

# Biofuels in China: An Analysis of the Opportunities and Challenges of *Jatropha Curcas* in Southwest China

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Southeast Asia



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## **Abstract**

Over the past decade China has quietly emerged as the world's third largest biofuel producer. Concerned over rising food prices, in June 2007 China's central government banned the use of grain-based feedstocks for biofuel production and reoriented the country's bioenergy plans toward perennial crops grown on marginal land. One such crop, *Jatropha curcas*, has emerged as a high potential biodiesel feedstock because of its adaptability to the diverse growing conditions where China's marginal land is abundant. Provincial governments in Southwest China, for instance, have drafted ambitious plans to increase *Jatropha* by over one million hectares in the next decade. This paper analyzes the opportunities and challenges for the development of a *Jatropha* industry in Southwest China. Given the scarcity of data on *Jatropha* productivity and economics, we argue that plans to rapidly expand *Jatropha* acreage and refining capacity could jeopardize the industry's longer-term viability. Alternatively, a commitment to silvicultural, engineering, and economic research could set the industry on a more sustainable path.

## **Keywords**

China, biofuels, energy policy, *Jatropha*

## List of acronyms and abbreviations

CO <sub>2</sub>	Carbon Dioxide
ha	Hectares
Kg	Kilograms
L	Liters
LHV	Lower heating value
MJ	Megajoules
RMB	Renminbi
SO <sub>2</sub>	Sulfur Dioxide
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
EIA	Energy Information Administration
EROI	Energy Return on Investment
FAO	Food and Agricultural Organization of the United Nations
GHG	Greenhouse Gases
GTZ	German Technical Corporation
IEA	International Energy Agency
KIB	Kunming Institute of Botany
MOST	Ministry of Science and Technology
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
OECD	Organization for Economic Co-operation and Development
UN	United Nations
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture
YAAS	Yunnan Academy of Agricultural Sciences
YFB	Yunnan Forestry Bureau
YFD	Yunnan Forestry Department

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# 1. Introduction

Biofuels have rapidly entered China's energy policy discourse. Once peripheral to policy, energy crops are now at the center of a broad debate in China that covers energy security, food security, climate change mitigation, international biofuel development, rural development, and ecological restoration. As in many other countries, conflicts between food and energy are at the center of this debate. Concerned over rising grain prices, in June 2007 the Chinese central government banned the use of grain crops to produce ethanol.

Among the diversity of potential energy crops, *Jatropha curcas*, an oil-bearing plant, has emerged as a high potential biodiesel feedstock in China because it grows on marginal land and thus does not necessarily compete with food systems. In Southwest China, the chief national target area for *Jatropha* plantations, provincial governments have plans to expand *Jatropha* acreage to 15.4 million mu (1 million ha) on marginal land over the next decade and a half, or a roughly 15-fold increase over current acreage, much of which is wild.

This paper analyzes the opportunities and challenges for *Jatropha curcas* in Southwest China. We begin with an overview of transportation energy policy in China, and how biofuels fit into that policy. After briefly describing *Jatropha curcas*, we examine *Jatropha curcas* development plans in Southwest China, highlight the challenges for establishing economically and environmentally sustainable markets for *Jatropha* oil, provide an assessment of how *Jatropha* oil production fits into Chinese central and provincial government socioeconomic development goals, and offer concluding thoughts.

While research on *Jatropha curcas* in China dates back to the late 1970s, the research infrastructure that would support a rapid scaling up of *Jatropha curcas* plantations in Southwest China is currently not in place. Achievable oil content and seed yields are still highly uncertain, and little is known about the incentive structures under which smallholder farmers would grow *Jatropha curcas* and smaller and larger companies would make investments in oil extraction and refining capacity.

Rapid expansion of *Jatropha* plantations with low quality planting stock and an incomplete understanding of incentive structures for different actors could jeopardize the longer-term viability of the *Jatropha* biodiesel industry. Alternatively, a major commitment to research that improves both trees and program design and regulation might set the industry on a more sustainable footing.

## 2. Transportation Fuels and Energy Policy in China

China's increasing dependence on foreign oil has positioned transportation fuels as a growing focus of the country's energy policy. China became a net oil importer in 1993, and became the world's second largest importer in 2004. From 1990-2004, China accounted for 26 percent of the growth in global crude oil consumption (EIA, 2006a), and the International Energy Agency (IEA) projects that crude oil demand in China will more than double from 2004-2020 (IEA, 2006). In 2005, imports accounted for 44 percent of the country's crude oil supply (NBS, 2006); by 2020, imports may account for as much as 70 percent of total oil supply (Downs, 2004). As a comparison, net oil imports comprised 60 percent of U.S. oil demand in 2005 (EIA, 2006b). The geopolitical and economic implications of China's increased dependence on foreign oil have generated strategic concern, both among policymakers in China and abroad.

While crude oil consumption in China has historically been dominated by non-transportation uses, motor vehicles are projected to account for the majority of growth in the country's crude oil consumption until 2020 (Fridley, 2007). As various forecasts of China's future oil demand illustrate,<sup>1</sup> demand growth depends significantly on how fuel economy standards and policies to govern motorized transportation in China evolve over the next two decades. The Chinese central government has taken ambitious moves to reduce petroleum products consumption by adopting stringent fuel economy standards in late 2004, with plans to tighten these again in 2008 or 2009.<sup>2</sup> Hybrid vehicles, road pricing, registration fees, and public transportation are all part of central government plans to restrain growth in vehicle stock and use, and thus in petroleum products consumption.

Even under aggressive efforts to improve vehicle efficiency and reduce vehicle use, growth in China's demand for crude oil over the next two decades will likely be considerable. Gasoline demand provides an illustrative example. Whereas car ownership in OECD countries has largely saturated, in 2005 per capita car ownership in China was roughly 11 per 1,000 people, or about 30 per 1,000 households (NBS, 2006). The auto industry is a "pillar" industry of the Chinese economy, and there are limits to how much the central government will restrict growth in domestic vehicle stock. Given China's 1.3 billion-person population, even small increases in per household car ownership and use will engender large increases in gasoline demand.

In recognition of the huge growth potential for petroleum products demand, over the past decade the Chinese government has begun to support research and development efforts on a range of potential supply-side alternatives; biofuels are one such alternative.

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<sup>1</sup> See, for instance, APERC (2004), Schipper and Ng (2004), Skeer and Wang (2007), and Wang et al. (2006).

<sup>2</sup> Originally scheduled for 2008, the imposition of more stringent standards (Euro III equivalent) may be delayed until 2009 because of difficulties in mass producing lower sulfur fuels.



### 3. Biofuels in China

At roughly one million tons, China was the world's third largest biofuel producer in 2005, behind Brazil and the U.S. (USDA, 2006). In 2006 the National Development and Reform Commission (NDRC), China's chief planning agency, set a target of meeting 15 percent of transportation energy needs with biofuels by 2020.<sup>3</sup> At, for instance, Wang et al.'s (2006) range of projections for 2020 motor vehicle gasoline and diesel consumption, 15 percent of China's motor vehicle consumption in 2020 would be 39-44 million tons, or a roughly 40-fold increase over 2005 biofuel production.

