxics (benzene, toluene, ethylbenzene among others), and GHG emissions (CO_2, CH_4).

2) Improve data collection and management. Possible partners: PEMEX, SEMARNAT, INEGI, universities and research institutes.

   A unified and transparent data management system must be developed. It should be very clear who collects the data, where to obtain it and who is responsible for its storage, management, and security. The protocol must be standardized.

   This system should consider:

   - How reporting regulatory requirements should be structured.
   - What is required for maximizing third-party transparent verification ability and reported data verification?
   - Consider data nature, either public or confidential. Some regions or countries require public data reports, others are very reserved and do not require public disclosure. The advantages of the public approach outweigh the disadvantages.
   - Sensor technology advances so quickly that soon "confidential" will not be an operationally viable option for emissions because remote sensors will reveal the quantity of emissions.

3) Improve data verification and validation. Possible partners: PEMEX, SEMARNAT, INEGI, universities and research institutes.

   It is necessary to develop a methodology to verify field studies collected data accuracy. The methodology must consider that:

   - The process must include field verification and validation.
   - Research and development may be required in new sensor technology to allow validated data flows at low cost.
   - Emphasize the ability to use new satellite products (e.g. EU Tropomi, EDF metanoSAT).
   - Public information for verification and validation studies has greater support than private information.

3.1.4 Impacts on Research

Research listed above will result in much improved understanding of the emissions and impacts of Mexico’s hydrocarbon industry. The resulting impacts on research include:

- Develop a hydrocarbon value chain emissions baseline by type of activity, equipment, emissions. Develop Mexico-specific emission factors, including combustion gases and specification for leaks of all kinds.
- Perform field validation program with site visits complemented with remote air measurements. This field validation program will allow better understanding of data accuracy as well as developing a comprehensive picture of emissions in Mexico.
- Develop a set of data protocols that include: quality assurance (QA / QC), coherent terminology, unified database systems, public information requirements, minimum and maximum emission limits.

3.1.5 Impacts on Technological Development

The above efforts will facilitiate or allow a number of technological developments. Some of these technological developments include:

- Data integration by a single institution will allow a continuous assessment of improvement opportunities and development of data portals on emissions sources that could be reduced.

- Data will focus capital investment and new technology implementation, since it will have the inventory of equipment that requires maintenance and those that do not operate efficiently and the failure sources or types.

- It will allow best practices development and application; emissions and leaks will be minimized since the facilities and environment impacts will be known in detail; production indicators from different operations and unit processes sets for the same product can be compared, which in turn will allow selecting the cleanest and most sustainable route for the hydrocarbon value chain.

- It will be possible to develop an information management system that best meets the necessity of collecting homogenous data. Such data management technology can be leveraged in other agencies or institutions.

3.1.6 Impact on Human Resources Formation

A robust information management system requires strong impact on information reliability. Such a need for reliable information requires a boost in personnel training and education on careers as petroleum, chemical and environmental engineering or process control. In addition, the information management system will require specialties such as information management, QA/QC, visualization, and scientific inventory verification.

3.2 Priority 2: Methods, models, and tools development

The Life Cycle Analysis (LCA) tools in Europe and US are mainly oriented to process and/or products. This LCA approach implies a broader approach to environmental problems, which gives it a preventive nature by allowing producers or engineers to correct negative impact characteristics before the product is in the manufacturing phase or, when it is already produced, to correct or change technologies within the process to improve overall product environmental performance.

In Mexico, LCA models and tools must be developed, for use with improved local fidelity. Also, there is a need to evaluate existing tools to determine their feasibility in the context of Mexico. Because many of the life cycle impacts from the hydrocarbon value chain occur offsite or outside of the purview of the hydrocarbon industry (i.e., due to purchases of electricity, steel, cement, or trucks), improving the broader Mexican LCA databases is needed.

3.2.1 Challenges and Opportunities

There is a need to develop, adapt or use LCA and eco-efficiency tools in the Mexican context. These science-based assessment methods and tools can be used to identify access points, improvement opportunities and verify benefits, but must be specific to the region of analysis.

In Mexico, some studies have been carried out for some of the links in the hydrocarbon value chain, but due to the complexity of the sector, there is no comprehensive effort that covers the entire value chain in our current and specific conditions.

Development of Databases and Life Cycle Impacts (LCI) results for Mexico are important challenges. This requires obtaining data from studies carried out in the Mexican oil industry and related sectors.

There are a number of existing LCA databases and studies and models for use in the hydrocarbon sector, largely developed in USA, Canada, and the EU. It is necessary to evaluate the existing information and models within the Mexican context. For example, is treatment of oil and gas processing emissions in existing tools accurate for how technologies are deployed in Mexico. For example, are acid gas removal (AGR) units modeled correctly and with the relevant technology characteristics for how such units are used in Mexico?

Because most environmental and emissions data are very place specific, the use of Geographic Information Systems (GIS) can be used to visualize the emissions impacts of the hydrocarbon value chain. There are a number of benefits of such geographically-resolved data (i.e., geographically-resolved LCA). Geographic datasets can also be used to map social improvements, school/training completion rates, training and scholarships, etc.

The methods, models, and tools needed can be divided into three categories: (1) validation of process-level models of hydrocarbon sector impacts; (2) development of regulatory and legal frameworks around reporting; (3) developing integrated decisionmaking tools; (4) development of input-output (IO) databses. These are described in more detail below.

1) **Validation of process models**: Process-level models of hydrocarbon sector emissions underly many LCA tools. These can be validated and improved.

a) Collect data from existing LCA tools on oil and gas sector emissions.
b) Compare to above collected data from baseline assessment of Mexico’s industry.
c) Calibrate and align results as needed to improve LCA models.

2) **Regulatory and legal frameworks**: Improved legal and regulatory frameworks are needed to ensure that data are collected and improve over time.

a) Specify required data disclosure on air impacts, other pollutants, social aspects, etc.
b) Design legal systems that support these requirements, leveraging requirements as specified in other producing regions that require significant data disclosure.
c) Promote clean technology adoption and pollutants reduction.
d) Determine appropriate methods to useLCA be used in the process of approving or denying projects?

- **Methods for integrated decision making:** Design methodological studies for incorporating integrated decision making, in so-called life cycle sustainability assessment (LCSA), which integrates social, economic and environmental data sets
  a) Align and integrate social, environmental and economic LCA using the same functional units. Each one must be measured on the same basis (i.e,. all costs and benefits measured per m^3 of gas or oil).
  b) The Life Cycle Sustainability Analysis (LCSA) includes: (1) life cycle environmental analysis (2) life cycle cost (3) social life cycle evaluation.
  c) Example of a social indicator: How many jobs per unit of energy are created in hydrocarbon value chain upstream and downstream?
  d) How can we track data in a consistent manner so that it can be used, accessible and verified to give confidence, which is important for project success?
  e) What technical data should be communicated? When and how? Commit to include people in the process.
  f) Special consideration of benefits and costs for indigenous communities.
  g) LCA social conference and group of academics to come to Mexico to develop strategy and best practices.

- **LCA input-output database:** Develop ways to integrate process level data (such as emissions intensity, energy and water use) into broader economy-wide IO models.

  a) INEGI has a well-developed economic I/O matrix for Mexico that tracks economic flows between sectors of the Mexican economy.
  b) UNAM has developed some information for the environmental I/O matrix.
  c) SEMARNAT has business emissions information.
  d) Throughout the world, I/O databases have been useful for LCA projection and economy-wide impact assessment.
  e) Methods and models (US EPA EEIO input-output).

- Dynamic LCA methods: Develop methods that incorporate changes over time, and include climate variability and technology change. This will enable forward-looking rather than retrospective analysis of impacts.

3.2.2 Barriers

There is little experience in Mexican industry and government in the use of these tools and models, as well as ignorance of their calculation algorithms. There is no Database that covers all of the hydrocarbon value chain stages in sufficient detail. There is a desire to avoid inconsistent methodologies in government, academic, and industry.

3.2.3 Strategies

It is necessary to have a reliable quantitative knowledge of different options and alternatives. This must include of environmental impacts for the hydrocarbon value chain links under real conditions, both present and future, in order to define short, medium and long term action lines.

A working group should be formed with well-defined objectives and knowledge on the use of LCA models, methods and tools. Environmental protection and sustainability goals should be included.

- Investigate which LCA tools can be adapted/adopted (ReCiPe - MeXiPe), with a particular emphasis on hydrocarbon-specific models (i.e., OPGEE from Stanford University and PRELIM from the University of Calgary).
- Develop a model adapted to Mexican context. Possible partners: PEMEX, SEMARNAT, INEGI, universities, research institutes. Incorporate international progress in these areas from USA, EU, and Canada.
- Integrate Geographic Information Systems (GIS) with LCA indicators to geographically visualize impacts and benefits and develop intuitive mapping systems.
- Formulate regulatory and legal frameworks for LCA. Possible partners: PEMEX, SEMARNAT, INEGI, universities, research institutes
- Develop life cycle assessment and management in legal frameworks using examples from main trading partners EU, Canada, Japan, USA/California LCFS, etc. That is, if impacts are recorded, mandated and managed, they should be recorded across the value chain upstream and downstream. Invite regulators and government ministers from partner countries with good data requirements in hydrocarbon sector, especially in Canada, U.K., and Norway.
- Conduct methodological studies for integrated decision making (LCSA): Integrate social, economic and environmental data sets. Possible partners: PEMEX, SEMARNAT, INEGI, universities, research institutes, CADIS
- Review LCA guidelines and apply them on specific projects.
- Develop an LCA I/O database for Mexico. Possible partners: PEMEX, SEMARNAT, INEGI, universities, research institutes, CADIS, UNAM (Institute of Engineering).

- Develop dynamic LCA methods that incorporate changes over time and include climate variability and technology change.

3.2.4 Impacts on research

The above activities will have a number of impacts on research in Mexico. These research impacts include:

1) Analysis of existing models, methods and tools and evaluation of their use in Mexico.

2) Continuous improvement by development of big data and decision science methods.

3) Evaluation of life cycle sustainability through EEIO, ReCiPE models or a Mexican model (MeXiPE).

3.2.5 Impacts on Technological Development

The above activities will have a number of impacts on research in Mexico. These research impacts include:

1) More sustainable hydrocarbon products manufacturing and export.
2) Technological innovation in the value chain.
3) Financing and investment attraction and justification and new business opportunities creation.
4) Development of an alternative methodology for Mexico particular conditions.
5) Development of software and hardware that supports large amounts of information, query operations, data and documents aggregation.

3.2.6 Impacts on Human Resources Training

Training will occur of specialized human resources in engineering, software, hardware required for the above life cycle analysis areas. In particular, development of Mexico-specific process models will require chemical engineering talent. Geographic (GIS) based models will require geospatial analysts that can leverage talents to solve other problems as well. IO-based models will require economic analysis and improve talent development at the interface of national-scale economic accounting and national-scale environmental or carbon accounting.

3.3 Priority 3: Build human capability in science, analysis and operations for LCA

This priority focuses on developing the necessary human capacities to support the hydrocarbon value chain sustainability objectives, both for equipment efficient operation and for LCA data administration/evaluation.

Recovery and integration of eco-efficiency and life cycle previous work is proposed within a new institute that manages LCI data, spatial analysis and offers training. It will be operational through collaboration with national scientific and academic institutions.

