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The little shrub that could — maybe

India, like many countries, has high hopes for jatropha as a biofuel source, but little is known about how to make it a successful crop. **Daemon Fairless** digs for the roots of a new enthusiasm.

With a top speed of about 110 kilometres an hour, India's Shatabdi Express is not much to brag about by the standards of a French TGV or a Japanese Shinkansen train. Nonetheless, as the stock for one of the country's fastest and most luxurious passenger lines, the Shatabdi trains have a certain prestige. So when, on New Year's Eve 2002, the Shatabdi train from New Delhi to Amritsar was powered in part with biodiesel for the first time, it was a clear statement of the government's desire to wean India off imported petroleum.

Diesel is India's main liquid fuel: the country burns roughly 44 million tonnes, or 320 million barrels, of the stuff a year, as opposed to about 94 million barrels of gasoline. The trains account for a significant part of that. Kunj Mittal, who heads the government-operated rail service's engineering and traction division, says its fleet of 4,000 engines currently burns about 1.7 million tonnes a year, and that he wants to replace at least 10% of that with biodiesel at some unspecified point in the future. But he would need 200 million litres of biodiesel a year. Which is a problem. "At this stage," says Mittal, "there is no mass production of biodiesel."

Like many others around India, the rail service is looking to an unprepossessing, poisonous scrub weed to try to do something about that. It has planted a million *Jatropha curcas* seedlings on unused land along its tracks and elsewhere. It's just one symptom of the jatropha fever that is spreading around the country and the world — to the slight bewilderment of some of the scientists who best understand the shrub.

Jatropha, a member of the euphorbia family, originated in Central America. It has long been used around the world as a source of lamp oil and soap, and also as a hedging plant. One of its great selling points as a biofuel is the fact that growing it need not compete with the cultivation of food. Of 306 million hectares of land considered in a report by India's Ministry of Rural Development, 173 million are already under cultivation but the rest is classified as either eroded farmland or non-arable wasteland. That's the sort of land that jatropha can thrive on, with bushes living up to 50 years, fruiting annually for more than 30 years and weathering droughts with aplomb[1]. In the early 2000s then-president A. P. J. Abdul Kalam repeatedly endorsed the plant for its potential contributions to energy security and as a route to greening barren land. Jatropha has been held to promise a reliable source of income for India's poor rural farmers and energy self-sufficiency for small communities — all while reducing fossil-fuel greenhouse-gas emissions and soil erosion.

In 2003, India's Planning Commission recommended a national mission on biofuel, a two-phase project for wide-spread cultivation of jatropha on wasteland across much of India. The first phase of the mission aims for 500,000 hectares of jatropha grown on government land across the country. The biodiesel would be produced primarily by panchayats — local governing bodies — at the village level, coordinated at the national level by a consortium of government departments. Should the first phase go according to plan, India's central government would embark on the second phase of the mission — planting a total of 12 million hectares of the plant and privatizing the production of jatropha biodiesel.

Although it seems likely to go ahead eventually, various ministerial meetings that might have given the national mission on biofuel the seal of approval have been postponed in favour of higher-priority issues. Despite this,

several states have enthusiastically hopped aboard the jatropha express, providing free plants to small-scale farmers, encouraging private investment in jatropha plantations and setting up biodiesel processing plants. The Ministry of Rural Development, which is set to coordinate the national mission on biofuel when it is approved, estimates that there are already between 500,000 and 600,000 hectares of jatropha growing across the country.

And India is not alone in its hopes for the shrub. In February 2007 China, which claims to have 2 million hectares of jatropha already under cultivation, announced plans to plant an additional 11 million hectares across its southern states by 2010. Neighbouring Myanmar (Burma) has plans to plant several million hectares; and the Philippines, as well as several African countries, have initiated large-scale plantations of their own. India looks forward to encouraging more such schemes and quite possibly profiting from them. "Once we have an operational programme and have something to offer the world," says Krishna Chopra, the recently retired principal adviser to India's Ministry of New and Renewable Energy, "I think exporting the know-how would certainly be one of the first areas to develop."