Although lagging behind ethanol production at roughly 100,000 tons in 2005 (USDA, 2006), biodiesel is an important part of China's biofuel development strategy. Diesel demand in China grew more than twice as rapidly as gasoline demand from 1997-2005, and diesel consumption was more than twice gasoline consumption in 2005 (NBS, 2006). The State Forest Administration (SFA) set a target of 195 million mu (13 million ha) of biodiesel plantations by 2010.<sup>4</sup> Under Ministry of Science and Technology (MOST) plans, biodiesel production would reach 1.5-2 million tons by 2010, and 12 million tons by 2020 (GTZ, 2006).

With 20 percent of the world's population and 10 percent of its arable land,<sup>5</sup> plans for rapidly increasing biofuel production in China have spurred domestic debate about the food security implications of a shift from food to energy crops. The primary feedstock for ethanol in China, which comprises the bulk of the country's biofuel production, has been wheat and corn. Concerned over rising food prices, in June 2007 China's State Council halted the use of grain crops for ethanol production, limiting biofuel development to non-grain energy crops. This strategy, if enforced and expanded to other major food crops, would presumably limit the range of developable oil-based energy crops as well. China is already a significant importer of edible oils; in 2005, imports accounted for 17 percent of China's total edible oil supply (NBS, 2006).

As a non-edible oil crop, *Jatropha curcas* has emerged both in Chinese and international policy circles as a high potential feedstock for biodiesel production. Much of the focus on *Jatropha curcas* production has been in Southwest China, where research on the plant began comparatively early and unused land is more readily available. The remainder of this analysis provides a brief description of *Jatropha curcas*; an overview of *Jatropha* production plans in Southwest China and their implications; a synopsis of the challenges for shaping economically and environmentally sustainable markets for *Jatropha* oil in Southwest China; and an examination of how planned *Jatropha curcas* plantations fit within the context of central and provincial government socioeconomic development goals in China.

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<sup>3</sup> See, for instance, "Planning for a New Energy Future: Biofuels Reach 15% in 15 Years with Three Steps" (规划新能源未来15年三步走生物质能源将占15%), <http://www.chinaenergy.gov.cn/news.php?id=2577>, and USDA (2006).

<sup>4</sup> See <http://www.biotech.org.cn/news/news/show.php?id=48961>.

<sup>5</sup> China population and arable land data are from NBS (2005); world population and arable land data are from UN (2005) and FAO (2006), respectively.

## 4. *Jatropha Curcas* as a Biodiesel Feedstock

*Jatropha curcas* is a drought-resistant perennial plant belonging to the Euphorbiaceae family. While the genus *Jatropha* contains approximately 170 known species, ‘*Jatropha*’ here will refer to *Jatropha curcas*. The oil from *Jatropha* seeds, which are highly toxic, can be extracted for direct use in modified diesel engines, or refined into biodiesel for use in standard diesel engines.

*Jatropha* is, in many ways, well suited to the complex landscape of southern and southwestern China. The plant grows on diverse soil types and in a variety of climatic conditions, has a relatively short gestation period, and requires comparatively low physical and human inputs. From a policy perspective, the two primary advantages of *Jatropha* over many other oil-bearing plants are indeed that it: can grow in a variety of landscapes, and thus does not necessarily compete with food production systems; and requires fewer inputs, and thus has a higher energy return on investment (EROI)<sup>6</sup> and lower CO<sub>2</sub> footprint than other oil-bearing crops, such as soybean or rapeseed. From a business perspective, a major strength of *Jatropha* is that its price, and thus the margins of *Jatropha* biodiesel producers, is not directly linked to international food prices.

In Yunnan Province, where much of the background material for this case study is drawn from, *Jatropha* can typically grow at an altitudinal range of 600-1400 meters above sea level (masl). Based on experience elsewhere, for reasonable fruit production the minimum required annual rainfall for *Jatropha* is around 600 mm with well distributed rainfall (Benge, 2006). With adequate and well distributed rainfall the plant does not require irrigation; however, in India seed yields for irrigated *Jatropha* can be more than double those for rainfed *Jatropha* (Neelakantan, no date). Sufficient research has not been conducted in China to estimate commercial yields in different ecological zones and with different levels of rainfall, and to determine a more specific range of fertilizer and pesticide inputs required for commercial *Jatropha* production. Additionally, provenance research on *Jatropha*, including seed trials and establishment of certified nurseries, is lacking in China. For most new plantations there is no valid record of where the seeds or seedlings come from, how suitable they might be for different ecological zones, and what best practices for silvicultural management (e.g., spacing, pruning) should be.

After harvesting, *Jatropha* seeds are crushed, pressed, and their oil is extracted and separated. Extraction and separation is a less capital-intensive process and can be fairly decentralized. Pure filtered *Jatropha* oil can be used directly in modified diesel engines.<sup>7</sup> A higher value, and significantly more capital-intensive, alternative is to trans-esterify (replace glycerol in pure *Jatropha* oil with a short chain alcohol, such as methanol) the *Jatropha* oil feedstock in a refinery, converting it into biodiesel for blending with petroleum-based diesel fuel. *Jatropha* blended diesel has several advantages over pure petroleum-based diesel, in particular due to *Jatropha* oil’s higher cetane number, higher flash point, and lower sulfur content.<sup>8</sup> As a lipid-

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<sup>6</sup> EROI is loosely defined as the energy required to produce a unit of energy.

<sup>7</sup> High viscosity of pure filtered *Jatropha* oil tends to present problems for diesel engine ignition; dual fuel tanks, which start the engine with conventional diesel and switch to *Jatropha* when the engine is hot, can overcome this problem.

<sup>8</sup> Cetane number is a measure of the ignition quality of diesel (i.e., compression ignition) fuels; higher cetane number fuels promote earlier ignition and more uniform combustion in diesel engines, and, although increasing the cetane number beyond a manufacturer’s requirements does not necessarily

based, rather than an alcohol-based, fuel, the energy content of Jatropha biodiesel compares favorably with petroleum-based diesel (*see Table 1*).

Table 1. Comparing Petroleum-based Diesel and Jatropha Oil

Parameter	Petroleum-based Diesel	Jatropha Oil
Density	0.84-0.85 kg/L	0.91-0.92 kg/L
Cetane Number	47.8	51.0
Flash Point	80°C	110-240°C
Sulfur Content	1.0-1.2%	0.13%
Energy Content (LHV)	~36 MJ/L	~34 MJ/L

Sources: All data except LHV estimates are from GTZ (2006); LHV estimates are based on 43 GJ/t for biodiesel and 36 GJ/ton for plant oil, and converted to volume using the density estimates above.