It requires the training of high-level experts, professionals and technicians with the skills and capabilities to understand the technological complexity of production, and the entire hydrocarbons value chain. This will be occurring with by the generational change in PEMEX and CFE, as well as by the new dynamics of growth and the entry of new energy companies into the Mexican hydrocarbon sector.

3.3.1 Challenges and Opportunities

Efficient human resources support for the above national priorities requires:

a) **Training and capacity development:** training and capacity development is sorely needed.
  a) There are established procedures and data are collected, although they are inefficient and agencies do not have sufficient capacity to ensure accurate and complete data collection.
  b) Training and capacity building will improve environmental outcomes and create human capital.
  c) The technological complexity of production and the entire hydrocarbons value chain, by the generational change in PEMEX and CFE, as well as by the new growth dynamics and the entry of new players into the sector, will all affect training requirements.

b) **Integration of existing work:** Integration of existing eco-efficiency and life cycle work within the new institute must be performed to avoid losing progress
  a) There are institutions that already have the required physical and human infrastructure to provide training and research services: IMP, public research centers, higher education institutions, public/private universities. These must not be lost when developing new capabilities.
  b) It is not necessary to create a new training institution, but to unite the capacities of existing institutes to design training programs; then these organizations or institutions must provide the training.

3.3.2 Barriers

A number of barriers exist in developing these human capabilities. Some barriers include:

- There is a lack of collaboration between existing institutions and the hydrocarbon sectors. This must be addressed before the above human capacities can be developed.

- Insufficient Life Cycle Assessment (LCA) knowledge within Mexican government and industry, as well as a lack of a culture for use of environmental assessment for products and processes evaluation.
- Petroleum industry in Mexico is not applying ecoeffciency practices in current operations, leading to cultural gaps and lack of expertise.

3.3.3 Strategies

Develop the necessary human resources to support the sustainability objectives, both for equipment efficient operation and LCA data administration/evaluation.

a) Scientific capacity development and building in these areas:
    a) inventory and data science;
    b) remote and aerial studies analysis;
    c) LCA; and
    d) process optimization.

2) Create a new institute that:

    a) Coordinates various institutions that are already working on the subject.
    b) Integrates with the Mexican university system.
    c) Collect the information on a regular basis in established and improved information management systems.
    d) Encourage specialized and high-level human capital formation.
    e) Encourage the offer of skills training and certification programs.

3) Consolidate training centers in companies related to the sector and establish a training and updating campaign.

    a) Contribute to national investment in scientific research and technological development grow and reach a high level.

3.3.4 Impacts on Research

Research will be impacted by consolidating eco-efficiency and life cycle work within a new institute that manages life cycle inventory (LCI) data, spatial analysis and offers training. This Institute will be operable through collaboration with national scientific and academic institutions.

This will not directly result in research outputs, but will greatly facilitate future research progress.

3.3.5 Impacts on Technological Development

As the new institute suceedsis successful, it will promote other projects and catalyze technological development, through a focus on monitoring which leads to technology deployment and continuous improvement.

3.3.6 Impact on Human Resources Formation

Guarantee efficient human resources support for other national priorities.

3.4 Priority 4: Analyze opportunities for new technology and future sector needs, by means of developing new equipment, processes, models and methods adapted to the evolution of the hydrocarbon value chain

The energy transition strategy must be considered to promote cleaner technologies and fuels use in the hydrocarbon sector. The energy transition strategy establishes a target that 35% of total electricity generation will be clean energy by 2024, 37.7% by 2030 and 50% by 2050 (SENER, 2016).

3.4.1 Challenges and Opportunities

Overcoming technological inertia is a difficult and long-term process, since it requires a substantial increase in research and development investment, as well as retraining and technology deployment. The main objective of this area is to give priority to this process for the hydrocarbon sector.

The growth of the hydrocarbon sector not only implies greater investment and more actors, but also calls for strong action to improve sector performance. This requires innovation, process improvement, and research for efficiency and competitiveness.

1) New refineries must implement new technologies for profitable and sustainable production.
   a) Carbon capture and storage (CCS) technology is still immature, although it is a key method for hydrocarbon sustainability and climate emissions benefits.
   b) Sustainable production must be pursued in in the context of changing raw materials (i.e., changing types and properties of crude with new development) and changing products demand (e.g., changes in gasoline or diesel demand due to new vehicles)?

2) New technology should be applied at existing and new facilities:
    a) New technology deployment should be planned not just for the next few years, but also, prepare the path for fully improved systems over longer investment times.
    b) Many new types of technology can be assessed for use at hydrocarbon facilities:
        i) Oxy-combustion technology for carbon capture and storage technology (CCS).
        ii) Catalytic technology to transform CO_2 into petrochemicals.
        iii) Catalytic technology for ethylene production from ethane.
        iv) Technology with both on-site (facility-scale) and remote (satellite) for methane detection and monitoring.

3) Changes in the hydrocarbon feedstock and demand profile demand investment and research and development:
    a) Due to a wide variety of changes, demand mixtures can change.
    b) Fuel efficiency and electrification of passenger vehicles can reduce gasoline demand.
    c) Diesel phase out (and/or introduce clean diesel technology) due to air quality regulation is occurring across North America and Europe.
    d) Regulatory requirements are changing and tightening in particular those about emission limits throughout the hydrocarbons value chain.
    e) Jet fuel increases demand due to increased international travel as economies grow
    f) Regulations requiring production of cleaner fuel, with new specifications aimed at minimizing environmental impacts and improving energy efficiency.
    g) Mexico’s hydrocarbons reserves are mainly heavy crude oil and there is a need to reconfigure and modernize the National Refining System to enable greater use of this type of crude oil.

3.4.2 Barriers

National research and technological development are "isolated efforts and sometimes disconnected from productive activities”.

The lack of contracting flexibility (technologies that have only one provider) and budget limitations restrict implementation. Insufficient organization structures and human resources exist to support adequate technological management.

Private operators may bring their technologies, their technicians and needed technology development specialists (scientists and engineers), mainly from other countries, as already happen in the whole energy sector.

3.4.3 Strategies

Research in the hydrocarbon sector is fundamental, and it must be conducted on state-of-the-art technology in strategic areas for the sector. Such research should consider operation, environmental protection, energy saving, and facility security. It is important that CONACYT and national research institutions be involved in Mexican technology and engineering development.

3.4.4 Impacts on Research

- Evaluate new technologies, development plans and processing methods based on life cycle impacts to ensure that new technology deployment is performed wisely.

- Develop new ways of using hydrocarbon raw materials in accordance with long-term energy strategy This can include: chemical loop, ecological fuel combustion, and carbon capture and storage (CCS) technology.
- Develop process optimization models that account for raw materials and products demand changes in accounting for technology investment.

3.4.5 Impacts on Technological Development

Decarbonizing plants and processes in order to mitigate GHG emissions.

3.4.6 Impacts on Human Resources Formation

The hydrocarbon sector requires human resources with professionals and technicians levels who have specialized knowledge to face challenges in a near future. With human resources training in this sector, the following will be achieved:

a) Develop technology and specialized and highly competent human resources to use and implement this technology.
b) Competition among specialists and purveyors of technology will be promoted.
c) Trained specialists will collaborate with hydrocarbon sector new operators.

3.5 Priority 5: Use tools to improve existing facilities operations in Mexico’s hydrocarbon sector

The purpose of this priority is to take advantage of current knowledge to evaluate and improve existing facilities.

3.5.1 Challenges and Opportunities

The key challenges is to establish the methods by which operators, including PEMEX, can analyze existing facilities for improvement opportunities. Improvement opportunities at current facilities include: efficient use of energy and natural resources efficient use; reducing greenhouse gases (GHG) emissions; reducing other wastes.

The goal is that natural resources extraction is carried out in such a way that ecological balances are respected and long-term national sustainable development is guaranteed.

A number of secondary challenges exist at existing facilities, including:

1) Comply with international standards to improve existing equipment operations.
2) Improve capture/transport gas capacity (for example, improve compression).
3) Improve field burner efficiency to reduce uncombusted gases.
4) Improve refineries and other workplaces energy efficiency, this could have a great impact on reducing pollutants by reducing the amount of energy used.

A number of factors must be considered, including:

1) Not only focus on local impacts at a refinery or installation processes, but also the way generated waste will be processed.
2) Initially focus on a refinery and then replicate and take advantage of the knowledge obtained for the rest of relevant facilities.
3) Each facility has a unique profile of equipment and processed raw materials, so it must be considered case by case.
4) Detailed data on energy, mass, waste and water flows will help to identify improvement opportunities.
5) Energy efficiency analysis must be carried out in such a way that it integrates the entire National Refineries System and other major facilities.
6) Set goals and objectives based on key performance indicators.
7) PEMEX knows in detail the existing problems at its refineries, so it is not necessary to carry out the study at the process level.

Such factors must be implemented in a framework of continuous improvement:

1) Work in management must include modeling, optimization and data integration based on the most advanced chemical engineering principles.
2) The intersection of "big data" and chemical engineering is important for overall improvement.
3) Pollution is often a non-optimal process operation consequence, so measures must be taken to optimize operations.
4) Gradually evolve towards international best practices in terms of emissions intensity and energy efficiency.

3.5.2 Barriers

How much capital is required? Some efforts have been made but a better implementation is needed.

The existing facilities in the hydrocarbon sector have lower yields of high value products and higher energy consumption and comparable facilities.

National Refining System facilities maintenance is more reactive than planned, its execution is not very effective and there are no comprehensive diagnoses, which results in unscheduled stoppages.

It is necessary to have sufficient economic resources and time to carry out the proposed actions.

3.5.3 Strategies

1) Carry out a project about field burners. The objective is high efficiency operation without reducing performance either on land or offshore facilities. A goal is that venting burners, exhaust vent recovery systems and vapor control systems operate efficiently even in adverse climatic conditions. It should be investigated: What are the current efficiencies? How can they be improved? How can burn volumes be reduced?

2) Energy efficiency improvement in refineries and plants. Identify and apply best practices that could have a significant impact on heaters and boilers energy consumption reduction, considering energy saving profiles and their associated costs for each measure, taking as a basic indicator the reduction of energy required to refine an oil barrel.

3) Continuous improvement. Evaluate continuous improvement possibilities in refining and petrochemical facilities. Possible partners: PEMEX, SEMARNAT, INEGI, universities, research institutes. It should be investigated: What do intermediate users and other products consumers do? Can we demonstrate value to consumers and companies? What is the business case?

3.5.4 Impacts on Research

This work can have a number of possible research outcomes:

1) Burner efficiency improvement;
2) Energy efficiency improvement;
3) Analysis to support facilities/operations optimization;
4) Data-based process automation; and
5) Raw materials utilization and products/pipeline optimization.

3.5.5 Impacts on Technological Development

Short-term improvements may be possible without new technology. Long-term improvements will benefit from new technologies. Establishment of major repairs standardized programs with a focus on eco-efficiency. Replacement of obsolete infrastructure will be required in the long run, which can then be replaced with advanced technology.

3.5.6 Impacts on Human Resources Formation

The human resource improvements will be large. Training in continuous technical progress for existing hydrocarbon sector facility optimal operation. Such progress should consider as a whole multiple factors, including: reliability, energy efficiency, safety and environment protection.