The great unknown

Although there is reason to be enthusiastic about jatropha's potential as a biodiesel feedstock in India and beyond, there is one rather sobering concern: despite the fact that jatropha grows abundantly in the wild, it has never really been domesticated. Its yield is not predictable; the conditions that best suit its growth are not well defined and the potential environmental impacts of large-scale cultivation are not understood at all. "Without understanding the basic agronomics, a premature push to cultivate jatropha could lead to very unproductive agriculture," says Pushpito Ghosh, who has been working on the plant for the best part of a decade, and who is now director of the Central Salt and Marine Chemicals Research Institute (CSMCRI) in Bhavnagar.

When Ghosh first arrived at the CSMCRI, the United Nations Development Programme (UNDP) had already given the institute funding for the cultivation of a modest jatropha plantation, although not for biofuels work. The idea was to see "how to make use of waste land, coastal areas and sand dunes", Ghosh says.

The plantation started off as an unirrigated, unfertilized, 20-hectare patch of exhausted scrub: Ghosh wasn't particularly impressed when he first saw it. "There were shrubs and they were growing," he recalls, "but it didn't look to me that it had what was required to make a successful plantation. 'Where are the seeds?' I said to myself. I didn't see too many of them. Merely planting and letting jatropha grow doesn't necessarily lead to productive growth." Nonetheless, the fact that jatropha lived up to its reputation as a shrub that could eke out a living on relatively barren land piqued the interest of India's Department of Biotechnology, which provided a little further funding for exploration of biofuel possibilities using cuttings from three of the most productive plants in the UNDP trial.

> **"I saw all this green in what is otherwise a complete desert."**
> — Klaus Becker

The seedlings were planted in small plots spread over patches of degraded, untended land in the eastern state of Orrisa. "The results were not outstanding," says Ghosh, "but they were consistent." Several plants yielded around 1.5 kilograms of seed, enough for about 0.4 litres of diesel. As modest as the results were, says Ghosh, they created a lot of interest. "For the first time," he says, "we were doing something in a systematic way."

The CSMCRI's work also caught the imagination of Klaus Becker, who arrived at the institute in 2000 as a visiting agricultural scientist from the University of Hohenheim in Germany. The original UNDP plot inspired him far more than it had the sanguine, measured Ghosh. "I saw all this green in what is otherwise a complete desert. There was absolutely nothing else around it. 'Look,' I told Ghosh, 'if you get this working, you'll be the first in the world'."

From seed to oil

Becker returned to Germany and set about fund-raising. By 2003 he had cobbled together a €1.7-million (US$1.9-million) research fund comprised of grants from DaimlerChrysler, the German Investment and Development Company in Cologne, India's Council of Scientific and Industrial Research and the University of Hohenheim. With these funds, Ghosh and his team — working in collaboration with Becker and scientists at DaimlerChrysler — began exploring the transesterification needed to turn jatropha into biodiesel. The process had already been established by Nicaraguan researchers during the 1990s[2] and it wasn't long before Ghosh and his team were producing small batches.

"You could tell simply by looking at it that it was fairly good quality," says Ghosh of their first attempts. Chemists at DaimlerChrysler's Stuttgart labs analysed it in more detail than the CSMCRI was able to and judged it easily good enough to meet European standards. Further tests at the Austrian Biofuels Institute (ABI), which pitted the CSMCRI's jatropha biodiesel against fuels from other feedstocks, showed that it "clearly outperformed biodiesel from rapeseed, sunflower and soya bean oil in [its lack of a propensity to oxidize]," says the ABI's Werner Körbitz, adding that the fuel "showed a fully satisfying performance concerning power, efficiency and emissions".

Ghosh's vision — and part of the CSMCRI's mandate — was to create a version of this transesterification process that was both inexpensive

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Oasis in the desert: Jatropha cultivation can halt soil erosion, increase water storage in the soil and transform barren expanses into lush, productive land.

