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DEVELOPMENT OF A RESEARCH, DEVELOPMENT AND INNOVATION (R&D+I) ROADMAP FOR SECOND AND THIRD GENERATION BIOFUELS IN COLOMBIA

ATN/OC-10796-CO y ATN/KK- 10795-CO

Final Report
Executive Summary



Departamento Administrativo de Ciencia, Tecnología e
Innovación - COLCIENCIAS
Banco Interamericano de Desarrollo

September 2012

EXECUTIVE SUMMARY

1. The Administrative Department of Science, Technology and Innovation (COLCIENCIAS) has received financing from the Inter-American Development Bank (IDB) and the technical assistance of the Consortium Numark Associates Inc., (NUMARK), Universidad Nacional de Colombia (UNC), and Mitsubishi Research Institute (MRI) in the development of the Research, Development and Innovation (R&D+i) roadmap for second and third generation biofuels in Colombia. The objective of the study is to assist COLCIENCIAS and the Colombian Government in the definition of R&D+i policies, based on scientific and technological trends in the world and the country's potential to improve the long term competitiveness of the sector. To achieve the objectives the consortium assessed the global biofuels market; value chains, scientific, and technological trends; the scientific and technological capabilities of Colombia--in terms of infrastructure and human resources--for the development of second and third generation biofuels; and, international experience in promoting advanced biofuels. In the intermediate stage of the project, the priority areas for R&D were considered and discussed at an experts' workshop.

2. The areas where the work on advanced biofuels should be focused were selected on the basis of the attractiveness of the products for the country, available raw materials, and technology options. The selected ones were those where there is an internal or external market and that require a relatively short learning curve. The analysis of the global market biofuels showed that cellulosic ethanol, renewable diesel, and biobutanol have international market potential due to policies in U.S., European Union, and Japan related to energy security, climate change, and rural development. There is progress in R&D regarding to ethanol and renewable diesel in Colombia, and a potential market thanks to the national blending targets of biofuels. The conclusion is a focused effort on the short-to-medium term R&D programs in those products. The medium- to long-term should include bioethanol and biodiesel from algae and biocrudes.

3. Raw materials should be prioritized based on the greatest availability and fewest complex logistical barriers. This criterion is essential considering that the costs of raw material has a great impact on the overall production cost (between 30 and 40% approximately). Ideally, the raw material should be abundant, located in a relatively small area, and have homogeneous quality. The raw materials most relevant to Colombia from the point-of-view of availability would be the agricultural waste from sugar cane crops, sugarcane, coffee, rice, palm oil, as well as the municipal solid waste. Energy crops and algae could be considered in medium- and long-term, respectively. However, the identification and selection of most promising biomass sources for the country and the mechanisms to improve productivity is one of the priorities of the roadmap.

4. The main criteria for the selection of priority technological options is its readiness for the commercial stage to guarantee that R&D investments become cost-effective and allow for an efficient technology transfer. The processes of liquid biofuel production can be divided into three main areas: biochemical, thermochemical, and physicochemical processing. For products identified as priorities (ethanol and renewable diesel) the best new technologies are biological for ethanol and thermochemical for renewable diesel. The medium-term goal should be to produce biobutanol by biochemical pathway and renewable diesel and biojet by biochemical pathway. The long-term goal should be to produce ethanol and biodiesel from algae and biofuel by Fischer-Tropsch synthesis pathway.

5. Relating to specific R&D feedstock in the short-term (2012-2018) the Experts' Panel recommended first, the identification and selection of biomass sources; second, mechanisms to improve their productivity; third to fifth, identification, selection, and adaptation of biomass from other sources (municipal solid waste); sixth, the development of integrated models for the sustainable production of biomass-bioenergy; and finally, activities related to algae. For the medium-term (2019-2024) the experts recommended as a priority activity in the R&D plant biomass, the mechanisms for improving the productivity of biomass, and then the logistics and mechanisms to collect/adjust biomass sources to transformation processes. They are followed by the activities related to algae and the development of integrated models for the sustainable production of biomass-bioenergy. For the long-term (2025-2030) they recommend again as priority the R&D in plant biomass: mechanisms to improve the productivity of biomass. Second, mechanisms to collect/adjust biomass to conversion processes. Third and fifth place is for activities related to algae; and the fourth for plant biomass logistics. The development of integrated models for the sustainable production of biomass-bioenergy is ranked in the last place for the long-term.