Jatropha commercialization in China is fairly recent, with commercial seedling production beginning in 2005. Most existing Jatropha trees are used for fencing. As a result, a wide range of estimates exist for production requirements and yields. As part of this study, we assembled available information on a range of Jatropha production parameters for southern and southwest China. These parameters are shown in Table 2. Some of the lower bound estimates in Table 2 are based upon small-scale trials and observations of wild Jatropha, and are not necessarily reflective of what conditions might be at a plantation scale (*see Table 2 notes*). However, the upper bound estimate for normal soils is based on a high rainfall area in Xishuangbanna Prefecture (southern Yunnan Province), where Jatropha would compete with other crops; median yields on marginal or unused land are likely to be considerably lower. Particularly at higher stocking densities on marginal lands without irrigation and fertilizer, seed yields are unlikely to significantly exceed the lower bound estimate for barren land (i.e., 110 kg/mu).<sup>9</sup>

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enhance an engine's performance, higher cetane biodiesel can be used as an additive to increase the cetane number in lower cetane petroleum-based diesel fuels. Flash point is the temperature at which a fuel can form an ignitable mixture in air; higher flash point fuels are safer to store and handle. As most of sulfur in the fuel is oxidized during combustion, sulfur content is a proxy for SO<sub>x</sub>, and primarily SO<sub>2</sub>, emissions; lower sulfur content fuels, depending on potential sacrifices in energy content, produce lower SO<sub>2</sub> emissions per kilometer driven.

<sup>9</sup> Personal communication, Southwest China-based researchers.

Table 2. Production Parameter Estimates for *Jatropha Curcas* in China

Parameter	Range	
	Low	High
Oil Content <sup>A</sup>	30%	41%
Spacing <sup>B</sup>	80 trees/mu (1,200/ha)	130 trees/mu (1,950/ha)
Seed Yield, Barren Land <sup>C</sup>	110 kg/mu (1.7 t/ha)	140 kg/mu (2.2 t/ha)
Seed Yield, Normal Soils <sup>C</sup>	270 kg/mu (3.9 t/ha)	500 kg/mu (7.5 t/ha)
Extractable Oil Content <sup>D</sup>	60%	80%
Biodiesel per Mu, Barren Land <sup>E</sup>	20 kg/mu (0.3 t/ha; 340 L/ha)	50 kg/mu (0.7 t/ha; 795 L/ha)
Biodiesel per Mu, Normal Soils <sup>E</sup>	50 kg/mu (0.7 t/ha; 795 L/ha)	160 kg/mu (2.5 t/ha; 2,840 L/ha)
Seed-Biodiesel Conversion Ratio <sup>F</sup>	5.5	3

- A. Oil content is based on KIB (2007). The Yunnan Forestry Department's estimate for seed oil content used in their Biodiesel Development Plan is 30%.
- B. Spacing estimates are based on personal communications with Southwest China-based researchers.
- C. Seed yield estimates are based on personal communications with Southwest China-based researchers and a small-scale study conducted by the Yunnan Academy of Agricultural Sciences (YAAS, 2006) on wild *Jatropha* plants in four sites in Yunnan Province. Two of these sites were on barren land; the other two on farms. Both "low" and "high" estimates for barren land are based on this study; the "low" estimate for normal soils is based on on-farm wild *Jatropha* in the YAAS study. The high estimate of 500 kg/mu is based on yields in high rainfall areas of Xishuangbanna..
- D. Extractable oil content estimates are based on GTZ (2006).
- E. Biodiesel yield per mu is calculated using an extractable oil per seed (tons oil/tons seed) factor, which is the percent extractable oil times the seed oil content, and multiplied by an assumed refining efficiency, which in this case we assume to be 99%. Throughout this paper we take the density of *Jatropha* biodiesel to be 0.88 kg/L.
- F. Seed-biodiesel conversion ratio is the required mass of seeds required to make one mass unit of biodiesel, and depends on extractable oil content. Note that at the 'high' range here less seeds are required to make 1 kg of biodiesel than at the 'low' range, and that this ratio is the same for barren and normal soils here because we have assumed that extractable oil content is the same at the extremes for both.

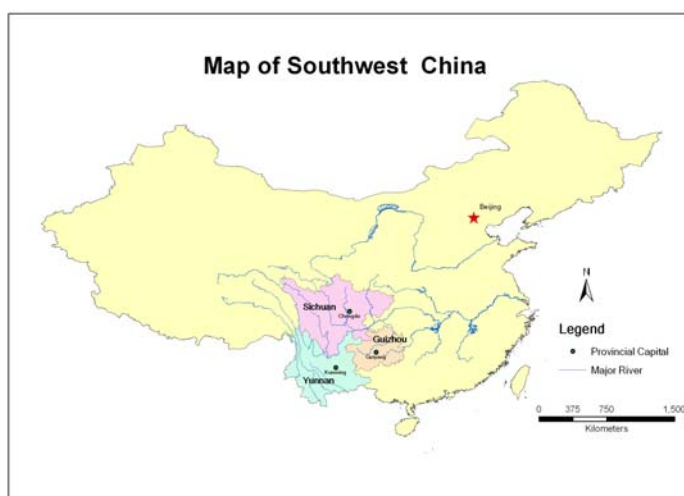
Publicly- and corporately-funded research and demonstration efforts with *Jatropha* germplasm and tissue culture are ongoing. For instance, current research at the Kunming Institute of Botany (KIB) seeks to increase seed yields by 10-30 percent over present estimates of 2.2-4.5 t/ha, and achieve an average oil content of 40 percent. KIB has been conducting smaller-scale research on *Jatropha* since 1979. The Xishuangbanna Tropical Botanical Garden also has a long history of *Jatropha* research. In 2006, the China National Petroleum Corporation (CNPC) provided 5 million RMB (US\$658,000) to initiate 4 demonstration projects in Yunnan as part of a 5-year program focusing on seed selection, tree improvement, and management practices. As we describe in greater detail below, much less attention has been given to *Jatropha* economics in China, and particularly how *Jatropha* biodiesel markets might be shaped and regulated.

An important component in the calculus of *Jatropha* economics is how the seed cakes and glycerol from *Jatropha* oil, removed as part of the trans-esterification process, are used. Seed cakes, residue byproducts from the oil extraction process, are valuable as an organic fertilizer

and can contribute to pest management due to the presence of potent but biodegradable toxins, such as phorbol esters. Seed cakes can be also used for co-firing in a combined heat and power plant, with the heat used to pre-heat the seeds to improve oil pressing efficiency. Roughly 1 kg of glycerol is produced per 10 kg of biodiesel, and the glycerol can be used to make soaps, industrial lubricants, and other products. Based on experience from Germany and India, if seed cakes and glycerol can be sold the economics of *Jatropha* biodiesel look significantly more attractive.

