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The current status of liquid biofuels in Chile

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ABSTRACT

Chile depends on foreign sources for energy. A solution for this problem is needed to guarantee stability and economic development. Public policies have been proposed involving diversification of the power matrix with an increasing share for Non-conventional Renewable Energies (NCRE) from unconventional resources in the medium- and long-term. In this framework, new funding strategies are fundamental to encourage applied research in this field. Main research subjects are considered: survey, quantification and characterization of raw materials, introduction of energy crops and studies focused on transportation, management and conversion of lignocellulose for the second-generation biofuel industry. A recent regulatory framework allows the substitution of 2 or 5% of gasoline and diesel by ethanol and biodiesel, respectively; however, this is not mandatory because biofuel supply is still non-secured. On the other hand, the scenario for private initiatives focused on first-generation biofuels is not promising, and this may continue in time depending on the price of imported biofuels and local production costs. In 2015, production of second-generation biodiesel in Chile should be fundamentally based on forestry residues using Fischer–Tropsch processes. Local efforts consider biochemical transformation of lignocelluloses including agricultural wastes. Our group is focused on optimization of local second-generation bioethanol production; preliminary results are presented here.

1. Chilean scenario in the global context, some particular characteristics

At a worldwide level, energy demand grows constantly [1], and there is a progressive exhaustion of fossil and non-renewable energy sources [2]. Oil, natural gas and coal reserves are, hence, deemed to be enough for 41, 64 and 167 years, respectively [3]. According to [4], the Reserve/Consumption ratio is kept constant and, therefore, other alternative sources such as tar sands and oil shales could be able to meet future demand. However, the energy released from fossil fuels evolves gases that contribute to the greenhouse effect. Therefore, one of the greatest challenges for our society in the future is to meet the growing demand of energy and supply of raw materials for the industry in a sustainable manner [5]. According to [4], the "Living planet index (LPI)" is estimated to have declined about 30% since 1970, and the "Ecological Footprint" to have increased by 70% in the same period: so it seems the world is running out of environment much faster than out of resources. It is highly inadvisable, and unlikely, that energy resources, conversion and consumption will continue to be developed unsustainably. Sustainability is just emerging as a science, and must be developed and applied urgently.

In Chile, there is a huge dependence on energy sources (oil and natural gas) and their demand is satisfied by 98 and 90%, respectively, with foreign supplies [6]. Thus, the Chilean energy matrix is mainly based on oil with 40%, followed by natural gas with 24% (see Fig. 1).

More than two-thirds of the primary energy is imported (see Fig. 2). Therefore, the country is very dependent on foreign supplies and subjected to oil price fluctuations, compromising its development.

This dependence has given rise to exploration and assessment of new energy sources, the availability of which could be guaranteed. Simultaneously, such sources must have minor environmental impacts. An alternative for this challenge is Non-conventional Renewable Energy (NCRE), the adoption of which implies diversifying the energy matrix.

To meet these challenges, the use of biofuels such as bioethanol, biodiesel and biogas becomes a promising alternative that reduces the oil dependence and contributes to decrease the greenhouse effect [7,8]. The land available to produce plant biomass and the conversion efficiency of solar energy into plant tissues are the only restrictive factors for biofuel production [5].

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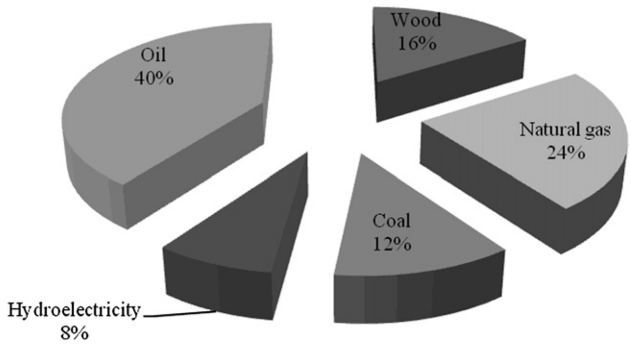

Fig. 1. Domestic energy matrix as at 2006.

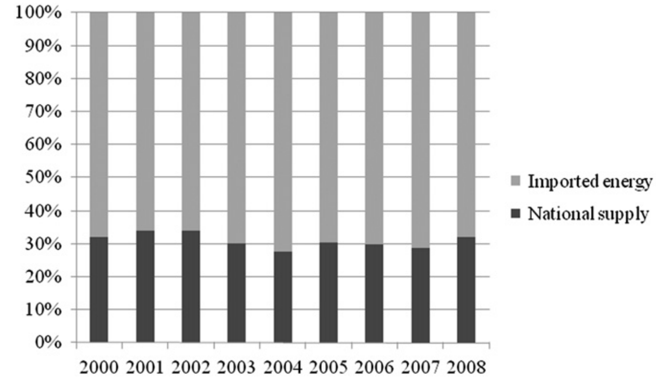

Fig. 3. Energy dependence of Chile for period 2000–2008.