The human resources training focused on this priority will result in specialized, competent and qualified personnel availability to optimize existing facilities operation in the hydrocarbon sector, with an eco-efficiency focus.

4 EFFICIENT USE OF WATER

4.1 Priority 1 Characterize and model deep aquifers and watersheds in unconventional shale fields.

4.1.1 Challenges and Opportunities in the Water-Energy Nexus

Challenges

Characterize deep aquifers that will support the exploitation of unconventional fields in the north and northeast of the country.

Develop a local hydro-geological model for sustainable water-resource management for use in unconventional oil and natural gas fields.

Develop a regional model for hydrological basins and sustainable water management in oil regions.

Assess the vulnerability of water resources in northeastern Mexico, particularly Coahuila, Nuevo León and Tamaulipas, for oil and gas extraction from unconventional fields.

Develop a national repository of data and complementary information on natural resources and hydraulic and energy infrastructure.

Opportunities

Locate and characterize potentially exploitable nonpotable aquifers for unconventional oil and natural gas development, isolated from shallow aquifers used as current or potential supply sources, and, ideally, with relatively poor water quality for primary uses.

Integrate water resources management for use in unconventional hydrocarbon fields.

Create a National Atlas of deep aquifers, including estimates of water quantity and quality.

Provide a comprehensive description of watershed attributes and dynamics for oil and natural gas provinces.

Create an Atlas of Vulnerability of different water resources attributable to unconventional hydrocarbon exploitation and operations.

Provide reliable information on natural resources and hydraulic and energy infrastructure in unconventional hydrocarbon exploitation fields, in order to develop sustainable management policies and guidelines.

Concentrate in a single system, reliable, validated and integrated data on:

Soil and subsoil - use, change of use, planning, quality, geology;

Water - uses, availability, quality, ecological flow, hydrogeology, hydrology;

Energetic resources;

Biodiversity - flora and fauna, endemic and endangered species;

Hydraulic infrastructure; and

Energy infrastructure.

Create a state-of-the-art monitoring network for surface water bodies and aquifers, including data registration, analysis, and validation.

Data integration model for decision making.

4.1.2 Barriers

Most shale basins are located in arid regions where water is scarce and typically overdrawn. Therefore, when hydraulic fracturing begins, the likeliest source of water for oil field operations will be deep groundwater. Little or no data exist for deep water resources, and what data do exist are often unavailable to researchers and the public.

The development of unconventional hydrocarbon fields with currently used technologies of hydraulic fracturing ("fracking") and other approaches requires additional water resources, both surface and ground waters, or else the reuse of wastewater. Such waters are not necessarily available in sufficient quantity and quality in the areas that have been considered to tender for oil and natural gas extraction in northeastern Mexico, particularly the states of Coahuila, Nuevo León and Tamaulipas.

Along with its economic benefits, unconventional hydrocarbon exploitation could generate important negative consequences for the environment if done poorly. The potential impacts on regional water resources include water pollution, the overexploitation of surface and ground waters, and other factors. These effects can worsen already critical scarcities in drier regions such as northeastern Mexico, already one of the main hydrocarbon exploration areas in the country and one with large potential for unconventional resources.

Deep aquifers are one option for supplying the water needed for drilling and completion activities in unconventional fields. However, very little information is available regarding groundwater resources. Along with limited data on deep groundwater quantities, data on groundwater chemistry and other aspects of water quality are also needed, as are modeling studies of groundwater flow, particularly recharge and discharge rates, to understand the limits of sustainable water use.

This research priority will provide data for deep groundwater quantity and quality that could be used for hydraulic fracturing and other industrial activities. Without it, shale oil and gas extraction will be limited and, most likely, opposed by the public.

4.1.3 Strategies

Aquifers with exploitation potential for unconventional fields will be located and characterized. For this, reliable information is required to determine water bodies' availability and quantify extraction for different uses. One of the objectives will be to involve innovative methodologies for aquifer characterization.

Studies will require data synthesis—including access to water datasets from PEMEX and other sources—new monitoring wells, and modeling studies. The modeling work will provide updating recharge and extraction data for different basins and identify the main consumers who must commit to optimizing the use of limited water resources. Specific parameters to be determined for various basins include geometry, hydraulic parameters, lower and upper basin limits, basin extent, piezometric levels, and annual water flow.

These studies will allow deep aquifers to be characterized, demonstrating that they are independent of shallow aquifers that already serve as supply sources for primary uses. The studies should also determine if chemical composition of an aquifer makes it unsuitable as a source of drinking water or irrigation water, reducing competition for exploitation with primary uses.

The information obtained from these aquifers will be complemented with baseline information generated by private operators and reported to CONAGUA. Water resource management applied to unconventional fields must guarantee that it will not affect water resources for other users, including environmental needs.

Additionally, resource-extraction activities may impact water quality. Therefore, vulnerability assessments of the aforementioned resources are required. The methodology should include factors such as the geometry of surface watersheds (boundaries, areas, etc.), rainfall regimes and variabilities, flows (estimated and measured), surface water dynamics, and surface water availability and quality. This characterization will generate vulnerability scenarios for water resources in northern and northeastern Mexico in the context of shale oil and gas exploitation activities.

The methodology for determining sustainable water availability will include the necessary water flows to sustain biodiversity (i.e., ecological flows) and acknowledge seasonal variations in rainfall throughout the hydrological year. The monitoring network should be optimized and strengthened for the collection of climatological, hydrometric, piezometric and water quality data in order to obtain reliable data on the behavior of local surface and ground water bodies.

The information gathered from the monitoring networks will be stored in a national database and used to help develop a basin-management model. This model will consider physical environment conditions, legal issues, concession volumes, population supply needs, sources of pollution and wastewater generation, with a focus on environment preservation, resource conservation and sustenance of productive activities, including those of the hydrocarbon sector.

Currently, information on natural resources, hydraulic and energy infrastructure is dispersed in different institutions. In consequence, it will be desirable to have in a single GIS database a repository of validated, updated, and integrated data on the following:

- Soil and subsoil - use, change of use, planning, quality, geology;
- Water - uses, availability, quality, ecological flow, hydrogeology, hydrology;
- Energetic resources;

- Biodiversity - flora and fauna, endemic and endangered species; and
- Hydraulic and energy infrastructure.

Finally, researchers will need to develop a hydrogeological model based on deep-aquifer characterization to help ensure sustainable water management for unconventional resource exploitation.

4.1.4 Impacts on Research

Research is also needed to develop spatial and temporal basin analysis models as a basis for decision making. Such efforts should include developing mathematical models associated with instrumentation for groundwater monitoring as well as developing and/or applying new methods for characterizing aquifers using imaging and remote-sensing technologies. The models should also take advantage of the latest innovations in drilling technologies and geophysical methods.

4.1.5 Impacts on Technological Development

Examples of impacts on technological development through these efforts include:

- Technologies for aquifer characterization and modeling;
- Development of methodologies for assessing the vulnerability of water resources;
- Creation of a vulnerability Atlas for different water resources potentially available for unconventional hydrocarbon exploitation;
- Development of a model for the sustainable management of hydrological basins in oil and natural gas regions;
- Monitoring using Industry 4.0 technology (Internet of things, big data, and crowdsourcing);
- Evaluation of ecological attributes and vulnerabilities within basins; and
- Generation of databases on hydrology, soil, water and historical biodiversity that serve as a reference point for spatial analysis in a pilot oil- or natural-gas-producing basin.

4.1.6 Impacts on Human Resources Formation

Finally, in all research priorities, the development and maintenance of human capital is critical for the success of any efforts. For example, efforts are needed to create verification units to validate the technical studies carried out by companies. Specialists in hydrological basin hydrology, geochemistry, and model interpretation and diagnosis are all needed.

4.2 Priority 2 Water quality assessment across the hydrocarbon value chain.

4.2.1 Challenges and Opportunities

Challenges

- Flowback and produced water quality characterization in shale gas/oil extraction.
- Creation of a National Laboratory for water measurement and management in gas/oil extraction fields.

Opportunities

- Qualitative and quantitative detection capacity at threshold concentration levels (ppb or ppt) for priority pollutants associated with oil and natural gas extraction and solid waste and wastewater disposal;
- Identifying and, potentially, “zoning” sites and populations with greater vulnerability to shale gas/oil exploration and production activities;
- Preventing, containing, and controlling risks and impacts on socio-environmental systems associated with Mexico’s oil and natural gas regions;
- Preventing risks and impacts to water resources quality and availability associated with Mexico’s oil regions;
- Provide analysis and monitoring specialized services for shale gas/oil production pollutants; and
- Transferring technology and personnel training in specialized analytical techniques to commercial laboratories.

4.2.2 Barriers

As a result of hydraulic fracturing in shale basins, new analytes are transported into groundwater and, in some cases, surface waters. These compounds come from the chemicals used in hydraulic fracturing but mostly from the naturally occurring elements and compounds lifted from deep underground in flowback and produced waters (e.g., organics, naturally occurring radioactivity, etc.).

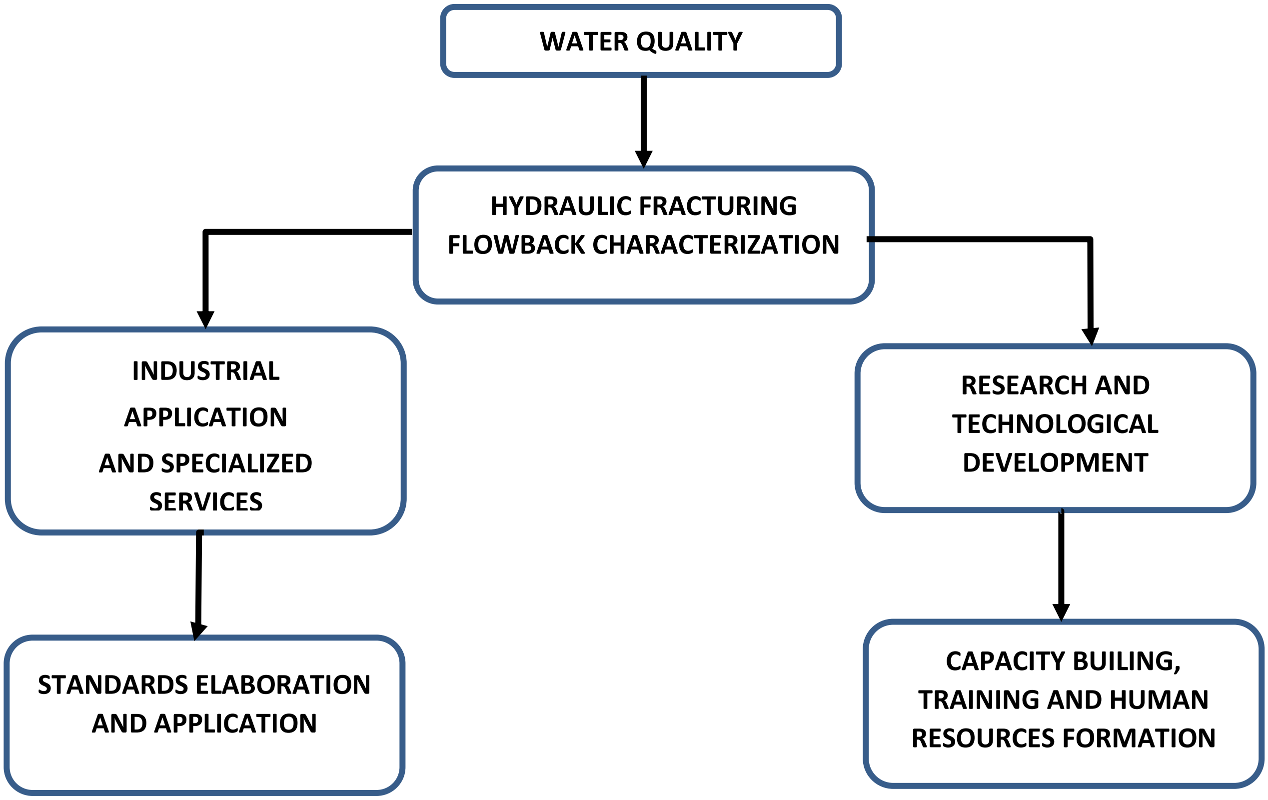
Research is needed to characterize flowback and produced waters with new physical-chemical parameters, as well as the creation of standards aimed at the regulation of shale gas/oil exploration and production activities.