## 5. Jatropha in Southwest China

Southwest China, including Guizhou Province, Sichuan Province, and Yunnan Province,<sup>10</sup> is the official target area for Jatropha production in China. Earlier NDRC strategies focused primarily on Sichuan and to a lesser extent Guizhou because of the provinces' comparatively early efforts in Jatropha research and development. However, surveys at the provincial level revealed that Yunnan has significantly more land available for Jatropha production than either Guizhou or Sichuan. Yunnan has since been designated the national Jatropha demonstration province and most central government funds for Jatropha research and development are being channeled to Yunnan.



The NDRC's original development plan for Jatropha envisioned 10 million mu of Jatropha plantations in each of Southwest China's three provinces (please see map in box).<sup>11</sup> However, Yunnan may be the only province capable of achieving this goal; forestry departments in Guizhou and Sichuan have reduced their acreage targets (*see Table 3*). Still, targets for Jatropha acreage

in Southwest China would total 15.4 million mu (ha), or a 15-fold increase over current acreage, most of which is wild. At a provincial level, targets such as these are fairly top down, handed down from the provincial level to local forestry bureaus, which are responsible for implementation.

Table 3. Estimated Current and Planned Jatropha Area in Southwest China by Province

	Estimated Current Area	Planned Area
Guizhou	0.02 million mu (1,300 ha)	0.4 million mu (26,667 ha)
Sichuan	0.30 million mu (20,000 ha)	5 million mu (333,333 ha)
Yunnan	0.75 million mu (50,000 ha)	10 million mu (666,667 ha)
Total Southwest China	1.07 million mu (71,300 ha)	15.4 million mu (1.03 million ha)

Sources: Current area estimates are based on personal communication with Southwest China-based researchers; planned area for Yunnan is based on YFD (2006).

<sup>10</sup> While technically part of Southwest China, we do not include Chongqing Municipality in our discussion here because of its smaller land area and more limited relevance for Jatropha plantation development.

<sup>11</sup> Personal communication, Southwest China-based researchers.

Government strategy for expanding the area under *Jatropha* cultivation has focused on planting plantation-scale forests on barren lands. ‘Barren’ land (Ch: 荒山 | *huangshan* or 荒地 | *huangdi*) is a specific, if slightly ambiguous, designation used in Chinese agriculture and forest accounting that loosely indicates land that is not being used for more obvious productive purposes.<sup>12</sup> Some barren land is owned by the government and would be managed by government agencies if put to use; a significant amount of barren land is owned by village collectives, with use rights granted to individual households.

While a breakdown of the shares of state-collective ownership of barren land does not appear to be publicly available for the provinces of Southwest China, shares of state-collective forest land in Yunnan are illustrative. In Yunnan, which has the highest share of collectively-owned forest land in China, 76 percent of forest land was owned by collectives and 24 percent owned by the state, according to the province’s most recent forest resource survey (YFB, 1999). As a rule, collectively-owned forest land is generally more degraded than state-owned forest land. Although *Jatropha* production will not be limited to marginal land currently classified under ‘forest,’ a significant portion of the land area planned for *Jatropha* plantations in Yunnan, as well as Guizhou and Sichuan, is likely collectively owned and contracted to individual households.

Owing to a diversity of often informal arrangements and rules, rural land management in China is highly complex. Without delving into excessive detail, it is important to note that village collective endowments of forest land are typically small; 5,000 mu (333 ha) or less is common for a “natural village.”<sup>13</sup> In many cases these small land parcels have been further distributed to individual households. The number of households involved in a 15.4 million mu *Jatropha* development plan would thus likely be in the hundreds of thousands.

Attracting private investment in both growing and processing is an important part of provincial government biofuel development plans.<sup>14</sup> However, in a highly fragmented supply chain with tens to hundreds of thousands of farmers, managing private investment, both domestic and international, in feedstock production is a major undertaking. Most private investment has thus far reportedly been limited to state-owned land. Only a few projects, including a joint four-year United Nations Development Programme (UNDP) - Ministry of Science and Technology (MOST) project begun in 2006, are explicitly cooperating with individual households. For both international and domestic investors, cooperation with individual households requires an intermediary because of often vastly different understandings and expectations between rural households and corporations. This intermediary role has thus far been given to local forestry bureaus.

Existing biodiesel refining capacity in Southwest China is negligible. Virtually no commercial-scale capacity exists in Yunnan. Sichuan has roughly 15,000 tons refining capacity, which until recently has been primarily using rapeseed as a feedstock. Refining capacity in Guizhou is 20,000 tons, most of which uses waste cooking oil. The scope of investment in biodiesel

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<sup>12</sup> In fact, some of this land is likely used for grazing livestock.

<sup>13</sup> Natural village (自然村 | *ziran cun*) is an administrative designation for a physically contiguous village. At one level above, the village committee (村民委员会 | *cunmin weiyuanhui*), formerly known as the administrative village (行政村 | *xingzheng cun*), includes several natural villages and acts as an intermediary with the township government. In some cases land management authority is held at with natural village representatives; in other cases the administrative village has authority for land management.

<sup>14</sup> For instance, in one plan for the Yunnan provincial government private investment, including investment from state-owned companies, would reach 70 percent (Che and Li, 2007).

refining capacity over the next decade remains uncertain. Provincial governments have ambitious plans for building out capacity. For instance, the Yunnan provincial government is proposing 14 biodiesel processing plants with a total output of 3.2 million tons/year (*see Table 4*).<sup>15</sup> Private companies have expressed interest in larger-scale refining facilities, but concrete investment commitments from private companies have yet to materialize.<sup>16</sup>

Table 4. Proposed Biodiesel Refining Capacity in Yunnan Province

Capacity Scale	Prefectures
First tier plants (3): 0.5 million tons/year	Dehong, Xishuangbanna, Honghe
Second tier plants (5): 0.2 million tons/year	Baoshan, Qujin, Simao, Lincang, Dali
Third tier plants (7): 0.1 million tons/year	Zhaotong, Chuxiong, Yuanmou, Wenshan, Nujiang, Yuxi, Lijiang

Note: This capacity would draw on feedstocks other than *Jatropha* as well, which may explain some of the discrepancy between our estimates for biodiesel production in Yunnan (0.2-1.3 million tons), and the planned capacity in Table 4. Additionally, the Yunnan provincial government's biodiesel production plans include land and output from Laos, Myanmar, and Vietnam.

Source: Che and Li (2007).

*Jatropha* biodiesel is probably not yet cost-effective at current government-set biofuel prices or vis-à-vis petroleum-based diesel, at least in the Chinese market. Estimates of *Jatropha* oil production costs currently range from 3.5-12 RMB/kg, of which the bulk (2.5-11 RMB/kg) pays for seed production costs and the remainder (1 RMB/kg) covers processing costs. The large spread in oil production costs arises from uncertainty in extractable oil content (*see Table 2*) and seed production costs; *Jatropha* seed prices currently vary from 0.8-2.0 RMB/kg.<sup>17</sup> Refining costs add 1-2 RMB/kg, which implies a total cost range of 4,500-13,000 RMB/ton (4-11.5 RMB/L). The significant variance in this estimate is to a large extent inherent because no commercial *Jatropha* oil or *Jatropha* biodiesel production exists at present in China.