1.1. Transport power matrix

Chile has a strong and constant dependence on foreign sources. This situation has become more critical in recent years. According to the information published by the National Commission of Energy (CNE) for 2008, around 70% of the net energy consumed by all sectors is imported (see Fig. 3). This situation apparently will not change significantly in the next five years.

Table 1 shows the last national balance of energy available. Strong dependence on foreign sources is verified with its analysis.

This dependence is even more serious for transport, as shown in Fig. 4. About 99% of the energy consumed comes from oil-based products such as diesel, gasoline, kerosene, aviation kerosene and liquefied gas, produced in the country by refining crude oil, 99% of which is imported.

Other economic sectors, such as industrial, mining, public, commercial, energetic, and residential, also consume oil-derived fuels. The transport sector accounts for 63.5% of total consumption of such derived products [9].

Table 2 shows the transport sector share for 2008. The road transport subsector is shown separately for sea, air, and railway due to its importance as liquid fuel consumer agents.

1.2. Raw materials for liquid biofuel production

Agriculture in Chile exhibits very high yields for some crops as a response to technological developments. For example, sugar beet yields are the highest in the world and they have the highest sugar contents; in consequence, this crop could be considered as an alternative raw material to obtain bioethanol. Similarly, the average yield of rapeseed-derived oil for biodiesel production is above the world average. The same can be observed for Chilean corn and white wheat, with yields over those achieved in USA and Argentina, the major producers of these crops in the world, respectively [10]. Nevertheless, the scarcity of agricultural soils for biofuel production is an important restriction that the country faces [6]. A very similar scenario is present in other countries, such as Germany [11].

Out of the 75,707,366 ha of continental territorial land area, only 34.9% are considered to be agricultural soils. They are distributed as indicated in Table 3 [12].

Considering the continental surface, only 5,000,000 ha are arable and most of them with important restrictions due to depth, stoniness or slope [13]. Such area is somewhat larger than the one stated by Gajardo in his vegetation classification [14], where the soils intended for intensive agriculture corresponds to 3,556,250 ha, equivalent to only 4.7% of the territory. In addition to scarce land availability, biofuel-oriented crops would be fully competing with food production activities. According to the document prepared by the Bioenergy Unit of the Office of Agricultural Studies and Policies (ODEPA), belonging to the Ministry of Agriculture [10], a major part of the soils available for rice, corn and wheat cropping are already being used in the production of those same grains, but with a different purpose; to get food. Table 4 shows the expansion capacity of the most suitable crops to generate the raw materials used to produce first-generation biofuels in Chile. From these data it can be inferred that the availability of potential lands to produce grains and starches for bioenergy purposes is very low.

1.2.1. Bioethanol

Brazil, a great bioethanol producer, uses mainly sugarcane as raw material; however, it is not viable to plant sugarcane in Chile. First-generation bioethanol could be obtained from some crops that normally grow very well under local conditions, such as sugar beet, wheat, corn or rice. Table 4 shows the surface currently used and the maximum available to cultivate these species. The agricultural soils with capability to produce biofuels, by region and species, are shown in Table 5. This table has been built using the

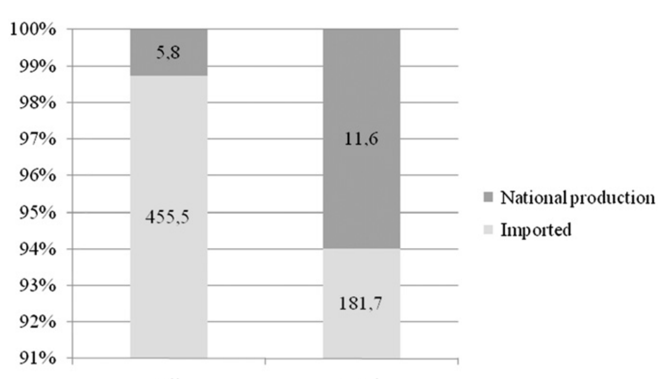

Fig. 2. Foreign dependence in the energy matrix, amounts have been expressed as PJ.

Table 1
Chilean balance of energy for 2008.