Unconventional resources exploitation requires large volumes of water, with resulting large volumes of flowback and produced water. Reliable characterization of these water streams is fundamental to support efficient operations and safeguard people and the environment. Hydraulic fracturing can incorporate new contaminants that are not part of existing regulatory standards or, in some cases, available for analysis through existing commercial laboratory services.

4.2.3 Strategies

Analytical capacity for flowback characterization and naturally occurring compounds from deep underground (i.e., NORMs) must be in place before the development of shale gas or oil production by hydraulic fracturing occurs in a given region. The need is to identify opportunities for flowback treatment, reuse and recycling within the hydrocarbons value chain, upstream and downstream.

Firgure 2: Water Quality & Hydraulic Fracturing



New analytical infrastructure is also needed for detecting specific chemical parameters and undertaking biological tests (e.g., ecotoxicology) to evaluate sustainable management of water resources in different geological-environmental scenarios in Mexico. In addition, sustainable management means acquiring the capacity and infrastructure for assessing impacts to water quality of surface and ground water in the case of shale gas/oil well leaks, spills and general leaks.

Such capacity building and infrastructure suggest the need for a national water quality laboratory (e.g., CONACYT) created for unconventional oil and natural gas development. The laboratory would provide specialized services for analysis and monitoring for natural and applied pollutants associated with unconventional oil and gas extraction. It should have new analytical capabilities for detecting specific pollutants, used to study hydraulic fracturing chemicals and pollutant toxicity. It will also provide research and technological developments in water management for oil and gas extraction.

Human use and consumption of water with adequate quality is essential to prevent and avoid adverse effects and damage to human health. As a result, parameters and permissible limits need to be established for pollutants associated with unconventional oil and natural gas fields in terms of physical, chemical, ecotoxicological, and radioactive characteristics, in order to ensure and preserve water quality in surface and groundwater supply systems (NOM-127-SSA1-1994).

Water quality in relevant aquifers must be protected during maintenance, rehabilitation and closure of all wells and other infrastructure; that includes shale gas/oil exploration, monitoring and production wells that totally or partially penetrate an aquifer destined for current or future primary water uses, similar need exists for wells drilled for other uses in the hydrocarbon value chain, including waste-disposal wells and abandoned wells. (NOM-004-CNA-1996).

The ecological or environmental flow concept establishes the relationship between water circulating flows, physical-chemical parameters, and the biota present in a basin or water body. This concept must be included when identifying the main impacts, direct and indirect or potential, on water quality due to shale oil and gas production. Particular consideration is needed for the areas of the greatest activity within the ecological flow study unit, as a possible source of contamination (NMX-AA-159-SCFI-2012).

4.2.4 Impacts on Research

Potential impacts on research include:

Modeling and spatial analysis of pollutants associated with leaks and spills during and after hydraulic fracturing of shale gas/oil wells in hydrological basins of Mexico.

Modeling and analysis of pollutants and secondary compound reactivity, as well as the degradation and bioaccumulation of pollutants in surface and underground aquatic systems.

Development of models that integrate hydrology with transport, reaction and destination of shale gas/oil new pollutants in aquifers and surface waters.

Research on the degree of toxicity of fracking additives, naturally occurring pollutants, and organic chemical compounds (e.g., benzene and toluene) present in flowback and produced waters.

Development of groundwater sampling techniques for dissolved hydrocarbon and associated gas analysis (e.g., methane, ethane, and noble gases such as He, Ne, and Ar).

Development of analytical and isotopic techniques to quantify and determine the origin of dissolved hydrocarbon gases.

4.2.5 Impacts on Technological Development

Development of analytical technologies for priority pollutant detection in shale gas/oil fracking activities.

Evaluation of water quality bioindicators and eco-toxicity in watersheds associated with shale gas/oil exploration and production.

Development of analytical techniques for specific pollutant determinations, as well as toxicity studies of fracking chemical reagents and pollutants, both natural and man-made.

Create a National Laboratory (CONACYT model) to address water quality issues on shale gas/oil exploitation, with capabilities on research, technological development, human resources training and industry service provider.

Benchmarking study to identify required modifications on existing regulations or development of a specific standard for shale gas/oil extraction.

4.2.6 Impact on Human Resources Formation

Transfer technology and personnel training in specialized analytical techniques to commercial laboratories.

4.3 Priority 3 Integrated, efficient and sustainable water management in the hydrocarbon value chain.

4.3.1 Challenges and Opportunities

Challenges

Research, technological development, and human-resource training for the sustainable use of water in the hydrocarbon value chain.

Opportunities

- Integrated management of water resources for unconventional hydrocarbon exploitation;
- Treatment capacity for priority pollutants at high concentration levels (ppm or more).
- Decreased environmental impact caused by off-specification discharges;
- Reduction of aquifer water extraction volumes (watershed conservation);
- Ecological maintenance in freshwater and coastal areas;
- Profitability increase of hydrocarbon value chain processes;
- Generation of treatment prototypes for different currents;
- Waste disposal strategies;
- Water use and treatment optimization through special software; and
- Training.

4.3.2 Barriers

Within the sustainability program in the hydrocarbon value chain in Mexico, water represents a strategic input and, therefore, its use must be efficient across different stages of this value chain, from the extraction of crude oil to refining and transformation. In all stages, opportunities can be found in relation to water volume and quality, and economic, environmental and social impacts.

On one hand, in the case of oil refineries, a lack of water availability can cause stoppages in operations. On the other hand, the high-water consumption in transformation processes causes social tensions, particularly in drier areas where water comes from wells located in aquifers whose water balances between recharge and discharge are negative. Therefore, to reduce "fresh or first-use" water consumption and to give sustainability to transformation processes, it is necessary to treat wastewater for its re-use or recycling.

A brief description of processes that consume water and generate wastewater in oil refining follows in Figure 3:

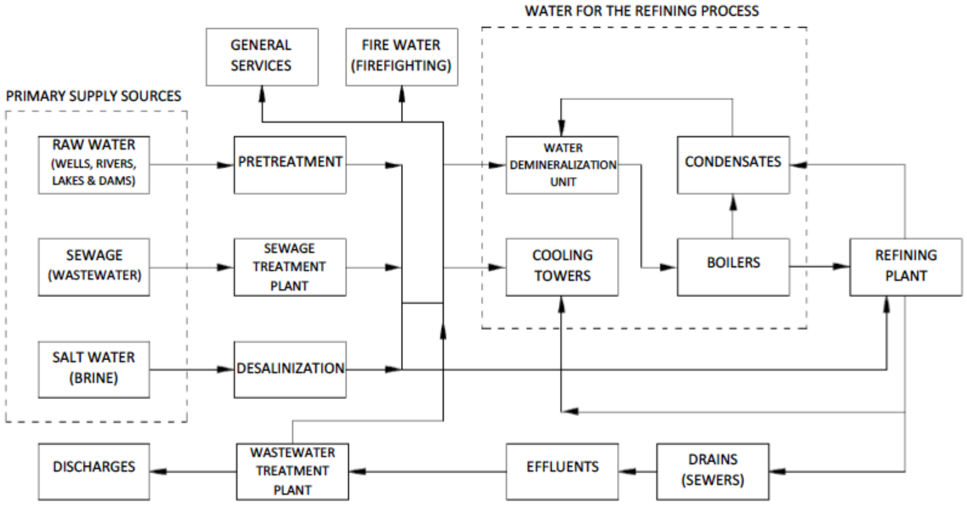


Figure 3: Flow Diagram of Crude Oil Refining

Processing wastewater contains many toxic compounds, including H_2S, sulfides, ammonium, phenols, mercaptans, salts, fats and oils. These compounds result in wastewater treatment plants with conventional biological processes that do not always work properly.

The oil industry is highly demanding of water resources, which are finite and scarce, especially in drier areas. High water demands for processing and refining result in competition for water, causing potential social conflicts and economic impacts. Refining in Mexico already uses >1 billion m^3 of water each year. Research is needed to reuse more wastewater and to reduce cooling water demands.

The unconventional gas/oil extraction (hydraulic fracturing) will require large volumes of water, this extractive industry will be set as one of the main consumers of water. As such, the impact of this new actor must also be evaluated.

Fracking typically requires from 15,000 to 25,000 m^3 of water per well. 10 to 30% of this volume is returned as flowback. Total dissolved solids high concentration represents a challenge.

Produced water, from conventional and unconventional plays, reuse and treatment depend on water quality and the associated final disposal.

4.3.3 Strategies

Research and technological development should be undertaken on water management for oil/gas extraction and refining, on reusing wastewaters to reduce freshwater needs upstream at oil and natural gas wells and downstream at refineries, and also to identify the best opportunities for water savings.

Progress is needed for wastewater treatment, reuse, and final disposal or discharge both upstream (shale plays) and downstream (refineries) to reduce impacts to watersheds, people, and biodiversity.

One solution for water supply is to locate and exploit alternate sources of water such as:

- Fresh or saline water from deep aquifers;
- Water treated for reuse and recycling; and
- Sea water.

Furthermore, current and potential water sources available for Mexico’s current six refineries should be evaluated, including the use of:

- Municipal wastewaters;
- Groundwater wells;
- Treated process water; and
- Rivers (Minatitlan) and creeks (Cd. Madero);

Additionally, it is necessary to integrate or generate information on:

- Water volume, quality and cost in each production area.
- Social impact study

Refineries water supply characterization (quality and volume):

- From external sources;
- From internal sources (recycled wastewater, for example);
- Water treatment evaluation for different processes;
- State-of-art study;
- Treatment testing of different water currents;
- Optimization through special software;
- Design and construction of prototypes for laboratory and bank tests;

- Design and construction of prototypes for testing in an environment similar to real;
- Design and construction of prototypes with sub systems in real environment with a representative flow; and
- Definition of generated waste disposal strategies.