What this range suggests is that using high quality seeds and well adapted varieties on good land, *Jatropha* biodiesel may already be cost competitive with biofuel and diesel at current prices. Retail prices for ethanol and diesel in northern China, for instance, were 4.36-4.73 RMB/L (5,450-5,913 RMB/ton) and 4.55-4.92 RMB/L (5,688-6,150 RMB/ton), respectively, in June 2007.<sup>18</sup> However, on more marginal land with lower quality growing stock, production costs will have to fall significantly before *Jatropha* is cost competitive with ethanol and diesel. Based on one set of middle of the road assumptions,<sup>19</sup> seed production costs would have to fall

<sup>15</sup> Based on a 130 kg/mu *Jatropha* oil yield; see footnote 11.

<sup>16</sup> Some of the hold up in investment commitments may be due to the lack of a biodiesel standard for China, which is expected to be released in 2007.

<sup>17</sup> From 2005 to mid-2006, *Jatropha* seed prices ranged from 0.8-1 RMB/kg, but this price does not reflect seed costs at a commercial scale. Beginning at the end of 2006 and into 2007, prices in many areas reached 2 RMB/kg because of the added cost of nursery operations. Prices are based on personal communications with Southwest China-based researchers.

<sup>18</sup> Based on a range of prices for ethanol and diesel products in different regions of the North China Plain. See "Refined Petroleum Product Markets in the North China Plain Region" [华北地区成品油市场], 18 June 2007, Ministry of Commerce website, <http://price.mofcom.gov.cn>. We are assuming here that retail prices for biodiesel will be on par with those for ethanol.

<sup>19</sup> Based on the following assumptions: i) near-term commercial-scale seed production costs are 1 RMB/kg(seed); ii) seed-biodiesel conversion ratio is 4 (equivalent to an oil content of 31.6% and an extraction efficiency of 80%); iii) oil extraction and refining costs are 1 RMB/kg(oil) and 1.5 RMB/kg(biodiesel), respectively; and iv) national oil companies have an internal rate of return of 20-30%. This calculation uses a current ethanol retail price of 5,500 RMB/ton, based on footnote 16.



roughly 48-57 percent before Jatropha biodiesel becomes cost competitive at current ethanol prices.

Until Jatropha feedstock is cost competitive at least at diesel prices, either processors or retailers will require subsidies to bridge the gap between actual feedstock costs and feedstock costs needed by refiners to maintain profitability. Southwest China-based researchers expect that central government subsidies in the range of 1,000-2,000 RMB/ton biodiesel will be provided to biodiesel producers, which is in line with those given to ethanol producers (1,300-1,400 RMB/ton).<sup>20</sup> However, the central government has not yet given any indication that subsidies for Jatropha biodiesel producers will be forthcoming. The scale of downstream subsidies will depend on seed production costs, but also to a large extent on seed quality; using the assumptions in footnote 17, increasing the average oil content of seeds from roughly 32 to 36 percent reduces required subsidies by 22-26 percent, or about 500 RMB/ton.<sup>21</sup>

The cost competitiveness of Jatropha biodiesel is insufficient for gauging Jatropha oil supply chain dynamics because it downplays the importance of profitability at the farm level. With farmers concerned about both demand security and price stability, farm subsidies will most likely be required to lower farmers' risk threshold for growing Jatropha. Provincial governments in Southwest China have recognized the need to subsidize farmers. For instance, a sizeable portion of the Yunnan provincial government's 100 million RMB (US\$13.2 million) investment in Jatropha development is being directed to district forestry officers as a 160 RMB subsidy for each mu (US\$337/ha) of Jatropha plantation established in that officer's district, with district officers given discretion over how subsidies are distributed.

The scale of these two kinds of subsidies — refiner and farm subsidies — depends on final markets. The price threshold for entering developed country markets is significantly lower, likely even after accounting for distribution costs. For instance, in the EU market, German rapeseed biodiesel production costs are 5.9-7.9 RMB/kg, and biodiesel sells at a retail price of roughly 8 RMB/L (7,400 RMB/ton). Additionally, developed country markets already offer a relatively secure source of demand and refining capacity. In the nearer term, biodiesel exports to developed countries might offer a means to expand and improve Jatropha growing without necessarily having refining capacity to match. Ultimately, Chinese central government regulation will determine whether biofuels are able to be exported, or restricted to domestic use.

For the Chinese market, some degree of subsidization is likely inevitable. The question is how large these subsidies will have to be, how long they will last, and who will pay for them. In Table 5, we estimate a range of potential subsidies, both on a per ton biodiesel basis and a per mu Jatropha seed basis. In other words, for each ton of Jatropha biodiesel produced or for each mu of Jatropha grown, what is the range of total subsidies required? In reality, farm and refiner subsidies are not necessarily additive on the same scale; farm subsidies are more likely to be given by provincial governments and biodiesel refiner subsidies by the central government. However, from the perspective of gauging total program costs vis-à-vis production or acreage targets, this kind of comparison is nonetheless instructive.

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<sup>20</sup> See, for instance, <http://biology.aweb.com.cn/news/2006/11/23/10383666.shtml>.

<sup>21</sup> At a 20% and 30% IRR, required subsidies at a seed-biodiesel conversion ratio of 4 would be 1,117 RMB/ton and 1,469 RMB/ton, respectively. Decreasing that ratio to 3.5 (i.e., increasing oil content to 36.1%) would reduce subsidies to 717 RMB/ton and 1,069 RMB/ton, respectively.

Table 5. Estimated Range of Potential Subsidies for Jatropha Biodiesel

<b>Subsidy</b>	<b>Estimated Range</b>	
	Implied per ton Biodiesel	Implied per Mu
Farm Subsidies	1,000-8,000 RMB/ton biodiesel	160 RMB/mu
Refiner Subsidies	0-9,990 RMB/ton biodiesel	0-500 RMB/mu
Total Subsidies	1,000-17,990 RMB/ton biodiesel	160-660 RMB/mu

Notes: Refiner subsidies are based on the assumption that subsidies would have to cover the difference between actual seed prices and seed prices that refiners would need to maintain profitability at 5,500 RMB/ton, minus extraction, refining, and opportunity costs. The upper range here assumes that seed prices are at 2 RMB/kg and that the seed-biodiesel conversion ratio is 5.5. Per ton and per mu subsidies were converted to per mu subsidies by using the range of biodiesel yield estimates in Table 2.

The huge variance in possible support subsidies shown in Table 5 reflects underlying uncertainties in Jatropha production parameters described earlier in Table 2. Narrowing yield and extractable oil content estimates to specific ecological regions is important for determining the underlying economics of Jatropha production. In particular, a better understanding of these parameters will help central and provincial government agencies determine how soon Jatropha biodiesel production can be commercially viable without direct subsidies, or alternatively the level of subsidies required to sustain production beyond the near term.