Energy source	Production (PJ)	Import (PJ)
Crude oil	5.85	455.55
Natural gas	82.46	30.51
Coal	11.58	181.71
Hydroelectricity	89.99	0
Wind energy	0.14	
Wood and other	214.24	0
Biogas	0	0
Total	404.26	667.77

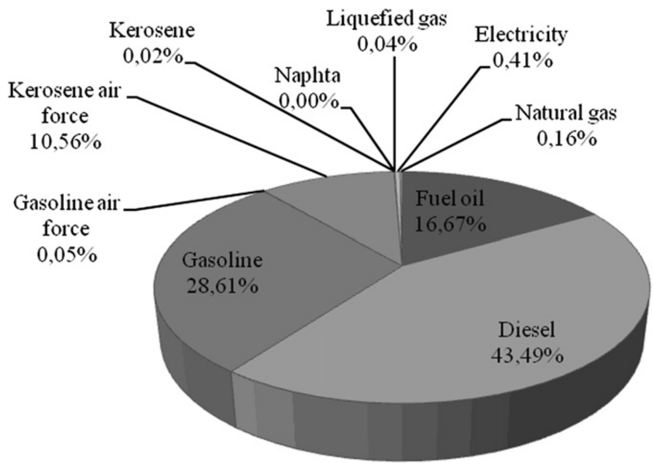

Fig. 4. Consumption structure of fuels for Chilean transport sector.

data of the VII Agricultural and Forestry Survey 2006–2007 [15]. From these data it can be inferred that is not feasible to produce bioethanol considering the potential expansion of the currently cropped soils. This fact establishes an important difference compared to other countries with a similar level of development of the bioenergy industry to that of Chile. In Argentina, for example, the development project for first-generation bioethanol production is based on sugarcane and, more recently, corn. With these crops, 350,000 m^3 of bioethanol production have been forecasted for 2010, well above the 200,000 m^3 deemed as necessary to substitute 5% of the domestic gasoline consumption per year, so that this surplus could go to the export market [16]. The difference is mainly due to the large quantity of cultivatable land that is available in Argentina, enabling them to produce more than the domestic sugar and grain demands.

1.2.2. Biodiesel

Its production based on transesterification of vegetable oils seems to be in a more favourable situation than the one described for bioethanol. Although there could be competition for soils intended for food production, the data in Table 4 shows greater availability of soils than what is feasible to be used for that purpose, at least for rapeseed and sunflower, the two major species suitable for Chilean edaphic and climatic conditions. Both crops were analyzed in the study published by the Advanced Centre for Agricultural Technologies (CATA) [17], where they state that 5% of diesel demands (242,000 m^3) could be supplied through domestic production, basically from rapeseed if new soils are cultivated.

The possibilities to develop the bioethanol and first-generation biodiesel industry in Chile are restricted to land availability. However, the country has 13,400,000 ha of native forests, from which about 5,000,000 ha are productive and with possibilities to be managed [10]. Furthermore, about 2,200,000 ha of industrial forestry plantations must be added, which are able to sustainably generate a substantial biomass amount feasible to be used for energetic purposes [10]. In addition to these existing forestry resources, Chile has an estimated area of 3,000,000 ha suitable for forestry but still not covered with forests. This area could be planted with the most suitable species to obtain lignocellulosic biomass for bioenergy purposes, and then it could be incorporated to forestry production, a strategic field where the country has natural advantages.

From a worldwide perspective, it is expected that a wider range of biomass resources can be used for these so-called second-generation biofuels, including agricultural and forestry residues. Chile, like other countries [18,19], is not outside this trend, especially considering the apparent advantages: no competition with food production, higher reduction of greenhouse gas emissions, and the availability of these resources in Chile. A similar scenario can be found in other countries, such as Sweden [20] or Finland [21].

Currently, the forestry sector is a major supplier of power to the country matrix with the use of wood, sawdust and other residues in sawmills and pulp mills, accounting for 14% of domestic consumption [9]. This input has increased up to 19% [22], that is above the 14% world average [23]. However, the amount and location of residual biomass produced are still unclear.

Residues generated by the sawmill industry, associated to pine plantations only, are estimated to be 1,400,000 m^3 [24]. The volume corresponding to residues generated from productive native forest management should be added to this amount, which on a conservative basis is estimated to be around 7,000,000 tonnes/year. Therefore, Chile has a forestry biomass usage potential that could even increase, in contrast to countries in Asia [23,25]. All this

Table 2
Consumption of fuels by transport sector in 2008.

Fuel type	Unit	Road	Railway sea air	Total
Fuel oil	Thousand m^3	0	1427	1428
Diesel	Thousand m^3	3823	449	4272
Gasoline 93 octane	Thousand m^3	3141	6	3147
Air force gasoline	Thousand m^3	0	6	6
Air force kerosene	Thousand m^3	0	1057	1057
Kerosene	Thousand m^3	1	0	2
Liquefied gas	Thousand tonnes	3	0	3
Electricity	GW/hour	373	53	426
Natural gas	Million m^3	15	0	15

Source: [9].