Table 1: Integrated System of Sustainable Water Management Global Projects

Sustainable Water Management Global Projects

Project number	Concept	Use	Application process	Remarks
1	Sanitary wastewaters reuse	Supply source	Production/ Refining	Reduce volume of groundwater extraction
2	Produced water reuse	Supply source	Production	Reduce volume of groundwater extraction Reduce environmental impact
3	Process effluents reuse	Supply source	Refining	Reduce volume of groundwater extraction Reduce environmental impact
4	Produced water injection	Final disposal	EOR/Disposal	Reduce environmental impact

The result is a wastewater treatment system prototype for a given flow, so that the existing biological WWTP can function properly.

The expected product is a set of suitable technologies according to the water current types to be treated, which are modular and easily scalable, so that part of it could be used in another refinery that uses water of different quality.

4.3.4 Impacts on Research

- Development and design of advanced water treatment processes based on wastewater quality and according to the destination process;
- Municipal wastewater treatment for reusing water as a source of supply;
- Flowback treatment for reuse/recycling in hydraulic fracturing, secondary recovery, and/or final disposal;
- Produced-water treatment for reuse/recycling in oil secondary recovery, injection to non-producing wells and/or disposal on water bodies;
- Transformation processes in wastewater treatment for their reuse/recycling in other processes and/or final disposal; and
- Research and development on hydraulic fracturing technologies using noble (e.g., He, Ne, Ar) and other inert gases in unconventional fields.

4.3.5 Impacts on Technological Development

- Treatment technologies need to be developed for transformation processes in wastewaters. These technologies should be, ideally, innovative (non-conventional) with a high effectiveness to reduce pollutants concentrations while maintaining economic and environmental aspects;
- Development innovative (non-conventional) technologies with a high effectiveness to reduce the levels of pollutants, taking care of the economic and environmental aspects;
- Development of models for water-use optimization in the hydrocarbons value chain;
- Studies on water treatment options for flowback and produced water reuse or final disposal in unconventional fields of Mexico;
- Development of models for oil refining effluents management with emphasis on reuse them, in order to reduce first-use water demand, which incorporates the evaluation of water use in the processes to identify opportunities for savings and currents segregation; and
- Advanced treatment technologies development for priority pollutants on shale gas/oil fracking activities.

4.3.6 Impacts on Human Resources Formation

Specialized, technical human resource training on advanced water analysis and treatment systems design and operation for the oil and gas industry.

5 Social Impacts and Co-Benefits of the Oil and Gas Industry

5.1 Challenges and Opportunities

Below are the key challenges identified in this topic area, according to the state of the art. The challenges are as expressed by the speakers of the plenary sessions and by the subject experts represented in the discussion panel by diverse actors (academia, private sector, public and NGO's), both national and international.

Challenge 1: Prioritize the importance of society and its relationship with the hydrocarbon sector in the management and modes of operation throughout the value chain.

Challenge 2: Appropriately manage and meet the growing expectations of communities for access to energy, given the ongoing migration of people from rural areas to cities.

Challenge 3: Universalize the right to free, prior and informed consent (FPIC), for both indigenous communities and other communities affected by oil and gas operations.

Challenge 4: Internalize Social Responsibility to the entire structure of the organization, as a functional part thereof.

Challenge 5: Ensure public access to non-strategic information, in an efficient, responsible and timely manner.

Meeting this challenge will provide opportunities also for the oil and gas sector, which could improve companies' business efficiency, generating certainty in their investments, improving their corporate images, fostering trust in their communities and developing a collaborative approach. Some of the opportunities are outlined below.

Opportunity 1: Design of social accountability mechanisms that promote transparency in the oil and gas industry, while neutralizing the potential for corruption and impunity that may develop in this sector.

Opportunity 2: Establishing a social dimension of sustainability to the ethical practice, integrity and political economy of the hydrocarbon industry.

Opportunity 3: The current paradigm shifts underway following the Energy Reforms and the opening of the energy sector is an ideal moment to strengthen the relationship between industry, society and government.

Opportunity 4: Verify that all participants in the sector have access to all information classified as public, which might be achieved by developing appropriate technology and technical skills.

Opportunity 5: When information and data are publicly available in a clear and validated database, there will be an opportunity to develop an advertising campaign about the certainties involved for companies when conducting energy businesses in Mexico, which will be useful for attracting new customers and operators.

Opportunity 6: Involvement and engagement of social actors with appropriate levels of government and operators in a free, facilitated, active, voluntary, substantive, direct, and full manner. This should be done not advisory but also should also be done in a deliberative manner.

5.2 Barriers

Below are the main barriers identified for closing the gaps that currently exist between the challenges and priorities foreseen. Note that some of these barriers apply to one or more priorities and one or more challenges.

Barrier 1: Resistance to change, which arises from the historical and cultural relationship that the oil and gas industry has had with various communities.

Barrier 2: Social asymmetry in energy-viable areas, which may be worsened or complicated by the new scheme of participation by multiple companies with differentiated practices.

Barrier 3: Competition of social priorities with other productive activities, and the tension for companies between obtaining an immediate economic benefit versus achieving long-term community advice and support, which can result in failing to seek community advice and to plan (pursuing actions focused only in the short-term).

Barrier 4: The processes of planning productive energy projects are carried out disconnected from society, impact evaluations are developed by third parties. There is a detachment in the conceptual birth of the project with society in a natural way.

Barrier 5: The country has experienced an increase in opposition groups or community representation figures, who possess increasing knowledge of legal language and resources for halting energy operations. In some cases, these groups are not directly associated with the communities. Hence, it is of vital importance for companies to develop communication skills, strong corporate images and knowledge of the community.

Barrier 6: Social investment for oil and gas projects is a concept that has been discussed but not evaluated or quantified. It also remains unclear what is a co-benefit and what should be the obligations on the part of companies for operating in communities.

5.3 Priority 1. Develop approaches and Instruments for Participation

The first priority is to develop approaches and instruments for participation by the different actors in the different links of the value chain. This will involve planning and participation by communities in the decision-making processes and in the initial stages of operations.

5.3.1 Strategies

Specify the representativeness, scope and functioning of existing mechanisms. Identify standards and safeguards that contribute to guaranteeing the right to information and its internalization in and dissemination by companies. Mechanisms must be designed to accommodate two binding visions: The value chain and the life cycle of the project, to ensure their representativeness and their monitoring and control. In addition to human rights, the mechanisms that will be designed must focus on gender, interculturality, disability and intersectionality.
Design and establish a consultative council that supports the work processes of SENER with a social dimension.

Open dialogue processes on human rights, including engaging with companies that demonstrate the vision to advance the discussion of the involvement of community representation in oil and gas operations.

5.3.2 Impacts on Research

Generation of knowledge and information systems about territories and communities with the approach and standard of guaranteeing and protecting rights.

Compilation of data, creation of data management systems, identification of missing data and conduction of research to complement this missing data.

5.3.3 Impacts on Methodological Development

- Development of schemes and mechanisms for citizen participation in the planning, execution and strengthening of public policy (systems planning in different areas);

- Expansion of the Social Impact Assessment to address cumulative and synergistic impacts, as well as prior consultation by impacted communities for the entire value chain;
- Development of tools and methodologies to design and implement participatory processes aimed at free, prior and informed consent (FPIC); and
- Development of regulations and tools related to various participation processes impacted by various aspects of the hydrocarbon value chain.

5.3.4 Impacts on Human Resources Formation

Development of the skills and abilities to design, execute and evaluate participation mechanisms.

Design of mechanisms for capacity development in communities.

5.4 Priority 2. Capacity Development

Capacity building, awareness-raising, sensitization and strengthening of skills by all actors, including communities, companies, governments and civil society.

5.4.1 Strategies

Industry actors require skills and tools for creating the conditions that 1. Facilitate a constructive dialogue between the various stakeholders, 2. Promote positive social impacts and 3. Mitigate or eliminate negative consequences produced by the decision-making process.

Governments and companies need to be professionalized, including additional staffing with public servants who fulfill functions described above, and who have the skills and tools to be able to dialogue with each and every one of the actors designated for decision-making and participatory processes.

The academy can serve to generate knowledge and pedagogy, and to steward and update that knowledge.

Generation of an energy and social anthropological Atlas, which serves as a basis for the zoning of priority development areas.

Introduce social research lines in the energy centers and programs financed by SENER and CONACYT.

5.4.2 Impacts on Research

Incorporate social research lines in the energy centers and programs financed by SENER and CONACYT.

Compilation of data, creation of data management systems, identification of missing data and conduction of research to complement this missing data.

5.4.3 Impacts on Methodological Development

Prepare documented manuals, best practices and protocols for developers, which together serve as guides for stakeholders.

5.4.4 Impacts on Human Resources Formation

Include social topics of energy development at all levels of professional education.

These efforts will guide certification, professionalization of actors and specialization (competences, train trainers), and will provide new avenues for competence development in Mexico.

Human resource development will be essential to facilitate dissemination and acquisition of information on the social impacts of industry activities.

5.5 Priority 3. Establish Regulation for energy sector activities.

It is a priority to establish appropriate regulations, methodologies, standards and compliance with social impact assessments for energy sector activities.

5.5.1 Strategies

- Conduct a review of regulations in other industries and in other countries in order to gain from comparative analysis;
- Conduct research to identify international standards and best practices;
- By understanding and evaluating relevant international standards, it will be possible to develop methodologies suitable to the needs and specific situations of the Mexican energy situation; and
- Establish clear criteria for compliance, either in accordance with standards or with performance criteria.

5.5.2 Impacts on Research

- Conduct a national socio-environmental research program to establish baseline knowledge for social impact studies for the sector;
- Investigate the appropriate baseline of social impact for specific project areas;
- Investigate the effectiveness of current regulations for development of social impact studies;
- Investigate where in the business process social impact studies should be done to ensure that projects are feasible; and
- Compilation of data, creation of data management systems, identification of missing data and conduction of research to complement this missing data.

5.5.3 Impacts on Methodological Development

- Compile methodologies to compare the quality of social impact studies for the actors that execute these studies;
- Develop open information systems and platforms for disseminating knowledge; and
- Assimilate and adapt cumulative socio-environmental impact methodologies.

5.5.4 Impacts on Human Resources Formation

Training of certifying agents, auditors and consultants in the methodologies of quality assurance in social impact studies.

Training of all actors involved in these new information technologies and their contents.

5.6 Priority 4. Integrate Social Dimension in Project Life Cycle

Integrate the social dimension of sustainability throughout the life cycle of the project.

5.6.1 Strategies

- Consider social impacts and co-benefits as an explicit criterion for tenders, auctions, assignments, etc.;
- Promote inter- and intra-actor dialogues between social organizations, companies, authorities and communities regarding social impacts and co-benefits of energy projects;
- Social evaluations should consider cumulative socio-environmental impacts incorporating the broader spatial and temporal context of a project;
- Prepare a glossary of terms with clear and approved definitions in order to provide clarity and regulatory certainty for all companies, communities, organizations and levels of government; and
- Ensure that the projects financed by SENER/CONACYT traverse the social dimension as a line of research.

5.6.2 Impacts on Research

Establish criteria for project abandonment.

5.6.3 Impacts on Methodological Development

- Identification of groups of interest in each stage in the project life cycle;
- Facilitation of technological development, platforms and media for disseminating information;
- Development of a final study of the project's social impact after the project has been completed;
- Compilation of data, creation of data management systems, identification of missing data and conduction of research to complement this missing data; and
- Compilate data, create data management systems, identify missing data and conduct research to fill data gaps.