6. Relating to transformation processes, the specialists recommended for the short-term, physical, chemical, and biological pretreatments to break down the lignocellulose structure; research in thermochemical technologies to obtain homogeneous raw materials to advance the new technologies; fermentation of lignocellulosic substrates, studying native strains and improving their fermentative capabilities by genetic engineering; evaluation and optimization of chemical processes for producing advanced biofuels and higher value-added products; and, assessing feasibility of co-processing with fossil fuels at petroleum refineries to integrate them to a process such as hydrotreating. In the medium-term, the specialists defined as priorities: laboratory, bench, and pilot plant testing for thermochemical processing; the assessment of pyrolysis processes, liquefaction to obtain homogeneous raw materials; the study of gasification and subsequent synthesis of fuels by biochemical or chemical conversion; chemical conversion of sugars and derivatives to hydrocarbons those related to algae and biorefineries. In the long-term the specialists recommended studies on processes integration and the chemical conversion of sugars and derivatives to hydrocarbons, evaluation and optimization of chemical processes for producing advanced biofuels and higher value-added products; and those related to algae and biorefineries.

7. Also, the Expert Panel recommended establishing the definition and uniform classification of advanced biofuels. The Consultant Group recommends adopting the definition of advanced biofuels as the second and third generation that meet the following characteristics: Second generation biofuels--those using non-traditional biochemical and thermochemical conversion processes and feedstocks mostly derived from lignocellulosic fractions for example, agricultural and forestry residues, municipal solid waste, etc. Third generation biofuels--those derived from feedstock such as algae and energy crops using advanced processes still under development.

8. The review of national R&D capabilities showed that there are several groups dedicated to researching advanced fuels issues, both public and private institutions, such as universities, but so far there have been no significant commercial results and no indicators for R&D. With the sole exception of Biocetano (Ecopetrol), there are no patents related to the topic and no standardized process for an advanced biofuels at a pilot plant scale production facility. In general, there is a high degree of dispersion within goals and a lack of awareness among the parties of the production chain.

9. The estimated human resource and training needs in terms of the number of PhD and Master's students required to generate a national impact in the R&D results was performed by consulting 35 research groups acknowledged by Colciencias in the biofuels area (8A1, 3A, 3B, 8C, 8D and 5 unclassified). The groups listed (44 percent) have research capabilities in raw material area, (46 percent) in transformation processes for second generation biofuels, (32 percent) in transformation processes for third generation biofuels, and (43 percent) in studies on the economic and environmental aspects. The groups indicated a significant need for human capacity-building/human resources training in all research areas. The 35 groups who participated in the survey would need 329 doctoral students and 504 Master's students per year, or an annual average of 9, 4 and 14, 4 PhD and MSc students per group respectively.

10. The Consultant Group recommends setting goals around the products that have a potential market, establishing mechanisms to facilitate interaction among researchers with common interests (e.g. annual symposia for project progress presentation), and enhance the research on advanced biofuels in Colombian graduate schools. It is recommended that the entire flow of information related to advanced biofuels should be channeled through COLCIENCIAS with the support of an Advisory Entity on Innovation for Advanced Biofuels (EAIBA) that will be tasked with strengthening and ensuring the successful implementation of the I&D roadmap, through the establishment of partnerships to implement advanced generation biofuel projects.

11. The roadmap proposed consists of the above-mentioned priorities (feedstock, products, and transformation processes) with specific targets regarding products (cellulosic ethanol and renewable diesel), a set of priority projects (first demonstrative and commercial plants in 2015 and 2018, respectively), specific R&D issues (identified in the expert workshop), financial strategies (sustained investments supported by local resources and international cooperation initiatives), and institutional strategies (agenda for monitoring and evaluating the implementation of the roadmap). The Figure 1 summarizes the proposed roadmap. The main technical targets are shown in Table 1.