Table 3
Use of soils in Chile.

Use type	Use	Land capability[a]	Surface (hectares)	Percentage (%)
Agricultural arable lands	Without restrictions	I	90,846	0.1
		II	711,625	0.9
	With restrictions	III	2,195,439	2.9
		IV	2,273,670	3.0
Non arable agricultural lands	Cattle	V	2,271,144	3.0
	Cattle-Forestry	VI	6,510,613	8.6
	Forests	VII	12,339,882	16.3
Non agricultural lands	Conservation	VIII	14,200,000	18.8
	Unproductive lands		35,114,147	46.4
	Total		75,707,366	100,0

[a] Land capability categories defined by the United States Department of Agriculture.

Table 4
Potential sown surface (in ha) for each of the most promising and feasible crops to be used to obtain raw materials for biofuels.

Crop specie	Cropped surface 2006/2007	Maximum available surface[a]	Potential available surface
Sugarbeet *(B. vulgaris)*	22,750	50,000	27,250
Wheat *(T. aestivum)*	282,400	315,000	32,600
Corn *(Z. mays)*	134,930	150,000	15,070
Rice (*O. sativa*)	26,530	29,500	2970
Potato *(S. tuberosum)*	63,910	65,000[b]	1090
Sunflower *(H. annuus)*	2680	90,000	87,320
Rapeseed *(B. napus)*	16,650	235,000	218,350

[a] Maximum existing surface for analyzed annual rotating crops (ha). Source: [17].
[b] The authors' estimation corresponds to the historical maximum for the last eight years, according to ODEPA.

Table 5
Cropped surfaces (in hectares) with species potentially used for producing biofuels based on first-generation technologies by Regions of Chile.

Crop	Regions															Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	RM	XIV	XV	
Rice						1263	17,336	4147	0	0	0	0	0	0	0	22,746
Oat	1	0	20	29	484	897	1290	20,037	48,290	6273	335		141	3956		81,752
Barley		1	6	509	190	256	183	1516	1711	792	91	15	115	1100		12,016
Rye		2	0	3	14	247	428	352	413	81			78	66		1684
Corn	1	153	189	662	1133	47,245	29,407	12,030	691				11,918		6	103,435
Potato	94	5	263	3237	2186	1689	3342	8293	14,029	11,154	185	133	5189	3957	24	53,780
White wheat	1	18	21	1149	2030	5220	22,781	67,743	93,652	11,389	22		1320	14,418		219,763
Durum wheat	0	2	24	609	329	2249	1320	2806	1090		1		2185		2	10,617
Triticale	1					215	49	2778	16,083	405			30	364		19,924
Castor plant			1													1
Jojoba			313	152											0	465
Flaxseed									56							56
Sunflower		0			0	123	100	160	173				1			558
Rapeseed					276		141	3489	6536	150			5	716		11,312
Sugarbeet					52	576	5222	12,740	976	83			34	1233		20,915
Soy													0			0
Olive	21	12	3326	2005	1494	2362	3496	813	74	0	0	0	1404		1513	16,520

biomass could be supplied to local companies dealing with second-generation biofuel production, being this one of the goals clearly stated by national authorities [10,26].

1.3. Biofuel legislation

In general terms, biofuel regulations are recent in Chile, and they are basically an adaptation of the regulatory framework currently applied on fossil fuels used in the transport sector. However, there are some initiatives, such as tax exemption, that may help to encourage the use of this new type of supplies. This is similar to the strategies initially implemented in other countries like Germany [11]. Besides tax exemption, other considerations must include the effect from: the capability to adopt, adapt and absorb technological options; availability of adequate information to assess the needs; proper institutional facilities for spreading information; options to access funding; subsidies; motivation and incentives [8,25], among other items previously analyzed. Nevertheless, issuing regulatory instruments is the first step for the adoption of biofuels. For example, countries like Brazil, Canada, Colombia, the European Union, India, Malaysia, the Philippines, Thailand, and the United States, have all set targets —some of them mandatory— to increase the contribution of biofuels to their transport fuel supplies [27]. Regarding the 27 countries of the European Community, there is an agreement establishing that 10% of transport fuel should originate from renewable sources by 2020 [28].

The set of regulatory instruments described below has been established in Chile:

Chilean Standard 59 (NCh 59) provides definitions for oil, diesel, gasoline, and additives. From this point of view, in spite of the fact that the authorized percentages of biofuels (bioethanol and biodiesel) are small, they are not regarded as additives even though they are just a small proportion of the mixes.