5.6.4 Impacts on Human Resources Formation

Training the relevant communities in human rights to help them integrate themselves in inclusive regional development.

Training human resources to understand technological developments, platforms and media for disseminating information.

5.7 Priority 5. Develop Co-Benefits Approaches

Develop approaches, instruments and frameworks concerning co-benefits and local, regional and national development.

5.7.1 Strategies

Evaluate the social impacts of various technologies and portions of the hydrocarbon sector and make stakeholders aware of the findings. Facilitate discussions of co-benefits or avenues for advancing mutual development.

Minimize negative impacts while maximizing positive impacts and co-benefits through best practices.

Establish clear indicators for measuring the performance of the Energy Reforms in terms of social impact and co-benefits, in order to correct deviations from the stated goals and to close opportunity and time gaps.

5.7.2 Impacts on Research

- Development of a set of indicators for success of the Energy Reforms related specifically to social impacts and co-benefits;
- Study established techniques for social investment in the realm of Social Impact Assessment (EvIS);
- Analyze and investigate the ways of employing and advancing the framework of profit-sharing (percentage of economic participation per project or per investment scheme);
- Compilation of data, creation of data management systems, identification of missing data and conduction of research to complement this missing data; and
- Study real beneficiaries within the scope of the commitments adopted by Mexico and the framework of the Extractive Industry Transparency Initiative (EITI).

5.7.3 Impacts on Methodological Development

Development of criteria and protocols for shared benefits and raise these for consideration with stakeholders in the hydrocarbons sector.

Definition and establishment of the appropriate scope for “positive impacts” and “co-benefits.”

5.7.4 Impacts on Human Resources Formation

Dissemination of protocols for co-benefits and raise it for consideration by stakeholders in the hydrocarbons sector.

Training the stakeholders in the energy industry in the definitions and scope of co-benefits.

Establishment of processes for disseminating good practices.

6 Policy options to support the transition to a more sustainable oil and gas industry

Overarching Goals for an Innovation, R&D and Capacity Building Policy Agenda

- Identify strategies and implementation paths for the most cost-effective, technically viable, politically feasible policy options for a sustainable hydrocarbon value chain that achieves Mexico’s energy reform goals now and, in the future;
- Develop approaches for strategic resilience in the Mexican hydrocarbon sector to manage uncertainty during the energy system transition;
- Identify opportunities for collaboration with other sectors and jurisdictions to identify low-carbon energy or other value-added products; and
- Support innovation and competitiveness of the Mexican economy by maximizing the business opportunities that low carbon business transformation of the oil & gas sector in Mexico presents given an ambitious climate and clean energy transition policy agenda.

The Hydrocarbon Value Chain

The value chain of the hydrocarbon industry is a complex system of processes and activities (e.g., production, innovation, marketing and maintenance) by which the corporations, entrepreneurs and productive entities add value to the goods and services in the oil & gas sector.

Technological advance and holistic, shared-resource system planning (i.e., one that integrates innovation in energy, water and infrastructure development) can help make this industry more sustainable. Carbon tech innovation and new businesses models as part of the transformation of the hydrocarbon value chain can foster economic development in Mexico. Figure 1 shows a diagram of the hydrocarbon value chain.

As shown below in Figure 4, the processes and subprocesses that describe upstream, midstream and downstream operations are divided through the oil and gas life cycle. In Mexico, the hydrocarbon value chain has been in constant evolution since the first oil barrel was exported by Mexico in 1911, the recent Energy Reform has triggered an unprecedented transformation of the sector but this time considering an energy transition perspective towards decarbonization. As the hydrocarbon sector expands into new areas of opportunity in today’s Mexico, the value chain grows in size and maturity with more processes and subprocesses in the three segments.

The "upstream" is the segment in which the exploration and evaluation are carried out: from contracts for tests and drilling, seismic and other surveys, to geological and geophysical studies. Finally, the production of the well is carried out: the daily production is administered, the performance of the reservoir is monitored and optimized, the well and equipment are maintained, storage management, water management and waste management are carried out, as well as the abandonment plan. This segment covers the two possible types of deposits: land and sea.

The "midstream" includes everything from marketing and wholesale marketing of unrefined oil and gas, to transportation and storage, as well as the processing of natural gas that allows transportation.

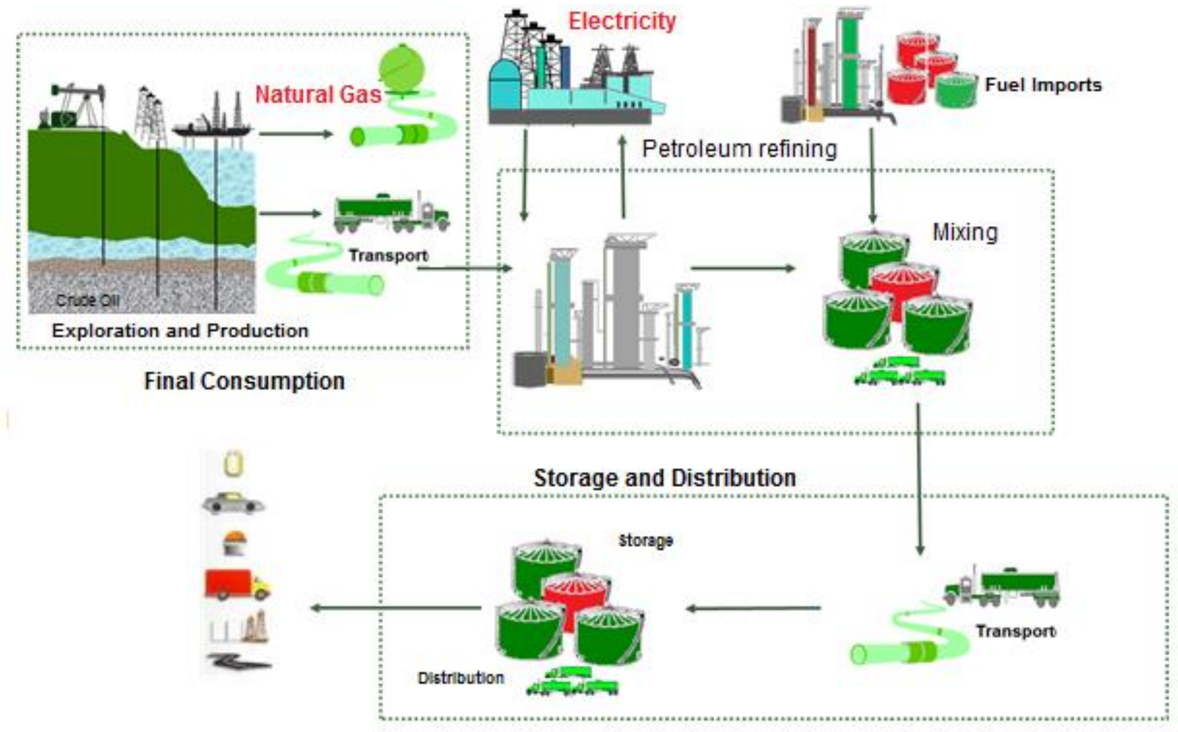


Fig. 4 Hydrocarbon Value Chain in Mexico. Source: IMP

Lastly, the "downstream" segment is the refining segment (in the case of oil) and the distribution and retail sale of refined petroleum and natural gas.

The increase in the share of renewable sources in the country's energy mix will play a central role in minimizing the environmental footprint of the sector. However, while the energy transition progresses hydrocarbons will continue to be the main source of energy in the near to mid future. Therefore, it is important to accelerate the transition to cleaner fuels such as natural gas and the deployment of renewables, as well as the more efficient use of natural resources. Therefore, conducting shared-resource systems analysis is important. For instance, the automobile industry in Mexico represents an important economic engine to the economy. Electromobility and shared economy business models such as Uber and Lyft are transforming transportation into a zero emissions, autonomous mobility and logistics service industry. Electric cars are improving their technology overall and expanding their market share. Moreover, range anxiety is being reduce by longer lasting and less costly batteries. Both social demand for cleaner urban environments and climate action at the local level are going to have an impact on both industries in Mexico. Electrification and clean energy power sourcing will be central to the next generation of transport-energy services. Integrated policy planning and the development of technological solutions in this nexus energy-transport, are key to address these emerging challenges. Analyzing how the oil and gas industry can prepare for the low carbon transformation of the transport sector should be a research National Priority. Mexico’s investment in the development of innovative technological and business solutions towards a clean economy will allow the country to meet its growing demand for energy, foster economic development while at the same time addressing the challenges of decarbonization.

6.1 Priority 1. Develop policies to decarbonize in the hydrocarbon value chain

Progress towards a sustainable hydrocarbon value chain requires clean economy-wide policies that cost-effectively and efficiently support the transition to a truly circular economy. An array of complementary policy measures and programs will have to be developed and implemented in an integrated and coordinated manner to make science-based decisions, achieve economic growth, optimal and responsible use of national hydrocarbon assets while protecting Mexico's environment and ecosystems, as well as complying with international climate commitments and other global commons issues such as oceans protection. Optimization and coherence of the policy measures across sectors is necessary to achieve these policy outcomes. Therefore, as the overarching National Priority for the implementation of the recommendations included in this report the creation of a knowledge exchange platform and/or binational policy and technological innovation implementation lab. This program would coordinate and integrate innovation, research & development and capacity building activities needed to support the transition to a more sustainable hydrocarbon value chain focusing, for instance, on the following activities:

- ✓ Develop technological and policy pathways towards the long-term vision of a Circular Economy in Mexico
- ✓ Support interagency cooperation and coordination of central government policies, with state and municipal jurisdictions, including for instance coordinated infrastructure planning
- ✓ Assist and inform the design, formulation of policy approaches for low carbon transformation of the oil and gas industry, as well as in the harmonization and rationalization of complementary policies (e.g. carbon taxes, cap-and-trade or carbon market, clean energy certificates) for cost-effective implementation
- ✓ Enhance measurement, reporting and verification (MRV) capacities, data collection and management, as well as support the development of digitalization and deep learning systems to enhance productive efficiency and environmental performance
- ✓ Develop knowledge-sharing platforms to encourage cross-sectoral collaboration and incentivization to advance a clean economy in Mexico
- ✓ Analyze and develop financing & asset risk management tools for hydrocarbon assets in the face of climate risk
- ✓ Develop national capacity for shared resource-system analysis to enhance sustainability of hydrocarbon value chain
- ✓ Build a knowledge exchange platform with Stanford/Silicon Valley to strengthen Mexican capacities in national research institutes, universities, industry and entrepreneurs to develop and exploit commercially viable R&D, structure innovative business models in order to maximize the business opportunities of the decarbonization of the oil & gas industry in Mexico through carbon tech innovation.[2]

---

[2] Carbon tech innovation results in new processes, products, or services that convert CO_2, methane and biomass into a tradeable commodity while mitigating emissions.

6.1.1 Challenges and Opportunities

Within the policies to decarbonize rapidly the global economy, the following Challenges and Opportunities have been identified:

- Reduce the use of energy by conservation;
- Reduce energy use by improving efficiency while minimizing emissions;
- Switch to fuels and energy sources with low or no carbon;
- Recover, capture and increase higher value utilization of CO_2; and
- Foster clean innovation for carbon tech in tandem with new business models and solutions.