Narrowing down program cost estimates is one among several challenges that central and provincial policymakers in China face in designing and regulating economically sustainable biofuel markets. As we describe in the case of Jatropha below, all of these challenges can ultimately be overcome, but not addressing them in the short term could jeopardize the longer-term viability of the biofuel industry.

## 6. Challenges for Establishing Jatropha Oil Markets

In a supply chain dominated by risk-averse smallholder farmers and large national oil companies with high hurdle rates, the challenges of developing viable markets for Jatropha oil are considerable, but by no means insurmountable. We highlight four of those challenges here:

- Ensuring sufficient quantity and quality of available, non-agricultural and non-forest land to meet a reasonable scale of feedstock demand;
- Building institutions that facilitate between smallholder farmers upstream and the oil and biodiesel processing industries downstream;
- Determining minimum efficient scales for Jatropha growing and processing; and
- Coordinating the timing of government investments in Jatropha research with the speed of the Jatropha biodiesel industry's development, and ensuring that the scale of implementation matches the appropriate scale suggested by research results.

**Available Land.** While there is perhaps less question that 15.4 million mu of barren land exists in Southwest China for growing Jatropha, the quality of barren land varies widely. Jatropha might indeed grow on this marginal land, but it is not clear that seed quality and yields would be sufficiently high, or that available plots would be sufficiently large, to make growing economic. A primary reason for the slow uptake of Jatropha among farmers in Yunnan, for instance, has reportedly been that much of the available land in Yunnan is either on steep slopes with high fire risk or on highly degraded slopes where remaining topsoil is less than 10 cm.<sup>22</sup> If Jatropha is planted on slightly better land, it begins to compete with other cash crops, such as maize, sugarcane, and coffee, and securing voluntary participation becomes more of a challenge. Part of this gap between perceived quantity and actual quality may stem from the different perspectives that provincial and local forestry bureaus have on land use statistics; at increasingly higher administrative levels forestry bureaus increasingly see only aggregate land use categories, which mask often considerable differences in land quality.

**Institutions.** The key challenge for building Jatropha oil markets is coordinating feedstock supply and demand when neither exists for lack of the other. Upstream, smallholder farmers are unwilling to take on the risk of paying for, planting, and maintaining Jatropha trees unless they have a secure source of demand in 3-5 years when their trees begin to bear seeds. Downstream, refiners are unwilling to make longer-term investments in refining capacity unless they have a secure source of adequate supply, which they will not have for 3-5 years. Institutional innovation, including contractual arrangements, fiscal and other incentives, blend ratio requirements, and other policy tools can help to overcome chicken and egg obstacles in Jatropha biodiesel markets. Institutions will also be key in determining the fairness of and allocation of risk in these markets. If farmers are not given long-term contracts for seeds, for instance, they will be at considerable downside risk to falling oil prices. Alternatively, requiring refiners to take on this risk would potentially lead to greater pressure on energy prices.

**Scale.** Appropriate levels of government support for Jatropha biodiesel markets are determined to a large extent by how small these markets can be and still be cost-effective. If Jatropha biodiesel's ultimate use is in diesel blends, China's three national oil companies — CNPC, Sinopec, and CNOOC — will dominate Jatropha biodiesel markets, regardless of whether

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<sup>22</sup> Personal communication with Southwest China-based researchers.

provincially-based biodiesel refiners actually produce the bulk of biodiesel. For CNPC, Sinopec, and CNOOC, building or buying biodiesel from a few 100,000 ton refineries is not likely to make economic sense. Similarly, a model where scattered small-scale Jatropha producers each produce a few tons of Jatropha seeds on scattered marginal land is not likely to be financially feasible for downstream processors. Vertical integration or smaller-scale aggregators might help to alleviate this problem. However, for Jatropha biodiesel to be cost competitive some degree of scale in both growing and refining is required. Getting the scale wrong, for instance by subsidizing the Jatropha industry too little or too much, would either cause the industry to flounder when it might have been viable or saddle the government, and ultimately taxpayers, with unnecessarily large costs.

***Research versus Development.*** A central question in the design of Jatropha programs, and biofuel programs more generally, is how much to fund research versus how much to subsidize industry growth. As we highlight throughout this paper, there is still a significant degree of uncertainty in how much it will cost to grow and process Jatropha into biodiesel. Some of this uncertainty is undoubtedly related to scale; once Jatropha growing begins on a commercial scale costs are likely to fall at some level. However, increasing Jatropha acreage does not guarantee improvements in oil content and seed yields. If these remain low, unit production costs for Jatropha and thus the subsidies required to make Jatropha biodiesel cost competitive will remain high. Moreover, rapidly increasing Jatropha acreage with low quality plant stock could lock farmers into low oil content and seed yields in the medium term in a market where refiners are likely to put downward pressure on prices, at the same time locking the central government into long-term subsidies for biodiesel producers to compensate high feedstock costs. While subsidies are needed to spur the establishment of Jatropha biodiesel markets, decisions on how fast and at what level to support the growth of a Jatropha biodiesel industry should be based on a systematic, intensive research program.

Indeed, what these four challenges have in common is the need for a significant scale up of research capacity, both in germplasm improvement and supply chain economics, to improve the Jatropha seed base and strengthen Jatropha oil market design and regulation. Viewing Southwest China's current Jatropha development plans against national and provincial socioeconomic development goals provides a helpful metric for weighing the magnitude and allocation of costs, benefits, and risks associated with Jatropha development.

## 7. Jatropha in the Context of National and Provincial Socioeconomic Development Goals

A viable Jatropha biodiesel industry could contribute to county- and provincial-level development, rural livelihoods, and environmental protection in Southwest China. However, without specifically designing Jatropha feedstock and biodiesel markets with these goals in mind, planned Jatropha plantations in Southwest China are not guaranteed to yield any of their expected benefits. Forcing a rapid expansion of Jatropha acreage without a more substantial knowledge and seed base could leave provincial governments with huge costs, increase rural households' financial risk, and decrease biodiversity while increasing fire and pest risk. Nor is there a clear rationale for such a rapid expansion in acreage on the basis on energy security or climate goals. With nearer-term yields and technologies, proposed Jatropha plantations in Southwest China would make a trivial contribution to China's national energy security and only a small reduction in the country's GHG emissions.

If current provincial targets for Jatropha plantation area in Southwest China are met, Guizhou, Sichuan, and Yunnan could collectively produce an estimated 0.3-2.0 million tons<sup>23</sup> (0.4-2.2 billion L) of Jatropha biodiesel annually from mature trees. This rough estimate is based on assumptions that Jatropha seed yields range from 110-390 kg/mu (1.7-5.9 t/ha), and that seed oil content is between 30 and 41 percent.<sup>24</sup> The lower and upper estimates for biodiesel production differ by a factor of nearly seven; actual output from planned Jatropha plantations will depend on land availability and how oil content and seed yields improve. As we noted previously, if Jatropha production is limited to marginal land without irrigation and fertilizer yields are more likely to be on the lower end of this range.