Furthermore, there are legal and regulatory provisions tangentially related to liquid biofuels. For example, there is a special tax that can be applied to the first sale or import of automobile gasoline and diesel oil [29]. Such tax is refunded when the domestic companies levied with the Value-added tax (IVA) use the oil for production, in accordance to the decree established by the Ministry of Finance [30].

A law published in 1991 [31] sets forth the creation of a Price Stabilization Fund for Oil (FEPCO) in order to soften the fluctuations of oil prices and their derivatives in the domestic market. Subsequently, in 2000 the Ministry of Mining, through a decree, approved the establishment of the systems designed to apply taxes intended to maintain the FEPCO for: automobile gasoline, home kerosene, diesel oil, combustible oils, and liquefied gas [32]. In 2006, the enforcement of the latter law was extended, setting specific rules for the price stabilization of automobile gasoline, diesel oil, and home kerosene [33].

None of the aforementioned regulatory documents covers the inclusion of biodiesel and bioethanol. The latter substance in its pure state is a component of some beverages, and for this reason it could be subject to specific regulations. In 1974, an extra tax was levied on alcoholic beverages, to be paid additionally to IVA [34]. However, the ethanol used as fuel is not a pure substance, since its use requires the addition of denaturing substances authorized by the relevant authority, in this case, the Livestock and Agricultural Service (SAG) [35].

Considering the previous references, the taxation treatment of biofuels shows some specific characteristics, such as: (a) They are levied with IVA; (b) Biodiesel and bioethanol are not levied with the special tax applied to the first sale or import of automobile gasoline and diesel oil, pursuant to Law 18,502, since they do not fit in the definition from a strictly chemical point of view, according to which biodiesel is produced using vegetable or animal oils and fats, and contains a mixture of alkyl esters. Bioethanol, on the other hand, is an ethylic alcohol produced through the fermentation of certain agricultural products and not a volatile hydrocarbon; (c) They are not subject to taxes intended to stabilize fuel prices; (d) When mixed with conventional sources in percentages defined by the current regulatory framework, they lead to a decrease of the tax in equal percentage that is applied in the mixture and, therefore, only the percentage corresponding to biofuels is not levied with special taxes, except for the IVA.

In 2008, the Ministry of Economy approved the definitions and quality specifications for production, import, transport, storage, distribution and marketing of bioethanol and biodiesel in the country, both for imported and domestic products [35]. Subsequently, the Superintendence of Electricity and Fuels (SEC) established the technical regulation protocols for analysis and/or tests of bioethanol and biodiesel [36].

A summary of the specifications and methodologies applied is provided in Tables 6 and 7. These tables refer to pure biofuels. On the other hand, mixed products must comply with the required quality of fossil fuels. The authorized mixtures are: bioethanol–gasoline at 2 and 5% of total volume and biodiesel–oil in the same proportions. There are no parameters for quality and methodologies to be applied to second-generation diesel.

Table 6
Parameters of quality for bioethanol and methodologies used for its determination.

Property	Unit	Values		Technical Standard
		Minimum	Maximum	
Ethanol content	% vol.	92.1		ASTM D 5501
Methanol content	% vol.		0.5	ASTM D 5501
Rubber washed	mg/100 ml		5.0	NCh 1844
Water content	% vol.		1.0	ASTM E 203 or E 1064
Denaturalizing content	% vol.	1.96	5.0	NBR 13993
Inorganic chlorine	mg/L		32	ASTM D 512
Copper	mg/kg		0.1	ASTM D 1688
Acidity (as acetic acid)	mg/L		56	ASTM D 1613
pH	pH	6.5	9.0	ASTM D 6423
Sulphur	% weight		0.003	NCh 1896 or 2325
Sulphates	ppm		4	ASTM D 4806
Appearance	Visually free of sediment and suspended material. Bright and clear at room temperature or 21 °C			Visual inspection

2. Current ongoing initiatives

Nowadays, there are no plants in Chile dealing with the production of biofuels in operative phase. The non-mandatory use of mixed fuels or the partial replacement of fossil fuels with biofuels could be responsible for this situation, as well as the inexistence of subsidies encouraging the generation of raw materials intended for biofuels production. However, the Environmental Impact Evaluation System (SEIA), managed by the National Commission of Environment (CONAMA) has approved a project entitled "Preparation of methyl ester," which is focused on the construction and operation of a plant intended to produce methyl ester from plant-derived oils and discarded materials, i.e. ex fries.