6.1.2 Barriers

Mexico is party to international agreements and treaties such as the United Nations Framework Convention on Climate Change, the Paris Agreement, and collaborative efforts such as the methane global initiatives. At the national level, Mexico was the second country in the world to pass a climate federal law in 2012, and recently amended in December 2017 this legislation in order to align it to the national commitments under the Paris Agreement. For the implementation of its climate action agenda, the federal government has also developed institutions, regulations, standards, in order to control greenhouse gases (GHG) and co-pollutants. However, during the workshop, this working group agreed that there are a series of obstacles to advance such a policy agenda:

- Lack of coordination of central government policies with state and municipal jurisdictions, including coordinated infrastructure planning.
- A need to avoid adding new environmental burdens while solving other environmental problems.
- Need for knowledge exchange platforms to encourage intersectoral collaboration and encouragement.

- Shared resource system analysis to improve sustainability throughout the hydrocarbon value chain.
- There are no robust data management platforms with traceable information in the hydrocarbon industry, and the national GHG emissions inventory system overall requires to be credible and verifiable to support the cost-effective operation of the Mexican ETS, and to participate in international carbon market.

6.1.3 Strategies

One of the aspects in which it is necessary to pay more attention is that by allowing the entry of foreign and private domestic investors into the energy industry, the exploitation of unconventional sources of hydrocarbons such as oil and shale gas will be drastically increased (shale gas and oil) as will and oil in deep and ultra-deep waters, which until recently were (for reasons of cost, technology and economic risks) almost impossible to undertake.

Obtaining hydrocarbons from these sources involves risks of high magnitude and environmental and social costs, as well as safety for workers and affected communities. The extraction of shale gas could bring serious collateral effects, such as the use of large amounts of water in its extraction, contamination of the subsoil and release of methane. On the other hand, the extraction of hydrocarbons from deep waters carries the risk of serious oil spills.

That is why, if extraction is necessary, it must be carried out with extreme care and vigilance, as well as in compliance with strict technical, operational and environmental regulations. Likewise, in compliance with Article 1 of the Constitution, the right to information, participation and consultation of affected communities must be guaranteed. It should go beyond this regulatory compliance by incorporating the best international practices in environmental, social and industrial safety matters. There should be a strong commitment to minimize environmental impacts and ensure access to environmental justice and the repair of damage in case of accidents by the hydrocarbon sector.

The regulatory sector must have powers that are well defined. They must be legally and technically sound in such a way that legal security is provided to regulated subjects, forcing them to adopt the best national and international practices in these matters.

The regulatory sector must have sufficient strength and tools to act effectively; as well as avoiding over-regulation and duplication of functions, considering that similar or identical powers exist in other bodies such as the Federal Attorney for Environmental Protection (PROFEPA), the Safety, Energy and Environment Agency (ASEA), the Directorate of General Risk and Environmental Impact (DGIRA), the General Directorate of Energy and Extractive Activities of SEMARNAT, the Secretariat of Energy (SENER), the Ministry of Labor and Social Security (STPS), the Secretariat of the Navy (SEMAR) and the National Commission of Hydrocarbons (CNH).

6.1.4 Impacts on Human Resources Formation

Identified as a National Priority is the need to invest in human resources to have the most qualified energy regulators and policymakers in charge. The ongoing energy reform process and new investment in the energy sector demand expertise in areas where there is a lack experience, for instance in unconventional and deepwater and ultra-deepwater operations. Therefore, it is urgent to provide human resources the tools to develop next generation

regulatory frameworks to ensure the best national and international practices on sustainability of the hydrocarbon industry are in place and enforced in Mexico.

6.2 Priority 2. Establish incentives for carbon pricing, markets & innovation

Workshop participants agreed that in Mexico a well-functioning carbon pricing system will play a key role in the decarbonization of the hydrocarbon value chain. In particular, with the implementation of the new emissions trading system (Mexican ETS) that the amendments to the federal climate change law of 2017 mandates. It is also important to have clear understanding of the interoperability and complementarities with the existing carbon tax and the clean energy certificate systems already in place. Therefore, it is recommended to invest in conducting research towards a cost-effective implementation such policy approaches to the oil & gas industry. A priority should be to analyze cost minimization opportunities or arbitrage based on the development of marginal abatement cost estimates for reducing CO_2 emissions, establish emission baselines towards the establishment of the national emissions cap, and more importantly contribute to the development of a credible emission inventory among other key aspects for the participation of the sector in the Mexican ETS.

For instance, a technology that would benefit from costing carbon emissions appropriately by this market approach is carbon capture and storage (CCS). This technological approach is key for the hydrocarbon industry to comply under the Paris Accord and make continued use of fossil fuels sustainable. Today CCS is not a cost-effective investment for companies and nations when economic incentives are not sufficiently high (e.g., carbon pricing, market incentives and tax credits). Technological advances are expected continue to enhance its financial and technical viability in the future. Mexico needs to be prepared to scale up this technology when it is viable. Mexico has launched a national innovation center on carbon capture utilization and sequestration. To both support the capture potential but more importantly develop economic activity through applied research to develop the value chain around the utilization of CO_2 for CO_2-EOR and other less mature applications. Therefore, it is necessary to analyze such scenarios while such a condition exists and to consider at this stage the adoption or design for implementation of Measurement, Reporting and Verification (MRV) mechanisms to quantify the CO_2 that is being captured effectively and ensure that it is maintains in the reservoirs in a "permanent" manner, in accordance with international standards. MRV provides certainty on the carbon commodities created by these emission reductions, therefor is essential to access funding mechanisms, financing and to participate in the global carbon markets. Public-private partnerships for clean innovation toward cost-effective carbon tech solutions will be important in the process of decarbonizing the hydrocarbon value chain.

6.2.1 Challenges and Opportunities

An economy-wide carbon price is not enough to launch new technologies such as carbon capture and utilization on dilute sources of CO_2 such as from power plants and cement manufacturers without additional incentives. It is necessary to promote economic and regulatory incentives for the implementation of new technologies that allow the development of pilot projects and also to promote emissions transactions between carbon markets in which Mexico can participate, as well as facilitate the flow of international resources and support.

- Creation of special funds to finance pilot projects.

- Inclusion of projects in the carbon market, including offset and tax compensatory measures.
- Stakeholder management and education processes to build a constituency around the environmental and business opportunities around carbon capture, storage and utilization
- Design of economically efficient and effective transitory incentives (including new measures and commercial models, such as public-private partnerships).
- Build partnerships among key technological innovation partners (i.e., industry, academia, research centers) to advance decarbonization of the hydrocarbon value chain.

6.2.2 Barriers

- Specific incentives are needed to expand new technologies. It is vital to consider the need to access international funds to jumpstart the use of CCUS technology in the country. However, important support infrastructure investments must be made by government. Otherwise it will not be possible to give continuity to the goals that are established.

- There is no carbon pipeline network. One of the actions that will help in an important way to make the implementation of technology attractive is to be able to offer CO_2 in sufficiently important quantities to be considered as a reliable input in some industries, such as enhanced oil recovery (EOR). This is achieved if a carbon pipeline network can be built to facilitate the transport of CO_2 from isolated places in the country, and probably where there are no nearby injection sites with economic interest, to regions of Mexico or abroad where it is (USA mainly). Otherwise, thinking of the issuing sites as attractive in the individual will be an error. A policy regarding this issue should be designed with sufficient anticipation based on the analysis of the carbon market and other price incentives (i.e., tax credits) carried *ex ante* to the development of CCUS in Mexico.

- Promotion policies are lacking. For the private sector to invest in CO_2 usage and storage technologies, it is necessary to create public policy mechanisms to finance projects and monitor their progress and results to obtain credits for emission mitigation.

6.2.3 Strategies

As already stated in article 6 of the Paris agreement, through voluntary cooperation schemes, public financing, and funds from the private sector. As well as, putting a price on emissions, either through taxes, fees or other market instruments that provide incentives for private investment. Sustainable development can be promoted throughout the hydrocarbon value chain. Therefore, a key strategy is to support be the implementation of a well-functioning carbon market in Mexico (i.e., Mexican ETS) that can eventually link to the global carbon market, thus facilitating the flow of international climate investments such as CCUS.

It is important that support interagency coordination between the Ministries of Energy and Economy, as well as the National Council of Science and Technology, with the Ministry of Finance and Public Credit, given that decarbonization of the hydrocarbon value chain will require a climate risk assessment to revalue national resource assets, major investments in carbon tech and the need to create a set of economic incentives to industry in support of the energy transition. If implemented correctly, the Mexican ETS will send a price signal to all industries to decarbonize. International cooperation, in particular with California, that is a leader in implementing such market approaches and developing carbon tech solutions is important.

6.2.4 Impacts on Human Resources Formation

In Mexico, knowledge related to CCUS technology is scarce. It is necessary expand the links with international science and technology institutions that dominate it, with the intention that soon Mexican technicians will be able not only to operate CCUS facilities but also to guarantee the monitoring of the sites to ensure storage inperpetuity. This is a temporary action line since Mexico should be able to develop its own human resources on the subject in the medium term. This stage should be aimed at training the first technicians, who in the near future will be the transmitters of the technology to other national technicians, either from the industry or the classroom. For this it is necessary to integrate students of different levels, from national institutions of science, academia and industry and international.

To achieve this goal, it is necessary to obtain the right knowledge and information, to the right people, at the right time. To do so, it is necessary to provide a traditional combined university, postgraduate and postgraduate education necessary to support the development of skills and customize approaches of additional training to provide more specific and faster information.

Finding and/or preparing the right type of talent for regulatory sectors, industry and research centers will allow us to define the course towards a sustainable oil and gas transition.

6.3 Priority 3. Develop policies for the development of new carbon technologies

Clean innovation for the hydrocarbon value chain is known as Carbon Tech, where new processes, products, or services that converts carbon waste into a tradeable commodity that mitigates emissions compared to the alternatives. Currently, carbon intensive industries in Mexico are not ready to adopt a capture scheme and other emerging carbon tech solutions

without requiring a major reconfiguration. New regulatory frameworks should be developed to support the development and use of new technologies to decarbonize the hydrocarbon industry in Mexico from the onset. In short, both policy and technological innovation is necessary to advance the sustainability of the hydrocarbon value chain.