To put these numbers in context, China's total diesel demand in 2005 reached 109.72 million tons (NBS, 2006), of which on-road motor vehicle demand accounted for roughly 65 million tons (Wang et al., 2006). At 0.3-2.0 million tons of biodiesel production, Jatropha plantations in Southwest China would offset 0.3-1.8 percent of total 2005 diesel demand, or 0.5-3.0 percent of motor vehicle diesel consumption. Even a 1.8 percent reduction in petroleum-based diesel consumption would amount to only a roughly 1 percent reduction in total 2005 crude oil imports (168.1 million tons) (NBS, 2006), and an even smaller percentage reduction in crude oil imports at the margin.<sup>25</sup> Even if biofuels collectively increase to 5-10 percent of China's transportation energy fuels, at more realistic yields Jatropha's contribution to this total would be negligible.

Planned Jatropha plantations in Southwest China will similarly not lead to significant reductions in China's GHG emissions. Using 2.6 t(CO<sub>2</sub>)/kL-year estimates of Jatropha offset potential elsewhere (Mitsui, 2005), Jatropha plantations in Southwest China would lead to 0.9-5.6 million t(CO<sub>2</sub>)/year reduction in CO<sub>2</sub> emissions, or far less than 1 percent of either China's total CO<sub>2</sub>

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<sup>23</sup> Note that YFD (2006) lists the "biodiesel material" potential for Yunnan as 2.3 million tons, but this is most certainly Jatropha seeds rather than Jatropha oil. Even under unrealistic assumptions that all the oil can be extracted, producing 2.3 million tons of Jatropha oil on 10 million mu would require an average seed yield of 767 kg/mu (11.5 t/ha), which is currently not within the realm of possibility.

<sup>24</sup> Seed yield assumptions are based on KIB goals for raising yields by 30% over 4.5 t/ha; oil content assumptions are based on the estimates in Table 2.

<sup>25</sup> If crude oil and diesel consumption double over the next two decades (IEA, 2006; Wang et al., 2006), with China's crude imports expected to increase biodiesel from Southwest China's planned Jatropha plantations would make an even smaller reduction in crude oil imports at the margin than as a percentage of 2005 crude oil imports. Assuming a roughly 1:1 ration for crude oil-diesel conversion.

emissions from oil products consumption [799 million t(CO<sub>2</sub>)] or total fossil fuel energy use [4,769 million t(CO<sub>2</sub>)] in 2004 (IEA, 2006). With growth in China's total CO<sub>2</sub> emissions and oil consumption-related CO<sub>2</sub> emissions projected to roughly double from 2005-2020 (IEA, 2006), GHG emission reductions from Jatropha plantations in Southwest China will make only a minute reduction in China's GHG emissions growth at the margin.

Table 6. Estimates of Potential Benefits of Jatropha Plantations in Southwest China

	<b>Planned Jatropha Area</b>	<b>Estimated Reduction in National Crude Oil Imports</b>	<b>Estimated Reduction in National GHG Emissions from Petroleum Products Combustion</b>	<b>Estimated Increase in Provincial Forest Cover</b>
Guizhou	0.4 million mu	0.0-0.0%	0.0-1.4 million t(CO <sub>2</sub> )	0.6%
Sichuan	5 million mu	0.1-0.4%	0.3-1.8 million t(CO <sub>2</sub> )	2.2%
Yunnan	10 million mu	0.1-0.8%	0.6-3.6 million t(CO <sub>2</sub> )	0.4%
Total Region	15.4 million mu	0.2-1.2%	0.9-5.6 million t(CO <sub>2</sub> )	1.2%

Note: Based on Table 2 production estimates. Forest cover estimates are based on NBS (2006).

While there is some potential for Clean Development Mechanism (CDM) credits to offset some of the cost of Jatropha production, at least in the near term CDM funding is likely to be peripheral to Jatropha economics. Based on the 3.0 ton(CO<sub>2</sub>)/ton(biodiesel) [2.6 ton(CO<sub>2</sub>)/kL] offset potential used above, at a commonly used estimate for CDM credits in China of US\$10/ton, pre-tax CDM funds would be equivalent to 225 RMB/ton(biodiesel) [0.2 RMB/L], or 1.4-11.2 RMB/mu. Although at some point CDM financing might push Jatropha biodiesel over the break even point, at present the main determinants of the longer-term economic viability of Jatropha biodiesel are Chinese government driven.

At a local level, Jatropha, and biofuels more generally, could be a significant new revenue source for provincial and county governments; all three provinces in Southwest China are well below China's per capita provincial revenue average (NBS, 2006). Particularly for Yunnan Province, Jatropha is part of a larger industrial strategy of shaping biofuels as a "pillar industry" (Che and Li, 2007). Benefits from Jatropha biodiesel markets will depend on how much value is captured at a sub-provincial level and how much provincial governments are required to spend to support Jatropha development. The former question has much to do with how decentralized or centralized oil extraction is. More decentralized oil extraction would spread revenue and employment benefits across counties. However, in the absence of explicit central and provincial government efforts to decentralize oil extraction, national oil companies are likely to integrate and centralize extraction and refining.

The latter question of how much provincial governments will have to pay to support Jatropha biodiesel markets, as noted previously, is highly uncertain. In addition to uncertainties over available land, oil content, and seed yields, it is unclear how much of the Jatropha bill provincial governments will be required to foot. For Yunnan Province, Che and Li (2007) argue that securing central government funding is the key factor to implementing the province's biofuel development plans. Even if central government funding does materialize to support Jatropha development and provincial governments only pay farm subsidies, the costs may still be substantial. At very high cost levels, the benefits of Jatropha may not warrant the costs.

Jatropha also has potential as a means to raise incomes in rural regions where more conventional agricultural markets have been comparatively slow to take shape. Many parts of Southwest China fit this description. Guizhou, Sichuan, and Yunnan are part of a mountainous region that is one of China's poorest areas. Guizhou (1,877 RMB/US\$247), Sichuan (2,803 RMB/US\$369), and Yunnan (2,042 RMB/US\$269) have the lowest, eleventh lowest, and third lowest rural per capita net incomes among China's 31 provinces, municipalities, and autonomous regions; all three provinces are below China's average rural per capita income (3,255 RMB/US\$428) (NBS, 2006). Particularly to the extent that it can be successfully grown on marginal land or intercropped on farms, Jatropha seeds can represent a new cash income source for farmers.

However, the income generating potential of Jatropha needs more in-depth analysis. A study for the UNDP-MOST Green Poverty Reduction Programme projected that households could generate a net annual income of 250-400 RMB/mu from Jatropha after 3-5 years, which would be equivalent to 250-400 kg/mu yields (i.e., at the higher end of Table 2 estimates) at a net income of 1 RMB/kg(seeds) and would imply either a seed price higher than our estimates or no input costs (i.e., subsidized inputs) for farmers. The Yunnan Forestry Department estimates new farm incomes of 100 RMB per person per year (YFD, 2006), which is likely a per capita average based on wholesale seed price estimates. How much farm households can earn from Jatropha on marginal land is at least specific to certain ecological zones, and understanding the earning potential for Jatropha in these different zones rather than at an aggregate level is critical for designing Jatropha support programs.