12. Presuming that the three strategy priorities are adopted: hiring the EAIBA, assembly of first cellulosic ethanol facility, and early adoption of measures designed to support the goals of medium- and long-term, it is estimated that three strategy priorities will require an investment of US\$ 12 million between 2013 and 2018. The consultant group proposes that in the next five years COLCIENCIAS distribute the budget for R&D biofuels as follows: 70% for short-term priorities, 20% for medium-term priorities, and 10% to priorities throughout term. Regarding the two products of short-term (cellulosic ethanol and renewable diesel) the consulting group recommends that financial resources be provided for the development of a cellulosic ethanol facility. In the case of renewable diesel, as the main beneficiary would be Ecopetrol, which does not require COLCIENCIAS financial support, it is recommended that most support will be provided through institutional and policy framework.

13. Additional resources and experience can be achieved through three types of alliances with international partners: government initiatives, private companies, and universities or R&D centers. For external government initiatives the consulting group recommends the Biomass Program of the Department of Energy of the United States (DOE), the Seventh Framework Programme for Research and Technological Development of the European Union (FP7), the Alliance for Science and Technology for Sustainable Development (SATREPS) of Japan, and multilateral institutions to support development (e.g. IDB). The report lists 50 private companies and a large group of experienced foreign universities and projects in the area. Investment projects to be promoted with these entities are the first

pilot/demonstration plant for cellulosic ethanol using the biochemical route by 2015, with a capacity of 1000-2000 L/day, the first cellulosic ethanol commercial plant in 2018, and the production of renewable diesel by hydro-treating using the process developed by Ecopetrol.

Table 1. Priorities and technical target of roadmap for different scenarios

Priorities	Technical targets
<p>Short term</p> <ul style="list-style-type: none"> • Cellulosic ethanol production by biochemical pathway • Renewable Diesel production by hydro-treatment 	<ul style="list-style-type: none"> • First demonstrative cellulosic ethanol facility by biochemical pathway in 2015 with 1000-2000 L/day capacity • First operating demonstrative cellulosic ethanol facility in 2018 • Renewable Diesel production by hydro-treatment pathway (patented by Ecopetrol)
<p>Mid term</p> <ul style="list-style-type: none"> • Biobutanol production by biochemical pathway • Renewable Diesel and biojet by biochemical pathway • Biofuels production by Fischer – Tropsch synthesis 	<ul style="list-style-type: none"> • Support three projects (one in each area) aims to develop each of these technologies at bench scale for 2018. Projects must take into account the priorities of feedstocks recommended in this study and solving technological challenges recommended by experts during the workshop, mainly by adapting existing technologies
<p>Long term</p> <ul style="list-style-type: none"> • Ethanol and biodiesel from algae • Biocrude by pyrolysis 	<ul style="list-style-type: none"> • Support the training of 10 doctors (5 in each area by 2016) at leading academic centers in R&D in these areas so they can act as future leaders, negotiators and adapters of these technologies.

14. In order to successfully implement the roadmap, the consulting group recommends encouraging public-private & researcher partnerships to allow priority programs identified in the report to begin to be implemented. Colombia has a clear delineation of property rights, land acquisition, equipment, and assets for the production of biofuels, which can generate confidence in investors. As an instrument to achieve truly interdisciplinary work that promotes training, it is recommended that criteria for beneficiaries' selection of projects financed by COLCIENCIAS encourages the participation of consortiums formed by at least one local university, an international college, a company or local entity related to biofuels and at least an international company leader in biofuels technology development.

15. In joint R&D development with countries or companies leading biofuels technology developments as well as in the search for international investors, it is necessary that when entering into an agreement, parties take into account the provisions of the Free Trade Agreements (FTA) signed by Colombia in recent years, particularly in relation to the area of intellectual property. Overall, the agreements with the U.S. and the European Union contain principles in defense of intellectual property and ensure the protection of trademarks, designation of origin, and industrial and commercial secrets. The FTAs make references to patents and agreements, adequate and effective protection of intellectual property rights, and sets out the theme of promoting innovation and technological development opportunities to foster cooperation in science and technology. These general guidelines serve as a good

framework, but specific issues must be specified jointly by researchers before initiating cooperative projects, and the extent of other issues not covered by trade agreements.