6.3.1 Challenges and Opportunities

The clean energy transition requires access to high-quality and geopolitically relevant analysis to support good policy formulation. This challenge requires the development of advanced decision-making tools and highly integrated policy design and programs. Below is a list of some of the projects identified as key priorities by the working group:

- Techno-economic and life cycle analysis of technologies, systems and impacts (engineering, economy and sustainability combined).
- Coordinated infrastructure planning for multisectoral and community development.
- Compile CCUS maps, enhanced oil recovery (EOR) / enhanced geothermal system (EGS) with spatial data, key information, missing information (e.g., composition of produced water, groundwater resources, petrophysical characteristics) and make information available currently not available in public access and search databases; produce maps that will be valuable to decision makers, researchers and the public.
- PEMEX, CEMEX, CEMIES, IMP, CONACYT, collaboration to launch a research and development program focused on CO_2 in cement and concrete.
- Take advantage of the results of the existing CEMIES and plan possible pilot projects (for example, on CO_2-EOR and hydraulic fracturing using CO_2 instead of water)
- Create and expand a detailed set of research and development roadmaps for each of the key problems of the hydrocarbon value chain.
- Involve PEMEX, IMP, CEMIES and power generators in research and development programs.
- Develop opportunities for the integration of solar and geothermal applications in the hydrocarbon value chain (including heat from renewable processes, integration of renewable energies in O&G operations, production of solar steam for EOR, enhanced geothermal energy, and so on).
- Develop field tests for new approaches (low-C) to increase hydrocarbon production and CO_2 storage in depleted and unconventional fields.
- Application of CCUS to unconventional gas development

6.3.2 Barriers

There is no national CCUS policy. Introducing this new carbon tech approach in Mexico must lead to the adaptation of existing regulation, as well as the issuing of new regulations for the correct development of CCUS technology. An essential public policy in CCUS is that which derives from the obligations of those who store anthropogenic CO_2 in the subsurface. This phase is perhaps one of the most delicate because in it lies the confidence of society in the security of geological storage. This policy should be sufficiently timely to guarantee its existence by the time the first geological sequestration projects are made, from the pilot

projects, although its definitive importance lies in the operation of projects on a commercial scale.

There are smart systems for policy support and efficient and sustainable operation of the hydrocarbon value chain in Mexico. Robust and efficient databases are required for data analysis and management. Thus, there is a need to create a framework of reference for the development of methodologies and systems for the identification, capture and analysis of data that allow the monitoring and management of the entire operation of the Hydrocarbon Value Chain. This includes the identification of the different needs of the various relevant actors (regulators, operators, communities, etc.) in order to access reliable, timely and accurate information that allows stakeholders to make decisions to improve key sustainability indicators (for example, emissions, performance, social impact, etc.). This also implies basing all the key sustainability indicators so that we can measure the impact of any action in the future.

Currently there is little collaboration between PEMEX, CFE, the two productive entitites of the state, and industrial groups such as cement (e.g., CEMEX), chemical (e.g., CYDSA) and the steel sector and Mexican centers for energy innovation (CEMIES). Thus, encouraging collaboration among major carbon-intensive national industrial consortiums and new energy innovation research institutes as well as the initiative and projects as the ones proposed in this report is needed to create innovative business opportunities and actively participate in international EOR and CCUS projects.

6.3.3 Strategies

As climate change is a serious global threat, regardless of who produces the emissions, there are international mechanisms aimed at facilitating the means for the development of technologies for the mitigation of greenhouse gas emissions or its tracking, as is the case of CCUS. CCUS is a demanding technology with high costs, which is why it is necessary to link the Ministry of Finance and Public Credit from the beginning of its development. This is the reason why it is currently only carried out in developed countries. Even in these, the participation of research centers, industry, and international financial organizations is required with a focus on sustainability to continue the development of the concept. While, Mexico is already receiving some benefits from these mechanisms (e.g., World Bank and cooperation with international research centers), these are not enough. In addition to the need to improve in terms of sufficiency, they must be sustained for a few more years, as long as the price of carbon does not become more attractive or the costs of technological inputs of the CCUS or both decreases.

Perhaps one of the most important objectives of organizing the adoption of technology in the country, is to obtain recognition of the vital importance both by the treasury authorities, as well as by the congress to invest in carbon tech development such as CCUS. Achieving earmarked budgetary allocations to give certainty to the necessary flow of economic resources needed for such major investments would be key. Technical studies to justify these allocations are important.

In the case of public policies on the use and sequestration of CO_2. These will have the objective of guaranteeing the security framework of the use of technology, the sustainability of its development and the availability of economic resources that guarantee the fulfillment of the goals that are established.

6.3.4 Impacts on Research

National success and international leadership in the sustainability of the hydrocarbon value chain require investments in Research and Development for the creation of new businesses.

- Innovation in Research and Development for the exploration and sustainable production of hydrocarbons.
- Easy access to information from the oil and gas sector to identify opportunities.
- Create a culture of development of commercial opportunities to accelerate the development of carbon technologies.
- Create an ecosystem to support the expansion of carbon technology innovation, including collaboration with innovation centers such as Silicon Valley.
- Development of capacities in universities and governmental research laboratories for the innovation and commercialization of carbon tech.

6.3.5 Impacts on Technological Development

As an example, the CCUS (Carbon Capture, Use and Storage) technology is actually a set of technological applications with the purpose of reducing carbon emissions in the atmosphere, capturing CO_2 and storing it in the ground in a safe and permanent way.

The technology of CCUS will be implemented in the country sooner or later, however, it will be necessary to constitute a strategic center in innovation in the subject that allows to guarantee the technological independence as a means of improving the opportunity, the design, and the costs of construction and operation of CCUS infrastructure.

Additionally, there must be a plan that must be developed jointly with the two main CO_2 emitting industries (hydrocarbons and electricity generation), in order to increase the possibilities of making the geological carbon sequestration industry an economically viable industry. The generation of electricity as the main producer of CO_2 emissions, and the industry of the Improved Recovery of Hydrocarbons as the entity receiving the emissions of the electricity industry mainly, as well as our own. This iterative planning process should be developed and systematically reviewed as the basis for the optimization of the emission-capture-storage cycle that can be modified over time, in light of technological advances and the price of carbon, among other factors.

6.3.6 Impacts on the Human Resources Formation

Although there have been efforts to disseminate knowledge of the management and application of the CCUS, it is necessary to accelerate the dissemination of knowledge and skills through regular and postgraduate university programs as well as customized, executive programs on policy, technology and business management in CCUS and all other aspects of the hydrocarbon value chain. The programs of study of the professional careers of the necessary disciplines must be adapted to the Mexican and North American context. Moreover, the development of coordinated plans for research grants, scholarships for graduate studies, and capacity building through customized executive education to enhance the sustainability of the hydrocarbon value chain are an important investments Mexico will have to incur in the short term, in particular with international partners. For instance, in the medium and long-term, under the concept of train-the-trainers to support the proposed innovation implementation lab/knowledge exchange program here proposed can coordinate the efforts to create technical capacities for human resource development for applied research and technology commercialization for carbo tech innovation and smart digitalization for the hydrocarbon industry in Mexico identified here as a key national priority. Table 2 summarizes the National Priorities and actionable sub-prioirites in time.

Table 2: National Priorities for Policy and Technological Innovation in Carbon Tech

Priorities	Actionable Sub-priorities
Clean Economy-wide Policy Measures	• Policy design & analysis for low carbon transformation in the oil & gas industry • Cross-sectoral collaboration • Financing & climate risk management • Circular economy
Targeted "Transitional" Measures for New Tech	• CCUS
Regulatory Implementation and Permitting Measures	• regulatory options analysis
CarbonTech Innovation and R&D	• Innovation and R&D for sustainable hydrocarbon exploration and production • Accelerating clean innovation and tech deployment • R&D demonstration & commercialization of carbon tech solutions
Human Capital Development	• Human capital development • Deeply embedded safety and sustainability culture
Analysis for Policy Support	• Shared systems analysis • Smart infrastructure planning • Techno-economic and sustainability analysis to support policy development
Smart Systems	• Digitalization, deep learning for smart and cleaner hydrocarbon systems management • Sustainabilty indicators & baselining • Measurement, reporting & verification (MRV) • Deeply embedded data analytics

	• Cybersecurity for hydrocarbon value chain smart energy systems & MRV (e.g. carbon market reportin): analytics & forensics

Table 3: Implementation Timeline for Enhancing the Sustainablity of the Hydrocabon Value Chain

	Short-Term (1-3 years)	Mid-Term (4-10 years)	Long Term (>10 years)
Clean-Economy-wide Policy Measures	#Cross-sectorial collaboration #Project finance mechanisms #Integrated Systems Analysis	#Cross-sectorial collaboration #Project finance mechanisms #Integrated Systems Analysis	#Cross-sectorial collaboration #Integrated Systems Analysis
Targeted “Transitional” Measures for New Tech	#CCUS	#Carbon Tech #Materials	#Nano
Regulatory Implementation & Permitting Measures	#Regulatory Options Analysis	#Regulatory Options Analysis	
CarbonTech Innovation and R&D	#Innovation 1-3 #Demonstration & commercialization	#Innovation 1-3 #Demonstration & commercialization	#Innovation 1-3 #Demonstration & commercialization
Human Capital Development	#Ongoing needs assessment & Design	#Ongoing needs assessment & Design	#Ongoing needs assessment & Design
Analysis for Policy Support	#Cross-sectorial collaboration #Integrated Systems Analysis #Circular economy #infrastructure	#Cross-sectorial collaboration #Integrated Systems Analysis #Circular economy #infrastructure	#Cross-sectorial collaboration #Integrated Systems Analysis #Circular economy #infrastructure
Smart Systems	#MRV1-5 #Digitalization & AI #Cybersecurity	#MRV1-5 #Digitalization & AI #Cybersecurity	#MRV1-5 #Digitalization & AI #Cybersecurity

7 CONCLUSIONS

The creation of a binational knowledge exchange platform and/or innovation implementation lab between Mexico and Silicon Valley can support innovation, research and development (R&D) for a more sustainable hydrocarbon value chain (HCVC) in Mexico. The decarbonization of this industrial sector presents both policy and technological challenges and opportunities. New solutions and emerging technologies require integrated policy frameworks and planning, as well as cost-effective mechanisms such as economic incentives for their development, commercialization and deployment.

Mexico’s plan to invest in fostering innovation to fuel the sustainable transformation of the HCVC underpins decarbonization. Developing a culture of continuous improvement, as well as an integration of social dimensions throughout the HCVC promises to enhance economic efficiency and equity, as well as to minimize emissions and impacts to communities. Shared-resources and integrated systems analysis will allow policy makers, scientists and industry to provide more holistic solutions as the silos between energy, water, transport and other sectors of the economy disappear to better address climate risk while fostering clean, smart economic development.

This process requires enabling and developing enhanced human and institutional capacities to take advantage of cutting-edge technologies, innovative business models, and evolving and emerging social engagement and partnership models to maximize efficiency and productivity as well as risk management in this industrial sector. Clean innovation for more sustainable practices, frameworks, processes and products using carbon tech and combined digitalization & artificial intelligence approaches among other emerging technological solutions will ultimately allow Mexico and its HCVC advance its decarbonization and economic development goals.

8 REFERENCES

Arroyave Rojas, J.A., Garcés Giraldo, L.F. and Cruz Castellanos, A.F., 2006. Fotodegradación del pesticida Mertect empleando fotofenton con lámpara de luz ultravioleta. Revista Lasallista de Investigación, 3(2).

Chapman, J., & Gant, N. (2007). Chapter 1: Introduction. Designers, visionaries and other stories. A collection of sustainable design essays.

Cote, R., Tansey, J. and Dale, A., 2006. Industrial Ecology: A Question of Design.

McHarry, J., Strachan, J., Ayre, G. and Callway, R., 2005. WSSD: A Plain Language Version of the Johannesburg Plan of Implementation.

Parto, S. and Herbert-Copley, B. eds., 2007. Industrial innovation and environmental regulation: Developing workable solutions. IDRC.

9 APPENDICES

- Workshop program
- Delegates & Institutions Represented