The plant belongs to FAME Ltda. and is located in Santiago, Metropolitan Region. The total investment is 210,000 dollars, with an estimated useful life of 15 years. The methyl ester generated will be used as a carrier for fungicides, while the glycerine will be delivered to the chemical industry and soap manufacturers. The estimated production capability is 4 m^3/day.

There are other two projects that have been submitted to SEIA to be qualified.

The first one entitled "Processing of used oils for biodiesel production" consists basically in the modification and adaptation of a previously existing facility in order to produce biodiesel through transesterification of fats and oils with methanol under the presence of sodium hydroxide as catalyst. The plant belongs to Biodiesel Chile Inc. and would be located in Cerrillos, Metropolitan Region. The investment is 50,000 dollars, with a useful life have not defined yet. The production capability of the plant is 20 m^3/day and the product will be sold in the internal market.

A second similar project called "Plant for biodiesel production" belongs to Comercial Bio-Diesel Chile Ltda. This project will be located in La Granja, Santiago. The investment is 55,000 dollars with a lifetime of 20 years. The project would start producing 50 m^3 of biodiesel per month supplying the national demand. The Company is currently supporting the development of energy crops such as castor plant (*Ricinus communis*) in the north of the country.

The Fund for the Promotion of Scientific and Technological Development (FONDEF) belonging to the National Commission for Scientific and Technological Research (CONICYT), has supported three projects focused on biodiesel production, two of them considering the partial implementation of pilot plants. Preliminary results of the project entitled "Optimization and biotechnological improvement of conditions for cultivation of green microalgae *Botry ococcus* Braunii to obtain biohydrocarbons" have demonstrated the utility of photo-bio-reactors with a capacity of 1 m^3 approximately. An associated company located in La Tirana in the Tarapacá Region has begun testing larger scale reactors 6 m^3, yielding 0.05 L of biodiesel from 1 kg of microalgae dry basis (Mariella Rivas, Project Director, personal communication).

In the project entitled "Utilization of *Brassica napus* to produce biodiesel: process development and optimization," the pilot plant uses rapeseed as raw material, reaching 210,000 kg of biodiesel per year (Robinson Betancourt, Project Director, personal communication).

Regarding first-generation bioethanol, a company called Ethanol of the South Pacific Inc. was established by a consortium that involves 150 medium-sized farmers dealing with corn production. They cover more than 8000 ha in the locality of Las Cabras in the VI Region. They plan to build an ethanol plant with an investment of 25,000,000 dollars and an estimated production up to 110,000 m^3/year using 90,000,000 kg of maize (Francisco Armijo, Manager of the South Pacific Ethanol Inc., personal communication). Simultaneously, refined foods would be produced from the proteins, fibres, oils and carbon dioxide that are generated during the process. The total volume of food adds up to 170,000,000 kg and represents about 70% of the total amount of processed corn. They have also established a partnership with the Canadian company Energy Quest to implement a plant that will produce second-generation diesel using residues derived from corn, the investment should reach 32,000,000 dollars. Raw materials would be supplied by farmers and the technology would be provided by Energy Quest.

Table 7
Parameters of quality for biodiesel and methodologies used for its determination.

Property	Unit of measure	Values		Technical Standard
		Minimum	Maximum	
Density at 15 °C	g/cm^3	0.86	0.9	NCh 822
Viscosity at 40 °C	mm^2/s	3.5	5.0	NCh 1950
Flashpoint	°C	120		NCh 69
Runoff point	°C		−1	NCh 1983
Total sulphur	% weight		0.005	NCh 2325
C. residues Conradson at 100%	% weight		0.05	ASTM D 4530
Sulphated ash content	% weight		0.02	ISO 3987
Water and sediments	% volume		0.05	NCh 1982
Corrosion of copper foil	Corrosion degree		N°2	NCh 70
Neutralization value	mg KOH/g sample		0.5	EN 14104
Esther content	% weight	96.5		EN 14103
Methanol content	% weight		0.20	EN 14110
Free glycerol	% weight		0.02	EN 14105
Total glycerol	% weight		0.25	EN 14105
Phosphorus	mg/kg		10	ASTM D 5185
Alkali content (Na + K)	mg/kg		5	EN 14108
Metals (Ca + Mg) content	mg/kg		5	ASTM D 5185
Oxidation stability at 110 °C	hours	6		EN 14112
Monoglycerides				EN 14112
Di and triglycerides				EN 14105
Clouding point				ASTM D 2500 or NCh 2296

3. Short-, medium- and long-term perspectives

As mentioned above, Chile does not have enough arable lands to establish crops with bioenergy potential; it would imply a competition for lands used for food production. Furthermore, there is also a strong need to reach energy independence ensuring stability and economic development for the different sectors.