Southwest China's 15.4 million mu of planned Jatropha plantations would increase regional forest cover by a modest 1.2 percent (*see Table 6*). Alternatively, rehabilitating degraded land with Jatropha might restore some of the ecological functions of forests, such as erosion control, particularly if planting takes place in a multistory agroforestry system. Many parts of Guizhou, Sichuan, and Yunnan harbor critical mountain ecosystems. Yunnan, for instance, is home to upstream portions of the Yangtze, Salween, Mekong, and Red Rivers. Restoring ecosystem functions on degraded land would require a more science-based approach to reforestation that matches planned Jatropha area with projected site-specific ecological benefits. Without having the necessary foundation of scientific experiments and data and systematic field trials, Jatropha plantations might have negative ecological consequences. If refineries are not sited with their potential environmental impacts in mind, for instance, the surrounding Jatropha plantations that supply them might decrease local biodiversity and increase the risk of fire, pest, and disease.

A final benefit of Jatropha development might be rural energy supplies. If able to be burned directly in diesel generators, Jatropha oil could either be used as a primary energy source in applications that are energy intensive, such as grinding wheat. Combined with solar PV for low voltage applications Jatropha oil could be an energy source in renewable mini-grids in communities that do not have access to on-grid electricity. More research is required on this front to determine the technical and economic feasibility of Jatropha as a reliable, cost-effective rural energy source.

## 8. Conclusions

As in many other countries, the development of biofuels in China has been and will continue to be accompanied by policy debate about potential economic, environmental, and social costs and benefits. While in China this debate has been wide-ranging, it has found focus in the potential tensions between energy and food crops. Recognizing the growing link internationally between food and energy crop prices, in June 2007 the Chinese central government banned the use of grain crops to produce ethanol.

Against this backdrop, *Jatropha curcas*, an oil-bearing, drought-resistant perennial plant, has emerged as a high potential biodiesel feedstock in China because it grows on marginal land and thus does not necessarily compete with food systems. Provincial governments in Southwest China, the primary national target area for *Jatropha* plantations, have plans to expand *Jatropha* acreage to 15.4 million mu (1 million ha) on marginal land over the next decade and a half, or a roughly 15-fold increase over current acreage, much of which is wild.

Although often justified from a national security and climate policy perspective, under realistic nearer-term assumptions about oil content and seed yields we demonstrate here that these 15.4 million mu will not contribute to either a meaningful reduction in China's oil imports or its petroleum-based CO<sub>2</sub> emissions. However, *Jatropha* development does have potential to increase provincial revenues, raise rural incomes, and restore environmental services from forests in Southwest China. Whether this potential can be realized will depend on how programs to support *Jatropha* development are structured.

Southwest China, including Guizhou, Sichuan, and Yunnan Provinces, is one of China's poorest regions, with provincial per capita revenue and per capita rural incomes well below national averages. It is also one of China's most ecologically important regions, harboring the headwaters of major domestic and international rivers. *Jatropha* could offer rural income generation and employment opportunities, as well as a new source of provincial and sub-provincial government revenue. Although adding forest to 15.4 million mu would produce a modest 1.2 percentage point increase in the region's forest cover, more targeted *Jatropha* growing could restore environmental services on degraded land.

All of these benefits are predicated on a reasonable quality of available marginal land, relatively high oil content and high yielding plants, and institutions that coordinate *Jatropha* markets and explicitly integrate environmental considerations into *Jatropha* planning. None of these conditions are certain to be met. In Yunnan Province, for instance, one reason that *Jatropha* uptake among farmers has been slow is that a significant portion of available marginal land is not currently suitable for commercial-scale growing. More detailed surveys are necessary to identify how much marginal land in Southwest China is of sufficient quality to grow *Jatropha* at a commercial scale.

Program costs for *Jatropha* development plans in Southwest China are highly uncertain; a large portion of this uncertainty is inherent since there is currently no commercial *Jatropha* growing in the region. Our estimated cost range for *Jatropha* biodiesel is 4,500-8,500 RMB/ton, with estimated biodiesel yields of 20-160 kg/mu. The large variance in both cases stems in part from the lack of a seed base (i.e., in quality, quantity, and suitability) for *Jatropha* in China. In the absence of a more intensive program to improve oil content and seed yields, lower quality planting stock will lead to higher subsidies to bridge the cost differential between



Jatropha oil production costs, and the wholesale prices biodiesel refiners need to remain profitable.

Similarly, the institutions to facilitate and regulate Jatropha biodiesel markets are still in a formative stage. Upstream, farmers are unwilling to grow Jatropha because they lack a secure source of demand. Downstream, processors are unwilling to make capital investments because they lack a secure, adequate source of supply. Institutional innovation can help to bridge this divide, but if designed poorly one party along the supply chain — most likely governments and ultimately taxpayers — will have to absorb a disproportionate share of the costs. More generally, there is currently little understanding of the required incentive structures under which farmers will grow and processors will make capital investments for Jatropha.

China's case is unique vis-à-vis OECD countries because of the sheer number of people that would be involved in a 15.4 million mu Jatropha project. Much of the marginal land in Southwest China is owned by collectives and contracted to individual households. A natural village in China might have 5,000 mu for 100 households as a rough approximation. Particularly to the extent that private investment is involved in Jatropha growing, developing the institutions to facilitate contractual agreements between potentially hundreds of thousands of households and corporations is a major undertaking. If these facilitating institutions are not properly designed, rural households, for instance, may take on most of the downside risk of falling oil prices.

The present, preliminary stage of Jatropha development in Southwest China suggests the need for further, intensive research to better understand potential costs and benefits before rapidly scaling up Jatropha acreage. Developing an improved seed base might require another five years, for instance, but could mean the difference between an expensive program that is ultimately abandoned and a viable Jatropha biodiesel industry that functions without government support. Similarly, a better understanding of supply chains could mean the difference between programs where poor farmers bear a disproportionate share of risks and costs, and one in which risks and costs are more evenly spread across government, farmers, and industry.

Jatropha is certainly not the only case where the Chinese government faces a choice between supporting a stronger research base and rapidly creating an industry. For Jatropha, as we have spelled out above, research is a means to lower program costs and create a more viable industry in the longer term. In the near term, Jatropha development should follow the route outlined by Chinese premier Wen Jiabao for biofuels writ large: "First understand, first take initial steps, first see results" (Che and Li, 2007).

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## Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating 'working trees' on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

## Our vision

Our Vision is an 'Agroforestry Transformation' in the developing world resulting in a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, income, health, shelter and energy and a regenerated environment.

## Our mission

Our mission is to advance the science and practice of agroforestry to help realize an 'Agroforestry Transformation' throughout the developing world.



A Future Harvest Centre supported by the CGIAR



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