A CHOICE OF CROPS

Biodiesel crop	Litres of oil per hectare
Oil palm	2,400
Jatropha*	**1,300**
Rapeseed (canola)	1,100
Sunflower	690
Soya bean	400

Source: United Nations Development Programme/World Bank
*Indian Planning Commission

Jatropha is already under cultivation in Tamil Nadu, India, where it can be grown with other crops such as sunflowers.

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and easily replicable at the village level. Nearly 80,000 of India's 600,000 villages currently have no access to fuel or electricity — in part because there isn't enough fuel for a fuel distribution network. "If people can grow oil directly in villages and produce biofuels themselves in decentralized plants," says Ghosh, "then they can achieve energy self-sufficiency. My colleagues and I are deeply committed to this principle."

"The constant urge to simplify and to ensure that every gram of jatropha is turned into something valuable was a tremendous motivator," he says, looking back at the project. But while he and his colleagues were still congratulating themselves on a job well done, the *Times of India* ran a story announcing that DaimlerChrysler was set to test two of its Mercedes C-Class cars on a 6,000-kilometre road test across the length and breadth of India using the CSMCRI's jatropha biodiesel.

Up the Khardungla pass

It was the first Ghosh had heard of it. "Our focus all along has been biodiesel as a fuel for village folk," he says, "not for fancy urban folk." And on top of that there was an obvious practical difficulty. Up to this point, Ghosh and his team had only ever produced a few litres of it at a time: you can't get across India on that.

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> — Pushpito Ghosh

Within a few months, though, Ghosh's team had developed a transesterification unit capable of producing about 250 litres a day — adequate for use in villages and small-scale industry[3]. The Mercedes ran entirely on 100% jatropha biodiesel from this unit throughout April and May 2004 without any significant engine modifications. In the summer of 2005, DaimlerChrysler had several automotive journalists take the cars on a high-altitude test through the Himalayas, including Khardungla pass, which, at 5,359 metres above sea level, is one of the world's highest motorable roads.

While Ghosh and his colleagues were making sure that jatropha could be processed as a reliable source of biodiesel, several of India's state governments were busy promoting their own jatropha cultivation campaigns. The state of Chhattisgarh, which has the most well-developed biodiesel programme in the country, has distributed 380 million jatropha seedlings to farmers, free of charge, over the past 3 years, enough to cover 150,000 hectares with the shrub. Shailendra Shukla, executive director of the Chhattisgarh Biofuel Development Authority (CDBA), says the state has also provided 80 oil presses to various village panchayats, and guarantees to buy back jatropha seeds — which have to be hand-picked off the shrubs — at 6.5 rupees (about US$0.16) per kilogram in order to stimulate confidence in the crop. Several local businesses have popped up across the state, says Shukla, that are now operating micro-refineries. "These are small businesses that provide biodiesel for the use in tractors, irrigation pumps, jeeps and village power generators."

Ghosh says that the CSMCRI has received an order for a refinery from the country's Defence Research and Development Organisation, part of India's Ministry of Defence. He explains that the unit would be capable of producing about 1,000 litres a day and would cost about 14 million rupees to install. In such a plant, he says, each litre of biodiesel would have a net production cost of about 26 rupees if the seed pods are bought at 6 rupees per kilogram and every scrap of seed and seed pod is converted into something valuable, with the seed going into oil, the bi-product seed cake into fertilizer and the seed husk into a high-density brick that can be burnt for fuel.

The wide governmental support has also attracted substantial business interest. D1 Oils, a UK-based biodiesel producer, is the world's largest commercial jatropha cultivator, responsible for around 81,000 hectares of jatropha in Chhattisgarh and in the southern state of Tamil Nadu, with plans for an additional 350,000 hectares over the next few years. "The entire programme revolves around the government-funded jatropha seeds," says Sarju Singh, until recently managing director of D1 Oils India. "The government gives farmers free or subsidized seedlings and D1 Oils guarantees to purchase the seeds at the price prescribed by the state." The company claims to have invested more than £3 million (US$6 million) in plant science and financing its share of the plantings, which are joint ventures.