Under this difficult scenario, the country has proposed the development of policies involving the diversification of the power matrix [10], based on an increasing share of NCRE and including those derived from biomass conversion. The use of these new sources should be encouraged in the medium- and long-term; one possibility is through the implementation of energy crops with new species in marginal lands, in order to avoid competing with food production. A response to this challenge has been proposed by the project "Value enhancement of fiscal land and marginal soils by means of bioenergy crop development," funded by Innova Chile, seeking to identify 25 crops with the highest agricultural energy potential, determine the area of feasibility to be developed and assess their economic, environmental and social viability, among other aims. To achieve this, agroclimatic cartography will be generated to be combined in an information system with other variables currently available. This system will enable the evaluation of suitability for energy crop development. Besides, the cartography will remain available for other potential uses (Manuel Paneque, personal communication). To reach these goals, a special Commission was created to study topics related to biofuels in order to advise the different actors that are involved, giving directions, supplying strategic orientations and providing support to implement these new policies.

Currently, there are some projects being funded and consortia being established involving the participation of companies and some technological entities to carry out specific research about these topics. Examples include: the creation of an agricultural and forest resource registry; the introduction of suitable species to implement energy crops or plantations, both agricultural (*Jatropha curcas*) and forestry (*Salix* spp., *Populus* spp.), among others.

The Innova Chile Committee, belonging to the Corporation for Production Development (CORFO) and managed by the Ministry of Economy, is presently financing two business-oriented consortia focused on research and development of biofuels derived from conversion of lignocelluloses and other three intended to research biofuel production from algae.

The first one, called BIOCOMSA Inc. is intended to improve the country's competitiveness developing the basis for second-generation diesel production through the implementation of 8 subprojects that include from characterization and quantification of potentially available raw materials; forest resource prospection; management and transport of raw materials, up to processes that involve the treatment of lignocellulosic complexes to get their optimal yields of syngas and biofuels as final products. The total funds for this consortium are 3,360,000 dollars, including participation of National Oil Refinery (ENAP), the Wood Consortium and the Universidad de Chile.

A second consortium, called BIOENERCEL S.A. has been created in order to develop, capture and adapt technologies and develop human resources capable of implementing the national industry to produce biofuels. This would be based on biochemical and thermochemical conversion of lignocellulose, generating bioethanol and second-generation biodiesel, respectively. The research and development programme is focused on two projects: biomass and bioprocesses. The biomass project will address the generation of raw materials including forestry residues and the development of energy crops; the bioprocesses project will be focused on the production of bioethanol from biomass and their value-added by-products. The total funds for this consortium are 9,110,000 dollars, including participation of Universidad de Concepción, Pontificia Universidad Católica de Valparaíso, Fundación Chile, Arauco, Paper and Board Manufacturing Company (CMPC) and Wood Panel Manufacturing Company (MASISA).

A third consortium named "Algafuels: technological entrepreneur consortium for biofuels from microalgae in the northern regions of Chile" submitted by the company BIOSCAN S.A., has been granted funds up to 5,900,000 dollars on a total cost of 12,500,000 dollars. This consortium intends to include a new non-conventional renewable biofuel into the energy matrix, giving rise to new business opportunities through the implementation of programs for research and development, training human resources for new capabilities and more infrastructure, besides a technological transfer program. After five years, they expect to get a collection of the best microalgae strains, the know-how to produce the algal biomass, taking advantage of the natural conditions in the desert located in the northern part of Chile, and using CO_2 at industrial level, oil to get liquid biodiesel and meals for the food and feed, livestock and agricultural industries. The first microalgae production centre should cover 300 ha.

A fourth consortium, "Consortium desert bioenergy Inc. for research and development of microalgae biofuels industry" submitted by the Universidad de Antofagasta, has been granted funds up to 4,500,000 dollars, on a total cost of 6,500,000 dollars. The purpose of this consortium is biodiesel production by optimizing biomass production in terms of cultivation time and yield/surface unit, besides developing processes to reduce production costs. No agricultural lands are required to cultivate these microalgae nor does this compete with food production.

Finally, the project "Biotechnological consortium (BAL BIOFUELS) of R + D + i for biofuels production from *Macrocystis pyrifera* algae" submitted by the company BAL CHILE S.A. has been granted funds up to 6,900,000 dollars, on a total cost of 10,850,000 dollars. They intend to develop technologies for extensive cultivation of *Macrocystes pyrifera*, that is a marine macroalgae yielding as much as 50% fermentable carbohydrates from a production of 250,000 kg of material/ha/year. In a five-year term they expect to: (a) cultivate raw material at industrial level; (b) produce biofuels and specialized chemicals; (c) sell these products; and (d) generate by-products from fermentation residues.