16. Colombia has developed an aggressive policy to promote first generation biofuels, establishing technical standards such as the quality of biofuels, the percentage of blended fuel with oil and diesel, and a clear definition of the pricing structure and incentives for biofuels to promote the development of a domestic market. There is already experience in establishing mechanisms to promote biofuels market, which can be adjusted to encourage the market for advanced biofuels. Additionally, the National Development Plan 2010-2014 has identified some strategic guidelines to stimulate innovation as a vehicle to achieve sustainable growth and competitiveness; including knowledge and innovation, entrepreneurship, intellectual property and promoting competition in markets. The intention is to assure tax benefits on science, technology, and innovation activities. Moreover, a seed capital fund was established by the Development Unit of Bancóldex to foster a competitive biofuels industry. The Tax Statute (2011) includes some articles that may benefit this market.

17. It is recommended that COLCIENCIAS widely disseminates the results of this study within the community and promotes the national and international portfolio of research and development projects to encourage future investment in advanced biofuels. The main objectives of the promotional plan are:

- Raise awareness in the country on the initiative for creating a market on the sustainable production of second and third generation biofuels Promote the participation of universities and research centers in the R&D activities related to the priority areas identified for the development of second and third generation biofuels
- Invite potential investors to participate in the creation of partnerships with Colciencias, universities, and research centers to develop second and third generation biofuels. The aim is to explain the competitive advantages of the advanced biofuels and therefore the benefits of participating in the market at early stage.
- Share the opportunities for supporting the Plan with biofuels experts and consulting firms as well as the different options for the production of advanced biofuels.

18. The overall agenda recommended to COLCIENCIAS for the successful implementation of the roadmaps is as follows:

- Appoint the Coordinator of the Advanced Biofuels Program within COLCIENCIAS to lead the development of the roadmap
- Hiring the services of the EAIBA to support the development of the roadmap
- Preparation of the terms of reference (ToR), by EAIBA, and EAIBA-COLCIENCIAS selection of the consortium that will implement the pilot plant for cellulosic ethanol
- Development of the promotional plan
- Monitoring and tracking the progress of the roadmap

Figure 1. Summary of Proposed Roadmap

	Short Term 2012-2018	Mid Term 2019-2024	Long Term 2025-2030
Products	Cellulosic Ethanol (BP)	Biobutanol (BP)	Ethanol and biodiesel (Algae)
	Renewable Diesel (HDRD)	Renewable Diesel and biojet (BP)	Bio crude (Pyrolysis)
Technical trends	First demonstrative cellulosic ethanol facility in 2015, with a capacity of 1000-2000 l/day	Biofuel (Fischer –Tropsch synthesis)	
	First operating commercial cellulosic ethanol facility in 2018		
	Renewable Diesel production (patented by Ecopetrol)	Developing at bench scale and adapting existing technologies (biobutanol and algae)	
	Training leaders (PhD) with capacity to negotiate and adapt technologies (biobutanol and algae)		
R&D Feedstock	VB: Identification and selection of biomass sources		
		VB: Mechanisms to improve productivity	
		VB other sources: Logistics and mechanisms to collect / suit transformation processes	
R&D Transformation processes	BP: physical, chemical and biological Pretreatments of lignocellulosic material		Activities related to algae
	TP: Thermochemical technologies assessment (pyrolysis and liquefaction) at laboratory, bench and pilot plant.		BP: Process Integration Studies
		TP: Gasification processes analysis and chemical / biochemical conversion at laboratory, bench and pilot plant	
	BP: native strains improvement and genetic analysis for fermentation of lignocellulosic hydrolysates.	BP: Chemical conversion of sugars and oil derivatives	
	FP: Evaluation of chemical processes and optimization for producing advanced biofuels and higher value-added products		FP: Evaluation of chemical processes and optimization for producing advanced biofuels and higher value-added products
	FP: feasibility study for the co-processing fossil fuels with biomass (by hydro-treating)		Algae and biorefineries.