Cautious approach

Yet most of these plantings have yet to reach whatever maximum level of productivity they might eventually attain — the plants need a few years to bed in. And Ghosh is wary of subsidizing jatropha too much before mass cultivation of the plant is fully understood. "A lot of government funds may go down the tube," he warns. Ghosh doesn't want the farmers to take on too much risk, so he is suggesting that they intersperse jatropha between their current crops, rather than banking on it as a cash crop. Shukla has similar reservations. "My immediate concern," he says, "is that because the seeds are derived from wild plants there is no assurance of yield." Shukla says the CBDA, like Ghosh, is promoting jatropha as something farmers limit themselves to planting between their rice fields. The only situation where all are agreed that it makes sense for small farmers to cultivate whole fields of jatropha is on farm land that has become or is becoming unproductive. It is a good fallow crop, says Becker: "It has a deep root system which stops ground erosion and increases water storage in the soil." This, he says, leads in turn "to more biomass growth and an accumulation of organic carbon in the soil".

Henk Joos, D1 Oils' director of plant science and agronomy, agrees that assured yields and the techniques needed to achieve them on a

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large scale need a lot more research. Yield estimates currently vary a great deal. India's Planning Commission estimates about 1,300 litres of oil per hectare, but Ghosh, conservatively, foresees a figure of about half that. Yield research is the main focus of D1 Oils' Indian operations, he says. The company is currently testing a number of jatropha varieties to see which ones grow best in India's varied climatic zones. "It will be two or three years before we get real scientific data to base an industry on," he says. "We are not there yet, we have a lot of work to do."

Pushpito Ghosh tops up a vehicle that has covered 48,000 kilometres powered only by jatropha biodiesel.

This is the sort of work Ghosh is currently overseeing at the CSMCRI's test plots. "It isn't the most glamorous work, but the mass multiplication of reliably producing plants is key to developing an industry, he says. Ghosh and his team are looking at precisely what kind of soil conditions and just how much water jatropha needs in order to reliably pump out oil-bearing seeds. The fact that jatropha plants can survive droughts does not mean they will not be more productive if they get more water. The optimum amount of water is still unknown.

The team is also continuously on the lookout for plants that could be potential progenitors for a generation of a high-yield crop. "We have one plant which has given us 5 kilograms of seed," says Ghosh. "We have yet to get that from any other plant." The CSMCRI is trying to perfect the use of shoot-tip cuttings as a means for mass-replication of jatropha plants so it can capture their best attributes. Culturing tissue cuttings from the plant's growing tip, says Ghosh, is the most reliable means of propagating exact copies of a parent plant, an important step in creating an army of dependable high-yield clones. It's a common enough technique — but like so much technology, it hasn't yet been reliably adapted to jatropha. "The problem is, we just don't have the protocol right," says Ghosh.

These various efforts are not part of any overarching plan. Despite the general enthusiasm for India's national mission on biofuel, there is a definite lack of cohesion at the national level. "Right now, ad-hoc research is being done by different agencies," says Chopra, "but it doesn't add up, because they each do their own thing." A national biofuel policy that was written by Chopra and his colleagues shortly before his retirement might help. It envisages an authority that would coordinate research and provide funding through various government agencies in order to cultivate jatropha on an industrial scale. But this policy, like the national mission on biofuel, has yet to go through the cabinet. In this case, it has been stalled by disagreements between various ministries on how to price jatropha — the Ministry of New and Renewable Energy suggests subsidizing seeds; other government ministries suggest subsidizing biodiesel itself. But, says Chopra, "I expect it will come together, perhaps this year or early next year".

Ghosh remains cautious and optimistic in level-headedly equal measure. "We must neither get carried away by hype nor get despondent if the initial results of cultivation are not as per expectation," he says. "The future will depend on how seriously and scientifically we pursue our goals." ■

Daemon Fairless is this year's winner of the IDRC-Nature fellowship.

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