Private initiatives considering the production of biofuels based on first-generation technologies are still waiting for proper regulations on subsidies and a more benign scenario for investments.

It is expected that mixes are made with imported biofuels in the first stage. This situation may continue in time depending on the international prices of these biofuels and the costs involved to produce them under local conditions.

The national production of biodiesel and naphtha, based on biomass pyrolysis and Fischer–Tropsch technologies is expected to start in 2015. Raw materials should be mainly residues derived from forestry operations. There could be some local developments based on the production of second-generation bioethanol from agricultural and forestry residues.

4. Our contribution

According to [4], the research needed to get major progress in the use of biomass includes development of: (a) "new" biomass, via improved land use, waste utilization, and crop management, together with modified processing methods; (b) new methods to farm and harvest aquatic organisms; (c) genomics and transgenic plants (e.g., to engineer plants and microorganisms that would yield novel polymers, or to maximize carbon for high-energy content); (d) new processes, such as enzymatic conversion of corn carbohydrates to polylactic acid and other polymers, and the combination of photosynthetic processes with special enzymes to create solid structures that would capture sunlight and fix carbon into energy-rich materials; (e) improved use of conventional biomass (lignin and cellulose) by more efficient gasification, enzymatic conversion of lignocellulosic biomass to ethanol; and (f) cultivation of fast-growing hybrid plants (e.g., poplar or willow, switchgrass).

Under this proposed research scenario, our team is giving the first step into the challenging world of second-generation bioethanol production. We are prospecting the chances to use some local materials with ample availability, enabling them to be used as raw materials for bioethanol production. Local raw materials are being characterized from a chemical point of view in order to assess their potentialities.

We are exploring the possibility to use biological pre-treatment strategies for lignocellulose as a first step in the process, using the natural advantages of some fungi capable of selectively degrading the lignin present in all these sources. We have noted increasing contents of reducing sugars as a response to the bioaugmentation of residues such as wheat straw, corn stover, eucalyptus chips and *Nothofagus pumilio* residues with white rot fungi strains collected in Chile.

Additionally, collaborative work has been conducted with international partners in some novel options. Assays of ionic liquids (IL) applied in a pre-treatment step are giving some promissory results, increasing released sugars contents among other advances. However, it is necessary to complement the data with the analysis of solid and liquid fractions after saccharification [37].

Besides pre-treatment, production of bioethanol from lignocellulose requires the hydrolysis of glycosidic bonds in cellulose. Saccharification is carried out mostly by the action of cellulases, which are produced in nature by fungi and bacteria. Cellulases are enzymatic complexes with different and complementary roles that conduct the hydrolysis of cellulose. Despite important advances, the cost of producing bioethanol is still high compared to fossil fuels, and cellulases have an important impact in the total cost of the process.

In order to improve yield and productivity of the hydrolysis step, our efforts have been focused on the isolation and protein engineering of novel cellulase genes. We have cloned fungal cellulase genes into yeast expression systems. To address the problem of low efficiency from cellulase in the hydrolysis, we are carrying out protein engineering strategies to improve cellulase properties that are fundamental for the high performance desired from these enzymes in the saccharification, such as catalytic activity, (chemical and thermal) stability, tolerance to chemical inhibitors generated by pre-treatments, cellulose adsorption, and others. Previous results [38], have shown the important potential of these enzymes for improvement. More powerful cellulases are expected to be a key contribution to improve the complete bioethanol process and reduce production costs.

According to our estimates, bioethanol production from corn stover will cover 46% of E5 domestic demand for 2010 [39], another plant using eucalyptus residues will cover 48% of E5 domestic demand [40].

5. Conclusions

Second-generation technologies applied to the synthesis of biofuels seem to be promissory as a partial solution of the dependence of Chile on foreign liquid fuels. These techniques should consider the use of residues derived from forestry management operations and agricultural wastes as raw materials. These resources are still underutilized and, in many cases, some materials such as corn and wheat straws are just burned in the field releasing new emissions of greenhouse gases. However, the country has extraordinary features such as: competitive advantages to get residual wood from some exotic species such as radiata pine and eucalyptus; a big extension of native forests still unmanaged; and world record yields for some cereals such as corn. We suppose there is a great availability of lignocelluloses, but its screening is still starting. New research projects should contribute to solve issues related to biochemical and thermochemical transformations of biomass such as lignocelluloses and algae in order to update these techniques and adapt them to local conditions.

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